Contemporary Systems Thinking

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Currency Wars

Offense and Defense through Systemic Thinking

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Synopsis

Based on the concept of two-dimensional science, consisting of the classical science, the first dimension, and the systems science, the second dimension, as argued by George Klir in the 1990s, this book systematically presents how the recent systemic yoyo model, its thinking logic, and its methodology can be employed as a common playground and intuition to the study of money, international finance, and economic reforms.

After the introduction of the relevant historical grounds, this volume consists of six parts. The first part addresses issues related to systemic modeling of economic entities and processes; why a few policy changes could adjust the performance of the extremely complex economy, although such practice has been in use for decades with varying degrees of successes; and how to practically estimate the true state of the economy through using either observers or controllers. The second part investigates the problem of how instabilities lead to opportunities for currency attacks, the positive and negative effects of foreign capital, how international capital flows can cause disturbances of various degrees on a nation's economic security, and what could be done to reduce the severity of the disturbances to the minimum. The third part addresses how a currency war is initiated, why currency conflicts and wars are inevitable, and a specific way of how currency attacks can take place. The fourth part shows how one nation can potentially defend itself by manipulating the exchange rate of its currency and how the nation under siege can protect itself against financial attacks by using strategies based on the technique of feedback and develops a more general approach of self-defense. The fifth part addresses issues related to the cleanup of the disastrous aftermath of currency attacks through using policies and reforms. The sixth part analyzes specific cases, where in particular what is addressed includes a look at Renminbi as a new reserve currency and what China is doing to strengthen Renminbi's influence in the world finance, where the euro, the US dollar, and the Chinese Yuan will go in the coming years. Then Chap. 24 concludes the presentation of this book by addressing the ultimate problem of whether or not currency wars can be avoided altogether.

By looking at the issues of monetary movement around the world, this book shows that there are clearly visible patterns behind the flows of capital and that there are a uniform language and logic of reasoning that can be powerfully employed in the studies of international finance. By making use of the patterns and by employing the language and logic of thinking, one can produce interesting, convincing, and scientifically sound results. As shown in this book, many of the conclusions drawn on the basis of these visible patterns, language, and logic of thinking can be practically applied to produce tangible economic benefits.

By studying this book, the reader will walk away with a brand new tool to attack his or her problems and a collection of practically useful knowledge and conclusions.

Preface

Money connects people through exchanges of goods and services. It associates nations through trades. And because of the rapid advancement of modern technology, the circulation speed of money has been accelerating, making the originally separate and even isolated economies from different parts of the world amalgamate into one giant, complex economic system. This globalization has helped to create previously unimaginable amount of wealth. At the same time, it has also brought forward adverse effects, such as, among others, worsening severe uneven distribution of wealth and frequent occurrence of disastrous financial crises. It is these adverse side effects of the globalization that this book addresses.

Speaking differently, because of the development of international trades and markets, an integrated environment for a world economy has been created. So, events that take place in the financial market of one nation could produce and have produced magnificent impacts on the financial markets of other nations. For example, a regional subprime mortgage crisis of the United States in 2008 quickly escalated into a full-blown financial crisis with all major economies of the world involved. As the movement speed of money increases and as more and more barricades that affect the smooth transactions of money are removed, once distant economic systems are now interacting with each other in an unprecedented fashion. Therefore, implementations of monetary policies of various scales have become the core of debate on monetary policies among central bankers. Constant theoretical refinement and new understandings of money have forever sharpened our comprehension on the role of money in economy.

Through exploring systemic modeling of economic entities and processes, how economic instability could potentially lead to financial vulnerability, how policy observability could be limited so that opportunities for currency attacks are presented, what self-defense strategies could be developed, and how disastrous consequences of economic crises could be cleaned up through policies and reforms, this book addresses many theoretically important and practical significant issues related to money and its movement, estimate of the true state of the economy, economic security, design of economic policies, and economic reforms. The purpose of this book is to establish a new unified analytical framework and logic of economic thinking on the basis of systems thinking in general and control-theory models in particular for studying money and related matters.

The novelty of the approach used in this book is treating the movement of money as that of fluid, which is rigorously backed up with recent results established in systems science. On the basis of this theoretical realization on flows of money, methods of systems science can be readily employed to model economic entities and processes, each of which is conceptually seen as an input-output system. That is, this book enriches the existing literature not only by providing a brand new instrument of intuition, which has been badly needed in the study of social science, establishing new understandings on international hot money and related policy issues, but also by introducing a whole set of new tools for rigorous reasoning and theoretical analysis of economic issues and financial events.

On top of the newly established intuition, the new tools of reasoning have enabled us to investigate many problems that have been extremely difficult, if not impossible, to address previously and establish many theoretically important and practically significant results. For example:

- Although there are a large number of factors that affect the performance of the economy, it seems to be generally possible for policy makers to simply tweak a few of them to alter the direction of economic development. This empirical experience is now theoretically backed up with rigorous proofs.
- In recent decades, financial crises had time after time again wiped out the wealth, accumulated through years of diligence and discipline, of the hardworking people, while each of these crises had shown traces of play of speculative hot money. So, a natural question is: Can the maturity of the financial system help the nation dodge financial attacks? To this end, our result shows that any economic system, regardless of the maturity of its financial system, is vulnerable to financial attacks. This result theoretically confirms the empirical claim of the raiders of the late 1970s and early 1980s that if they want, they can attack any business entity (*When Giants Stumble*, by R. Sobel (1999), Prentice Hall, pp. 165–188).
- Is it possible for an emerging market economy to design a quickest path of financial reform in order to avoid potential crises and to minimize the disastrous aftermath of crises when the nation attempts to emerge into the process of economic globalization and financial integration? To this end, this book provides necessary conditions for the steepest financial reform path problem with variable boundaries.

As applications of what is first established theoretically, this book also features particular case studies on the US dollar, the euro, and the Renminbi while providing predictions on their respective futures.

Considering its unconventional theoretical foundation and thought-provoking conclusions, other than delivering a brand new theory on international hot money, fiscal and monetary policies, and a scientifically sound methodology, this book is expected to provide practically meaningful guidance for meeting challenges that appear in the development of international finance and economic globalization. It is our hope that you, the reader, will benefit from reading this book and referencing this book time and again in your professional endeavors. At the same time, we love to hear from you no matter what comments or suggestions you might have. The first author, Jeffrey Yi-Lin Forrest, can be reached at either Jeffrey.forrest@sru.edu or Jeffrey.forrest@yahoo.com; the second author, Yirong Ying, can be reached at yingyirong@sina.com; and the third author, Zaiwu Gong, can be reached at zwgong26@163.com.

Fasten your seat belt; we are now entering a previously unexplored territory in the world of learning!

Slippery Rock, PA, USA — Jeffrey Yi-Lin Forrest
Shanghai, China — Yirong Ying
Nanjing, China — Zaiwu Gong
March 6, 2017

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Contents

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Dr. Jeffrey Yi-Lin Forrest holds all his educational degrees in pure mathematics and had a 1-year postdoctoral experience in statistics at Carnegie Mellon University. He had been a guest professor of economics, finance, and systems science at several major universities in China, including Nanjing University of Aeronautics and Astronautics. And currently, he is a professor of mathematics at Slippery Rock University, Pennsylvania, and the president of the International Institute for General Systems Studies, Inc., Pennsylvania. He serves either currently or in the past on the editorial boards of eleven professional journals, including *Kybernetes: The International Journal of Systems, Cybernetics and Management Science*, *Journal of Systems Science and Complexity*, *International Journal of General Systems*, etc. Some of Dr. Lin's research was funded by the United Nations, State of Pennsylvania, National Science Foundation of China, and German National Research Center for Information Architecture and Software Technology. As of the end of 2015, he has published well over 300 research papers and 45 monographs and special topic volumes. Some of these monographs and volumes were published by such prestigious publishers as Springer, World Scientific, Kluwer Academic, Academic Press, etc. Over the years, Dr. Yi-Lin's scientific achievements have been recognized by various professional organizations and academic publishers. In 2001, he was inducted into the honorary fellowship of the World Organization of Systems and Cybernetics. His research interests are wide ranging, covering areas like economics, finance, management, marketing, data analysis, predictions, mathematics, systems research and applications, philosophy of science, etc.

Dr. Yirong Ying is professor of finance and is associate chair of the Department of Finance, College of Economics, Shanghai University. He earned his B.S. degree in mathematics in 1982 from the Mathematics Department of Northwest University (China) and his Ph.D. degree in mathematics in 2000 from the Mathematics Department of Xidian University. In 2002, Dr. Ying did a 1-year postdoctoral study in finance at the Institute of Contemporary Finance, Shanghai Jiao Tong University.

Professor Ying has taught many different courses in the areas of economics and finance, such as econometrics, financial economics, financial physics, applied statistics, financial engineering, economic cybernetics, low-carbon economy, and others. His research interests include financial engineering, financial mathematics, security pricing, and risk management. He has published four monographs:

- The Significance, Methodology and Application About Infinite (Xi'an: Press of Northwest University, 1996)
- Capital Account Liberation in the Post Financial Crisis Era (Shanghai: Press of Shanghai University, 2012)
- Econometrics (Shanghai: Press of Shanghai University, 2012)
- Applied Statistic (Shanghai: Press of Shanghai University, 2013)

Additionally, Dr. Ying has published more than 50 research papers in various professional journals, such as Kybernetes: The International Journal of Systems, Cybernetics and Management Science, Advances in Systems Science and Applications, Annals of Differential Equations, Journal of Management Science, Journal of Systems Management, Journal of Chang'an University, Chinese Journal of Engineering Mathematics, International Journal of Research in Business and Technology, and International Journal of Engineering Mathematics and Computer Sciences.

Currently, Professor Ying is director of the Shanghai Financial Engineering Association, System Science, Management Science and System Dynamics Association, and Chinese Enterprise Operations Research Association.

He has won numerous awards for excellent research. His works have been financially funded by the National Natural Science Foundation (China), the Ministry of Education (China), and various agencies of Shanghai.

Dr. Zaiwu Gong is professor and specialized in group decision-making, grey systems, and risk analysis. Among his main research achievements, Dr. Gong developed a group consensus decision-making theory based on optimization and a multisystem consensus decision-making theory with decision-makers' (DMs') intuitive preferences. He proposed a group consensus measure theory with utility constraint by considering DMs' behavioral characteristics and analyzed disaster risk evaluation theory's impact on rapid consensus decision-making by considering the emergency characteristics of disaster risk. Along these lines, he has published over 70 research papers on such well-known international journals as the *European Journal of Operational Research* and *Omega*. His applied works are mainly published in a special issue of *Natural Hazards* and have been incorporated into the Academic Committee Development Plan for the Chinese Meteorological Society of Meteorological Disasters and Services. Professor Gong has also published four monographs by *Science Press* and *Springer Press* and one textbook published by *Meteorological Press*.

Dr. Gong has been involved in more than 20 projects funded at the Chinese national and provincial levels and has directed three projects for the National Natural Science Foundation of China. He led one project for the Humanities and Social Science Foundation of the Chinese National Ministry of Education and four provincial projects that funded special talents (e.g., the Qinglan Project for the Department of Education, Jiangsu Province; the 333 High-Level Talent Training Project, Jiangsu Province; and the Six Talent Peak Project, Jiangsu Province). Dr. Gong has been awarded 10 prizes, including the Excellent Paper Award for the 4th IEEE International Conference on Grey Systems and Intelligent Services, the Outstanding Paper Award from an international publishing company, and the third prize for Excellent Achievement in Philosophy and Social Science in Jiangsu Province. Dr. Gong has supervised 30 graduates (including five international graduates majoring in business administration). Among his students, two were awarded the Excellent Master's Thesis of Nanjing University of Information Science and Technology, three have won a national scholarship, and two have won the third prize in the National Graduate Mathematical Modeling Contest.

Dr. Gong serves as a reviewer for more than 20 academic journals, including the *European Journal of Operational Research*, *Omega*, and *Information Sciences*. He is currently guest editor for *Natural Hazards* and editor for the *Journal of Grey System*, and he is involved as a director or member in six associations in the decision sciences branch of the Chinese Operations Research Society.

Chapter 1
Unconscious, Helpless, and Orchestrated Financial Crises

Contents

This introductory chapter presents the current landscape of international finance in terms of financial crises by reviewing the relevant literature and by posting problems that are challenging the world of learning, central bankers, and government policy makers. By looking at the literature holistically, this chapter associates the concept of money with that of fluids through using the concept of systems and the systemic intuition, named yoyo model.

This chapter shows why methods well developed for the investigation of fluids and systems in natural science are now readily applicable to the study of money and its movement around the world. What is demonstrated is why this special volume is timely at such a time that more and more financial crises in recent years have shown traces of looting and involuntary wealth transfer from people who have worked hard for years or even decades to accumulate their wealth.

An overall view of the issue of orchestrated financial crises is provided, while the urgent need for in-depth investigation of the relevant strategies of self-defense is presented. What is shown is why this special book is expected to be beneficial for scholars, central bankers, and government decision makers.

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1.1 Introduction

The history seems to suggest (Chen and Yang 2016) that financial crises occur over time throughout the ages; they appeared unconsciously in early times without much premonition; then with the growing amount of knowledge on finance, they still broke out helplessly even with some degree of advanced warnings; and then in recent decades, they have happened with proactive human interferences, where free flows of money have made originally not that major structural weaknesses of local economies to be blown into large-scale, wide-ranging regional or even international crises with disastrous consequences.

In order to predict and prepare for the breakout of the next financial crisis, scholars, central bankers, and government officers have been interested in the investigation of all the relevant issues. To this end, evaluating and modeling the performance of an economy and introducing adequate fiscal/monetary policies are the main content of managing risks associated with economic shocks and disasters. They constitute the knowledge basis for economic disaster prediction, prevention, compensation, and works related to economic development, international commerce, and interaction of regional economies. Such evaluation and modeling investigate what kinds of economic disasters would potentially occur at a particular region within a specific timeframe and the potential disastrous aftermaths. Adequate fiscal/monetary policies are employed to characterize patterns of economic disasters so that sound scientific methods can be established to reduce the devastating effects. By knowing the true performance of the economy, specific policy measures can be designed and implemented to reduce the severity of and/or to avoid risks.

Due to the globalization, economic crises have been occurring in increasing frequency since the 1970s and causing economic losses to various regional economies. Behind most of the recent economic crises, international speculative (or hot) money has been one of the factors that triggered the breakout of the crises. Therefore, the research on hot money is of great importance to scholars and policy makers alike. However, each economy is an open, complex, giant system, acted upon by various forces, and disturbed by shocks from the outside world. So, all conventional methods developed for studying regional events or isolated processes are no longer adequate for comprehending the holistic dynamics of economies. Because of the lack of systemic approaches in the literature, it has been theoretically difficult for scholars and policy makers to uncover the reliable relationship between the economic event of interest and its probability of occurrence. Without an adequate knowledge of the relationship, it becomes even more difficult for policy makers to practically design and implement appropriate policies in order to improve the economic situation in hands. Such defects of the literature could be remedied by employing the methods and conclusions of systems research, which has been widely recognized and employed in the spectrum of natural and social science research in the past 80 plus years.

The main premise on which the models and conclusions established in this volume is the general systems methodology at large and the systemic yoyo model in particular. One of the major results of systems thinking employed in this book is that money can be treated beautifully and vividly as fluid that permeates all corners of the world economy and connects all regional economic systems into an organic whole. Because of this result, behaviors of economic systems and laws that govern the development of economies can be more adequately modeled by using the methods established initially for controlling man-made systems and regulating media of fluid.

The literature on money and design of policies using models of differential equations has used characteristics of fluids without clearly showing the theoretical justification. The results established in this book are expected to create a novel theory and a holistic view on how hot money moves and how it might be monitored, traced, and potentially regulated; this new theory will not only realize an integration of the conventional results with systemic methodology but also develops a brand-new way for looking at hot money and how it is expected to behave so that appropriate fiscal/monetary policies can be designed and adopted in order to prevent financial crises and reduce the consequent losses if the crises are not avoidable.

The rest of this chapter is organized as follows: Section 1.2 presents how the phenomenon of increasing number of financial crises since the early 1970s can be associated with the systemic intuition, the yoyo model. Section 1.3 looks at the concept of currency wars and how free movement of money could potentially be employed to strip a local economy of its wealth accumulated through many years of discipline and hard work. Section 1.4 considers the problem of economic security and related issues. Section 1.5 concludes this introductory chapter by introducing all the chapters of this book.

1.2 A Systemic Association

Since the 1970s, developed nations have implemented financial liberation and gradually loosened up financial regulations (Luo 1996). With the strengthening of globalization, emerging market nations have also started to implement financial reforms and measures of capital account liberation, which have helped attract international capital to flow inwardly to provide the necessary funds for the increasing domestic demands of consumption and investment. So, these emerging market nations, on one hand, enjoyed abundant returns of globalization and, on the other hand, suffered from great pains inflicted on them by financial crises (Forrest 2014).

The literature shows that during the so-called financial repression from 1945 to 1971, there appeared 38 financial crises, seven of which were twin crises, while the emerging market economies experienced only 16 foreign exchange crises, one of which was a twin crisis (Zhang 2009). During 1975–1997, the proportions of international payment balance crises, bank crises, and twin crises that appeared to emerging market nations in the world were, respectively, 73.4%, 77.8%, and

72.7%, where a total of 234 such crises were tallied with 174 appeared to emerging market economies, amounting to 74% of the total. That is, during this time period, more financial crises broke out within emerging market nations with relatively immature financial systems. In other words, emerging markets had been hardest hit by financial crises, and financial liberation has led emerging market nations with immature financial markets to the suffering from more financial crises (Mussa et al. 1998). Noticeable behind the timeline here is the fact that when huge amounts of capital, especially short-term capital, move across national borders freely, they make it difficult for emerging market countries to resist their impacts. When there is still immaturity in the development of an economic system, a high degree of financial liberation combined with a fixed exchange rate system can potentially lead to hidden dangers for the economic security of the economic system due to interferences of foreign capital. Specifically when the international economic situation changes, foreign capital can flow adversely and inevitably creates shocks to the financial industry of the country in transition. For example, the 1997 financial crisis of Thailand was partially due to structural problems that inherently existed within the economic development and partially due to the immature liberation of the financial market and the fixed exchange rate system (Corsetti et al. 1999; Lindgren et al. 1999).

If the history is seen from the angle of how money flows between nations, then what is suggested by the literature is that when money control is in place (e.g., during 1945–1971), the frequency of financial crises is less than when supervision is lacking, while money can freely flow across national borders. To this end, one natural question is: how can we investigate the (free) flow of money so that we will know where and when the next financial crisis will be? There are of course many different approaches for us to investigate this important and far-reaching question. However, if we look at this question from the angle of fluids, where we see money as a fluid, then free movement of the fluid (money) will naturally lead to local chaos (crises) that is determined or caused by the boundary conditions that are particular to the specific location and time; see the related discussions on dishpan experiment in (Lin 2008). In order to make this intuition scientifically sound, let us associate the situation in hands with the concept of systems.

By system it means such an organization that consists of a set of elements and a set of relations that connects the elements and makes the set of elements an organic whole (Lin 1999, 1987). It is the relations that make the entity of concern an identifiable system. This concept of systems was initially proposed by (von Bertalanffy 1924) in biology when he recognized that "because the fundamental character of living things is its organization, the customary investigation of individual parts and processes cannot provide a complete explanation of the phenomenon of life." In the past 90-some years, systems science has made magnificent progress and been successfully applied in a great number disciplines of the traditional science. By comparing systems research with that of the traditional science, it became clear that there was an urgent need for the former to establish a platform and an intuition, which is similar to the Cartesian coordinate system on which the

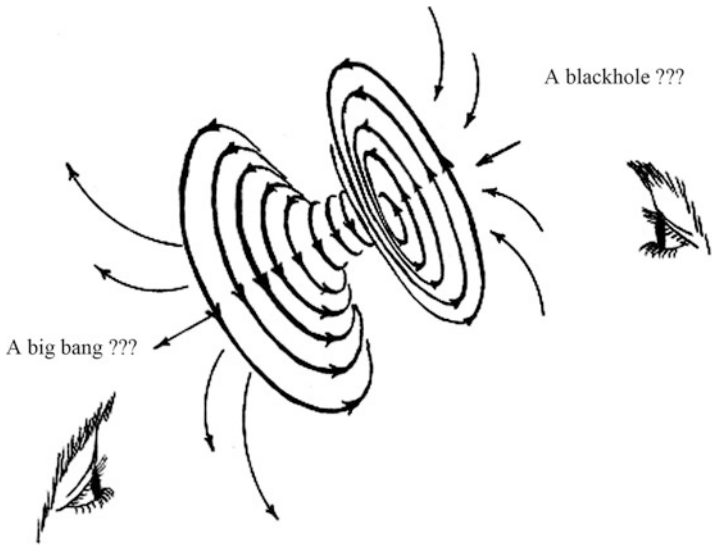

Fig. 1.1 The yoyo structure of the general system

traditional science is developed, on which the edifice of systems science could be further constructed to higher levels.

Such a badly needed platform, named yoyo model, was officially introduced in (Lin 2007). The model says based on theoretical reasoning and empirical evidence that each input-output system (Lin and Ma 1987), when studied from the angle of whole evolution (Wu and Lin 2002), possesses an abstract multidimensional structure such that it "spins" about its "invisible" axis. If we imagine the entity in our three-dimensional space, we have the structure shown in Fig. 1.1. The side of black hole sucks in all things, such as investment, information, energy, etc. After funneling through the "neck," all things are spit out from the end of the big bang. In particular, this model says that each entity, which can be identified as an input-output system in the universe, be it a tangible or intangible object, a living being, an organization, a culture, a civilization, etc., can be seen as a realization of a multidimensional spinning yoyo with a spin field around it. It stays forever in a spinning motion; and if it stops its spinning, it will no longer exist as an identifiable system.

With this systemic model in place, an economy can be naturally seen as a yoyo field and a dynamic ocean of various smaller yoyo fields, each of which represents an economic entity, that are fighting against each other with money connecting the interacting fields. One of the main conclusions that can be drawn out of this systemic model (Forrest 2014) is that each economic entity can be investigated as a system and money as a fluid that permeates all corners of the economic system. The significance of this conclusion is that methods developed in natural science for the study of systems and fluids now become readily available for the study of economic systems.

Because in natural science fundamental laws dictate how the nature evolves, it now makes it natural for us to think that there should be laws that are underneath the development of economies. On top of such premises, it becomes clear that those methods well developed for the study of natural systems can be readily employed in our investigation of economic systems. And this end is convincingly supported by the well-thought-of chapters of this special volume.

1.3 Currency Wars

Having money means holding power to purchase assets, to command the labor of others, and to enjoy comfort. Behind the transfer of goods, employment of labor, and facilitation of service, it is money that connects buyers and sellers and that makes international commerce possible. So, underneath all goods and services, money moves from one economic entity, region, or nation to another. When money circulates within an economy, it helps the economic system maintain its level of vitality, promote economic development, and improve the quality of life. However, when a large sum of capital suddenly flows either into or out of an economic system, the movement of capital would most likely create shocks and consequently chaos in the affected economy, causing economic depression or malaise. Although this end can be seen vividly from the yoyo model described in the previous section, it can also be shown by using mathematical rigors. In particular, according to Bernanke and Gertler (1999), the fundamental value Q_t of a particular depreciable capital in period t is equal to the present value of the dividends the capital is expected to generate throughout the indefinite future:

$$\begin{aligned} Q_t &= E_t\left(\sum_{i=0}^{\infty}\left[\frac{(1-\delta)^i D_{t+1+i}}{\prod_{j=0}^{i} R^q_{t+1+j}}\right]\right) \\ &= E_t\left(\frac{D_{t+1}}{R^q_{t+1}} + \frac{(1-\delta)^1 D_{t+2}}{R^q_{t+1}R^q_{t+2}} + \frac{(1-\delta)^2 D_{t+3}}{R^q_{t+1}R^q_{t+2}R^q_{t+3}} + \dots\right) \end{aligned} \tag{1.1}$$

where E_t stands for the mathematical expectation as of period t, δ is the rate of physical depreciation of the capital, D_{t+i} is the dividends, and R^q_{t+1} is the relevant stochastic gross discount rate at t for dividends received in period $(t + 1)$.

By analyzing this model carefully in a brand-new angle, Forrest et al. (2013a) concluded that when huge amounts of foreign investments gather in one place over either a long period of time or a short period of time, the local economy becomes increasingly more active than before – a positive economic bubble, caused by the increased money supply as a consequence of foreign investments; then at around the peak of economic prosperity, a large sum of foreign capital suddenly and strategically leaves the economic system, causing the local economy to fall off the positive bubble and to consequently suffer through a negative, disastrous bubble, caused by the sudden dry-out of the money supply. Because of a large number of economic activities that are either unexpectedly delayed or totally impossible to complete, the local investors will be unable to continuously collect their originally expected dividends for many time periods to come. That is, foreign capital can be employed as a weapon of mass destruction, if they leave strategically and suddenly, no matter whether they come quickly in a short period of time or slowly over a relatively longer period of time.

So, in general, what is likely to occur with a sudden, large-scale outflow of capital is an involuntary transfer away from the economic system of wealth that the system has accumulated through hard work in the past years or even decades (Forrest et al. 2013a). Any such kind of involuntary transfer of one region's wealth to another through the use of capital is what we refer to as a currency war.

With the present globalization and financial integration, what happens is that currency wars could appear in many different forms. For example, other than what is afore-described, one nation can readily transfer its economic problem, such as inflation, over to another nation or nations as their problem or problems by simply adjusting its domestic monetary policy unless the other nations also make similar adjustments accordingly. However, such similar adjustments in real life might not be possible due to the nations' specific situations. To this end, a good example is how George Soros made his fortune by betting against the European exchange rate mechanism in the early 1990s (Slater 1996), where due to its then recent unification, Germany had to adjust its monetary policy in order to cover its drastically increased expenditure, while other nations, especially England and Italy, could not follow the suit.

At the same time, there is currently a large amount of hot money that constantly moves around the world either within or between various markets in pursuit of short-term, high levels of profits without any particular fields of investment focus. Speculative capital tends to be short term even though there are exceptions to this rule of thumb. One of the modern characteristics of international speculative capitals is their camouflage. At the same time, these capitals can also go along with the market cycles by pursuing mid- and long-term investments. The existence and movement of hot money in recent decades have made traditionally not-that-great structural issues in the financial system of a region to become full-blown economic crises for the region due to the capability of hot money to quickly inflate a positive economic bubble by entering the region and then to burst it by suddenly and strategically leaving the region. By first inflating and then bursting the bubble, a well-planned involuntary wealth transfer is completed, benefiting the speculators. To this end, we can simply look at such crises as the 1994 Mexican financial crisis, 1997 Southeast Asian financial crisis, 1998 Russian currency and financial crises, 1999 Brazilian currency and financial crises, 2001 Argentine currency and financial crises, etc. All these events had shown traces of looting and involuntary transfer of wealth away from these involved nations and regions in the form of currencies (Forrest et al. 2013a). In other words, when capital control was widely applied as during the "financial repression" time from 1945 to 1971, economic crises occurred mostly unconscious without much prior knowledge. After the USA no longer fixed the value of its dollar with gold in the early 1970s, as more and more industrialized nations completed their financial liberation, some economic crises appeared helplessly although some degrees of advanced predictions were provided. Then in more recent decades, many economic crises occurred, or their severities were blown way out of proportion as consequences of orchestrated financial attacks by international speculative money.

Facing the bloody trail of financial crises, it becomes urgent for scholars, central bankers, and national government officers to figure out firstly how to predict where and when a potential economic crisis is forthcoming, secondly how to avoid the predicted crisis from actually occurring, and thirdly how to reduce the severity of the consequent aftermath if the crisis is not avoidable.

1.4 Self-Defense

To face the potential threat of financial attacks, as either consequences of the natural economic cycles or acts of strategically moving speculative money, we need to first recognize the issue of economic security, secondly know how to evaluate the true state of the economy, and then act intelligently by introducing appropriate policy responses.

1.4.1 The Problem of Economic Security

Along with the globalization, international trades and foreign direct investments (FDIs) have been evolving mutually with each other. The effect of FDIs has been an important research topic in the theory of international trades, initiated by Mundell (1957) and Hirschman (1958) and then integrated by Kojima and Osawa (1984), Hennart (1982), Cushman (1985), Dunning (1988), and others. From the angle of political economics, Bhagwati et al. (1992) showed that the effects of FDIs on the international trades of a nation are not isolated. Instead, the faster the scale of international trades develops, the greater the attraction there is to FDIs, while foreign capital also plays an obvious leading role in increasing the growth of exports of the hosting country. For a good survey, see (Denisia 2010).

With the influx of foreign capital, there comes not only advanced production technology and scientifically more efficient management methods, which increasingly stimulate the economic development of the receiving economy, but also promotion for optimal adjustments to the existing industrial structure within the economy (Forrest and Tao 2014). Hence, FDIs definitely have their positive significance. At the same time, one has to recognize that the essence of FDIs is in their constant search for optimal return. That constant movement somehow affects the economic security of the receiving economy. In 1980 the Research Institute for Peace and Security of Japan published a comprehensive report on national security, which posed the question of economic security for the first time in history. Since then, many countries, such as the USA, Germany, France, Canada, South Korea, Russia, and others, have formed government entities to safeguard their national economic security by reviewing business mergers and acquisitions by foreign entities and capital (Gen-hua 2011; Buzan et al. 1998). For general discussions, see (UNCTAD 2012).

The importance of economic security to the receiving economy is obvious, because the security is the material foundation for the existence and development of the economy. Especially since the time when the Soviet Union collapsed in the 1990s, the world configuration has changed from military standoff to economic collaborations and hostilities. So, at the same time, when an economy actively introduces FDIs to promote its economic development, it also needs to have a clear understanding of the adverse effects of utilizing FDIs by formulating relevant countermeasures and by following appropriate procedures to ensure a healthy and orderly development of the economy. So, a natural question appears: while taking advantage of FDIs, how can a nation protect itself against the potential disastrous aftermath in case some of the FDIs were actually part of an active currency war raged against the nation? To this end, the chapters in this special volume address this and other relevant questions thoroughly.

1.4.2 Evaluate the State of Economic Performance

To maintain a healthy operation of the economy, the economy (and the currency system) has to be stable. To achieve this goal, policy makers always look at some of the characteristics of the economic system and introduce appropriate policies to make necessary adjustments. Because the economy interacts with the outside world, that makes the operation of the economy frequently disturbed by external factors, causing it difficult for the performance of the economy to meet the expectations of the policy makers. Consequently, the policy makers need to adjust their policy tools to offset the external interferences so that the economy would possibly approach the expected state. A commonly employed method is to design feedback control rules to guarantee that the resultant closed-loop economy will possess the expected characteristics. For example, William Phillips in 1954 published "stabilization policy in a closed economy" and in 1957 "stabilisation policy and the time-forms of lagged responses" in *The Economic Journal of Royal Economic Society*. He reflected Keynesian policy method for economic adjustments by using the control theory's block diagrams with time delay and pointed out that to regulate the economy effectively and stably, one has to employ a PID (proportional-integral-derivative) controller on the expenditure of the government.

By feedback control, it means that one regulates the economy with either state feedback strategies or output feedback strategies by, respectively, using either the state variables or output variables of the economic system. By state it represents a group of variables that are endogenous to the economic system and describe the state of the system. In practice because some state variables cannot be directly measured, real-life applications of most state feedbacks of the economic system become either difficult or impossible to materialize. So, we face a dilemma between the irreplaceable nature of state feedbacks of the economic system and the practical difficulty of implementation. One way to get around this dilemma is to reconstruct the state of the economic system and then to materialize the state feedback of the economic system by substituting the actual state of the economic system by the reconstructed state. Hence, an important problem in the study of effective management of the economic system is how to estimate the unknown state variables of the economic system with relative accuracy.

Luenberger (1964) was the first to introduce the concept of state observers; and he established ways to construct these observers so that he successfully resolved the problem of being unable to make direct measurement of the state variables by employing the idea of reconstructing the state variables. Since then, investigations along this line have been becoming more mature and complete; relevant results have been widely employed in the control problems for estimating the unknown information (Sadaka et al. 2009). Then, by feedback control based on observers, it means that on top of an available observer, one designs a rule of feedback control (a policy) so that the system of concern (the economy) becomes stable and possesses some other desirable properties (Wang et al. 2005). The essence here is to construct a controller (a policy) that can guarantee the stability of the closed-loop economic system, while some of the indices of the economic system are smaller or equal to some pre-determined threshold values.

Due to the complexity inherently existing within economic systems, it makes it difficult for policy makers to fully understand the evolution of the state variables or the characteristics of the economy. So, policy makers have to renew their understanding and grasping of the objects of regulation through repeated measurements of the characteristics of the economy from the angle of the reconstructed system. Based on the renewed knowledge, and by comparing what is newly observed with the expected characteristics, they will adjust their adopted economic policies so that the performance of the economy will reach or approach the desired optimality according to the pre-determined standards. Therefore, only by accurately reconstructing the state variables of the economic system, the policy makers can materialize their expected outcome. To this end, this book provides detailed procedures and methods on how to reconstruct the state of an economic system.

1.4.3 Introduce Policy Responses

Adam Smith (1776) treated economy as a self-regulating system, where “an invisible hand” automatically adjusts the market so that the system reaches and maintains its equilibrium. If this so-called invisible hand is seen as a feedback controller, then we immediately acquire a readily available methodology that can be applied to bridge the production and the market and to regulate the relationship between the system's supply and demand in order to make this relationship as balanced as possible through adjusting prices, profits, competition, and other factors. With such understanding in place, methods of control theory can be handily associated with different theories of economics (Chow 1975; Shefrin and Thaler 1981) and provide economists with practically operational procedures for theoretical research and real-life applications (Kendrick 1981; Seierstad and Sydsaeter 1986). That explains why more and more results of control theory have been employed in the research of economic policies (McKinnon 1993).

For example, Pindyck (1977) resolved the control problem of deterministic secondary tracking of a mathematical model developed for the American economy. This work illustrates the importance of feedback control in the design of financial and fiscal policies. Moe (1985) presented an empirical analysis of the National Labor Relations Board by using feedback control and by focusing on the balance the agency strikes to achieve between the interests of businesses and labors. Kydland and Prescott (1980) presented recursive methods for designing optimal taxation plan. Because most economic systems are nonlinear, the so-called economic model predictive control (MPC) system, which is capable of optimizing closed-loop performance with respect to general economic considerations taken into account in the construction of the cost function, was used to design an estimator for nonlinear economic systems (Heidarinejad et al. 2012). Corresponding to the characteristics of the target entities of regional economic policy regulation, Hu and Hu (2005) used state feedback to offset the time delay and inertia of economic entities, which are to be regulated by policies, so that these entities would have good quality dynamic response characteristics and excellent regulation performance. Considering the theoretical continuity and practical discreteness of time in terms of the operation and regulation of economic systems, Wu and Liu (2004) employed the methods of systems theory and control theory to simulate the operational mechanism of macroeconomic systems and developed their replaceable cyclic control model and discrete successive input control decision model for macroeconomic systems. For dynamic input-output economic systems, Chow (1976) investigated a general production strategy based on monitors of consumption while developing particular strategies for structurally adjusting productions for several specific circumstances of consumption. Based on the methods of control theory, Yang et al. (2004) derived an optimal economic adjustment scheme for the optimization control problem of linear quadratic forms of the dynamic input-output model with integral inequality of the state by using the maximization principle. This scheme can be employed to materialize the optimal tracking of the actual output compared to the ideal output.

Each physical system inevitably involves uncertainty; when the uncertainty varies within a pre-determined range, Xiao and Lu (2002) successfully analyzed and optimally controlled a general macroscopic economic system while guaranteeing that the controlled variables could accurately trace the pre-determined objectives. For the control systems of macroscopic economies (Pindyck 1977), they are sometimes not only required to track the expected paths but also desired to have the controlled variables to be as close to the ideal measures as possible. That is the so-called ideal control strategy. By making the quadratic performance index equivalent to observation information of control, Wang and Wang (2006) transformed from the angle of information fusion the original problem on the regulation of the macroscopic economy into one of solving for the optimal estimation of the controlled variable by treating all such information as the expected trajectory, the system's dynamics, the ideal control strategy, etc., as the observation information of the controlled variable.

In particular, among several important problems on policy responses to the changing market environment considered in this book, one theoretical problem is: when the mathematical model of an economic system is established and the appropriate parameters of the model are determined, can one design the corresponding feedback control strategy (i.e., an economic policy) so that the variable of control could be made to approach the pre-determined objective?

1.5 How This Special Volume Is Organized

Addressing the challenges posed in the previous sections, all the chapters in this book are organized as follows: After the reader is introduced to the systems thinking and the systemic yoyo model in Chap. 2, the rest of the book consists of six parts.

The first part addresses issues related to systemic modeling of economic entities and processes. In particular, this part consists of Chaps. 3, 4, 5, and 6. Here, Chap. 3 looks at how each economic entity and process can be appropriately modeled by using control systems based on differential equations. Drs. Baohua Yang of Jiangsu Normal University, Jesus Valencia of Slippery Rock University, and Qiaoxing Li of Guizhou University also took part in this work. Chapter 4 considers the practical problem of how to reduce the dimensionality of the symbolic system developed for an economic system in order for the symbolic system to be useful in analyzing real-life situations. As a by-product, this work in fact provides the theoretical foundation for why a few policy changes could adjust the performance of the extreme complexity of the entire economy, although such practice has been in use for decades with varying degrees of successes. Drs. Jinsuai Zhao of Jiangsu Normal University, Jesus Valencia of Slippery Rock University, Baohua Yang of Jiangsu Normal University, and Yong Liu of Jiangnan University also took part in the work of this chapter. Chapters 5 and 6 investigate how to practically estimate the true state of the economy through using either observers or controllers. Drs. Baohua Yang of Jiangsu Normal University, Yong Liu of Jiangnan University, and Abdykappar Ashimov and Yuriy Borovskiy of Kazakh National Research Technical University named after K. Satpayev also took part in the work of these chapters.

The second part consists of Chaps. 7, 8, and 9. It investigates the problem of how instabilities lead to opportunities for currency attacks. In particular, Chap. 7 visits some of the major financial crises that occurred during the time from 1929 to 2008. Chapter 8 considers both positive and negative effects of foreign capital in the light of systemic yoyo model. Drs. Kurt Schimmel and Jeananne Nicholls of Slippery Rock University and Sifeng Liu of Nanjing University of Aeronautics and Astronautics also took part in the work of this chapter. Chapter 9 looks at the problem of how international capital flows can cause disturbances of various degrees on a nation's economic security and what could be done to reduce the severity of the disturbances to the minimum. Drs. Kurt Schimmel and Jeananne Nicholls of Slippery Rock University, Sifeng Liu of Nanjing University of Aeronautics and Astronautics, and Nicholas A. Nechval of Baltic International Academy (Latvia) also took part in the work of this chapter.

The third part consists of Chaps. 10 and 11 and addresses how a currency war is initiated. In particular, Chap. 10 shows why currency conflicts and wars are inevitable; and Chap. 11 shows a specific way of how currency attacks can take place.

The fourth part consists of Chaps. 12, 13, and 14. In particular, Chap. 12 shows how one nation can potentially defend itself by manipulating the exchange rate of its currency. Chapter 13 considers how the nation under siege can protect itself against financial attacks by using strategies based on the technique of feedback. Drs. Baohua Yang of Jiangsu Normal University and Sailau Baizakov and Oinarov Azamat Ryskulovich of SC "IEI" Economic Development and Trade of Kazakhstan also contributed to the work of this chapter. Chapter 14 proposes a more general approach of self-defense. Dr. Qionghao Chen of Shanghai University also took part in the work of this chapter.

The fifth part of this book consists of Chaps. 15, 16, 17, 18, and 19 and addresses issues related to the cleanup of the disastrous aftermath of currency attacks through using policies and reforms. In particular, Chap. 15 investigates when large amount of capital flows suddenly to or away from a particular economy and how the consequent economic shocks can be minimized by designing and implementing economic policies based on various performance indicators. Drs. Huan Guo of Jianghan University, Jinli Guo of University of Shanghai for Science and Technology, and Stephen Larson of Slippery Rock University also took part in the work of this chapter. Chapter 16 studies how to generally design economic policies that do not cause adverse effects to the economic development, such as bumpy recoveries. Drs. Qionghao Chen of Shanghai University, Huachun Zhao of Jiangxi Normal University, and Yingjie Yang of De Montfort University also took part in the work of this chapter. Chapters 17, 18, and 19 attempt to address some more or less particular issues related to self-defense. Specifically, Chap. 17 considers the problem of macroeconomic regulations, where Yan Yue of Shanghai University and Dmitry A. Novikov of Trapeznikov Institute of Control Sciences also took part in the work of this chapter. Chapter 18 looks at the issue of the steepest optimal policies for regulating capital flows and exchange rates. Drs. Guosheng Zhang of Beijing International Studies University and John Golden of Slippery Rock University also contributed to the work of this chapter. And Chap. 19 studies the problem of optimal paths for financial reforms. Here, Drs. Zhongyu Wang of Beijing University of Aeronautics and Astronautics and Jinli Guo of University of Shanghai for Science and Technology also took part in the work of this chapter.

The sixth part of this book consists of Chaps. 20, 21, 22, 23, and 24 and analyzes specific cases. In particular, Chap. 20 looks at Renminbi as a new reserve currency and what China is doing to strengthen Renminbi's influence in the world of finance. Chapter 21 presents a general theory of international money and then addresses the question of where the Euro will go in the coming years. Chapter 22 analyzes in details where the US dollar will go. Chapter 23 looks at the problem of where Chinese Yuan will go by analyzing Yuan history, present state, and its regionalization. As the concluding chapter, Chap. 24 addresses the ultimate problem of whether or not currency wars can be avoided.

Considering how the results presented in the following chapters are relevant to the current landscape of the international finance, we expect that scholars and decision makers will find that this book is timely and beneficial in their works in terms of protecting the hard-earned wealth people have accumulated through many years or decades of discipline and hard work from unconscious, helpless, or orchestrated financial crises.

To make this book reader friendly, each chapter in it is constructed as self-contained as possible so that the reader does not have to flip through the pages to look up the relevant concepts or results.

Chapter 2
Systems Research and the Systemic Yoyo Model

Contents

To prepare the theoretical foundation for the rest of this book, this chapter introduces the basics of systems thinking, the systemic yoyo model, and some elementary properties of this model. Then, for the completeness of this book, this chapter also glances through the theoretical and empirical justifications on why each and every system can be seen as a rotational yoyo.

The rest of this chapter is organized as follows: Section 2.1 provides an overview of systems science and why it can be seen as the second dimension of knowledge. Section 2.2 looks at the systemic yoyo model and some of its properties. Section 2.3 considers the laws of state of motion. Section 2.4 lists some of the theoretical justifications of the model. Section 2.5 provides a few empirical justifications.

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2.1 Systems Science and the Second Dimension of Knowledge

2.1.1 Systems Science and Its Importance

Since 1924 when von Bertalanffy pointed out that the fundamental character of living things is its organization, the customary investigation of individual parts and processes cannot provide a complete explanation of the phenomenon of life, this holistic view of nature and social events has spread over all the corners of science and technology (Lin and Forrest 2011). Accompanying this realization of the holistic nature, in the past 80 some years, studies in systems science and systems thinking have brought forward brand-new understandings and discoveries to some of the major unsettled problems in the conventional science (Lin 1999; Klir 1985). Due to these studies of wholes, parts, and their relationships, a forest of interdisciplinary explorations has appeared, revealing the overall development trend in modern science and technology of synthesizing all areas of knowledge into a few major blocks, and the boundaries of conventional disciplines have become blurred ("Mathematical Sciences," 1985). Underlying this trend, we can see the united effort of studying similar problems in different scientific fields on the basis of wholeness and parts and of understanding the world in which we live by employing the point of view of interconnectedness. As tested in the past 80 plus years, the concept of systems has been widely accepted by the entire spectrum of science and technology (Blauberg et al. 1977; Klir 2001).

2.1.2 A Two-Dimensional Spectrum of Knowledge

Similar to how numbers are theoretically abstracted, systems can also be proposed out of any and every object, event, and process. For instance, behind collections of objects, say, apples, there is a set of numbers such as 0 (apple), 1 (apple), 2 (apples), 3 (apples), etc., and behind each organization, such as a regional economy, there is an abstract, theoretical system within which the relevant whole, component parts, and the related interconnectedness are emphasized. And, it is because these interconnected whole and parts, the totality is known as an economy. In other words, when internal structures can be ignored, numbers can be very useful; otherwise, the world consists of dominant systems (or structures or organizations).

Historically speaking, on top of numbers and quantities, traditional science has been developed, and along with systemhood comes the systems science. That jointly gives rise to a two-dimensional spectrum of knowledge, where the classical science, which is classified by the thinghood it studies, constitutes the first dimension and the systems science, which investigates structures and organizations, forms the genuine second dimension (Klir 2001). That is, systems thinking focuses on those properties of systems and associated problems that emanate from the general notion of structures and organizations, while the division of the classical science has been done largely on properties of particular objects. Therefore, systems research naturally transcends all the disciplines of the classical science and becomes a force making the existing disciplinary boundaries totally irrelevant and superficial.

The importance of this supplementary second dimension of knowledge cannot be in any way overemphasized. For example, when studying dynamics in an n-dimensional space, there are difficulties that cannot be resolved within the given space without getting help from a higher-dimensional space. In particular, when a one-dimensional flow is stopped by a blockage located over a fixed interval, the movement of the flow has to cease. However, if the flow is located in a two-dimensional space, instead of being completely stopped, the one-dimensional blockage would only create a local (minor) irregularity in the otherwise linear movement of the flow (that is how nonlinearity appears (Lin 2008)). Additionally, if one desires to peek into the internal structure of the one-dimensional blockage, he can simply take advantage of the second dimension by looking into the blockage from either above or below the blockage. That is, when an extra dimension is available, science will gain additional strength in terms of solving more problems that have been challenging the very survival of the mankind.

2.1.3 The Systemic Yoyo Model

Even though systems research holds such a strong promise as what is described in the previous subsection, the systems movement has suffered a great deal in the past 80 some years of development due to the reason that this new science does not have its own particular speaking language and thinking logic. Conclusions of systems research, produced in this period of time, are drawn either on ordinary language discussions or by utilizing the conventional mathematical methods, making many believe that systems thinking is nothing but a clever way of rearranging conventional ideas. In other words, due to the lack of an adequate tool for reasoning and an adequate language for speaking, systems research has been treated with less significance than they were thought initially since the 1970s when several publications criticized how systems enthusiasts derived their results without sufficient rigorous means (Berlinski 1976; Lilienfeld 1978), even though most of the results turned out to be correct if seen through our 20–20 hindsight.

Considering the importance of the Cartesian coordinate system in modern science (Kline 1972), Wu and Lin (2002) realize that the concepts of (sizeless and volumeless) points and numbers are bridged beautifully together within the Cartesian coordinate system so that this system plays the role of intuition and playground for modern science to evolve; and within this system, important concepts and results of modern mathematics and science are established. Recognizing the lack of such an intuition and playground for systems science, on the basis of the blown-up theory (Wu and Lin 2002), the yoyo model in Fig. 2.1 is formally

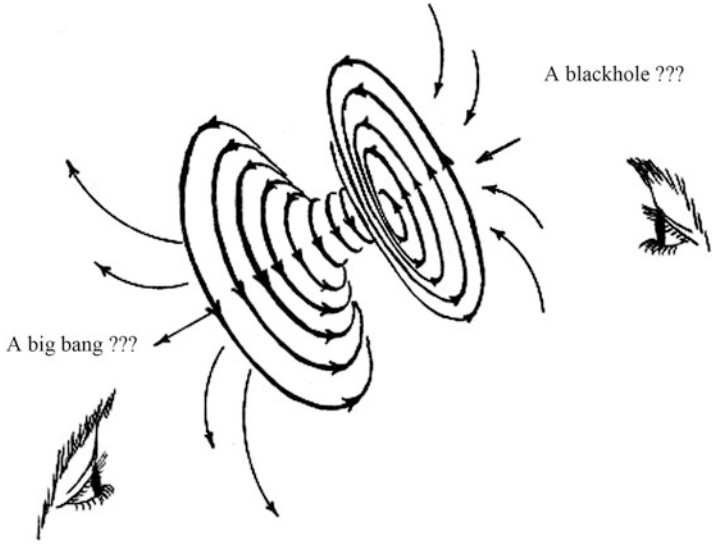
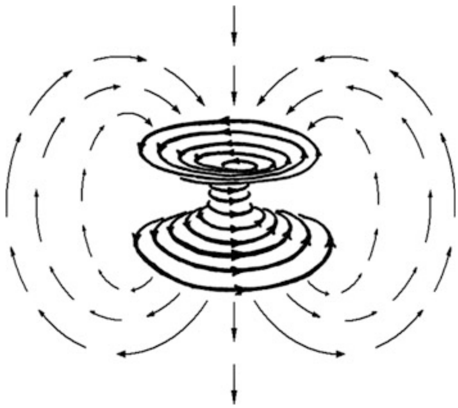


Fig. 2.1 Eddy motion model of a general system

Fig. 2.2 The distribution of a meridian field



introduced by Lin (2007) in order to establish the badly needed intuition and playground for systems science.

In particular, on the basis of the blown-up theory and the discussion on whether or not the world can be seen from the viewpoint of systems (Lin 1988a; Lin et al. 1990), the concepts of black holes, big bangs, and converging and diverging eddy motions are coined together in the model shown in Figs. 2.1 and 2.2. This model was established by Wu and Lin (2002) for each object and every system imaginable. In other words, each system or object considered in a study is a multidimensional entity that spins about its either visible or invisible axis. If we fathom such a spinning entity in our three-dimensional space, we will have a structure as shown in Fig. 2.1. The side of black hole sucks in all things, such as materials, information, energy, profit, etc. After funneling through the short narrow neck, all things are spit out in the form of a big bang. Some of the materials, spit out from the end of big bang, never return to the other side and some will (Fig. 2.2a). For the sake of convenience of communication, such a structure as shown in Fig. 2.1 is referred to as a (Chinese) yoyo due to its general shape. More specifically, what this systemic model says is that each physical or intellectual entity in the universe, be it a tangible or intangible object, a living being, an organization, a culture, a civilization, etc., can all be seen as a kind of realization of a certain multidimensional spinning yoyo with either an invisible or visible spin field around it. It stays in a constant spinning motion as depicted in Fig. 2.1. If it does stop its spinning, it will no longer exist as an identifiable system. What Fig. 2.2b shows is that due to the interactions between the eddy field, which spins perpendicularly to the axis of spin, of the model, and the meridian field, which rotates parallel to axis of spin, all the materials that actually return to the black-hole side travel along a spiral trajectory.

To show this yoyo model can indeed, as expected, play the role of intuition and playground for systems researchers, this model has been successfully applied in the investigation of Newtonian physics of motion, the concept of energy, economics, finance, history, foundations of mathematics, small-probability disastrous weather forecasting, civilization, business organizations, and the mind, among others (Lin 2009; Lin and Forrest 2011; Forrest 2013, 2014; Forrest and Tao 2014; Ying and Forrest 2015).

At this junction, as an example, let us look at how a workplace can be investigated theoretically as such a spinning structure. In fact, each social entity is an objectively existing system that is made up of objects, such as people and other physical elements, and some specific relations between the objects. It is these relations that make the objects emerge as an organic whole and a social system. For example, let us look at a university of higher education. Without the specific setup of the organizational whole (relationships), the people, the buildings, the equipment, etc. will not emerge as a university (system). Now, what the systemic yoyo model says is that each imaginable system, which is defined as the totality of some objects and some relationships between the objects (Lin 1999), possesses the systemic yoyo's rotational structure so that each chosen social system, as a specific system involving people, has its own specific multidimensional systemic yoyo structure with a rotational field.

To this end, there are many different ways for us to see why each social entity spins about an invisible axis. In particular, let us imagine an organization, say a business entity. As it is well known in management science, each firm has its own particular organizational culture. Differences in organizational cultures lead to varied levels of productivity. Now, the basic components of an organizational culture change over time. These changes constitute the evolution of the firm and are caused by inventing and importing ideas from other organizations and consequently modifying or eliminating some of the existing ones. The concept of spin beneath the systemic yoyo structure of the firm comes from what ideas to invent, which external ideas to import, and which existing ones to eliminate. If idea A will likely make the firm more prosperous with higher level of productivity, while idea B will likely make the firm stay as it has been, then these ideas will form a spin in the organizational culture. Specifically, some members of the firm might like additional productivity so that their personal goals can be materialized in the process of creating the extra productivity, while some other members might like to keep things as they have been so that what they have occupied, such as income, prestige, social status, etc., will not be adversely affected. These two groups will fight against each other to push for their agendas so that theoretically ideas A and B are actually "spin" around each other. For one moment, A is ahead; for the next moment, B is leading. And at yet another moment, no side is ahead when the power struggle might have very well reached an equilibrium state. In this particular incidence, the abstract axis of spin is invisible, because no one is willing to openly admit his underlying purpose for pushing for a specific idea (either A or B or other ones).

As for the concept of black hole in a social organization, it can be seen relatively clearly, because each social organization is an input-output system, no matter whether the organization is seen materially, holistically, or spiritually. The input mechanism will be naturally the "black hole," while outputs of the organization the "big bang." Again, when the organization is seen from different angles, the meanings of "black hole" and "big bang" are different. But, together these different "black holes" and "big bangs" make the organization alive. Without the totality of "black holes" and that of "big bangs," no organization can be physically and holistically standing. Other than intuition, to this end the existing literature on civilizations, business entities, and individual humans does readily testify.

From this example, a careful reader might have sensed the fact that in this systemic yoyo model, we look at each system, be it a human organization, a physical entity, or an abstract intellectual being, as a whole that is made up of the "physical" body, its internal structure, and its interactions with the environment. This whole, according to the systemic yoyo model, is a high-dimensional spin field. Considering the fact that the body is the carrier of all other (such as cultural, philosophical, spiritual, psychological, etc.) aspects of the system, in theory the body of the system is a pool of fluid realized through the researcher's sensing organs in the three-dimensional space. The word "fluid" here is an abstract term totaling the flows of energy, information, materials, money, etc., circulating within the inside of, going into, and giving off from the body. And in all published references we have searched, these flows are studied widely in natural and social sciences using continuous functions, which in physics and mathematics mean flows of fluids and are widely known as flow functions. On the other hand, it has been shown and concluded in Lin (2008) and Lin and Forrest (2011) that the universe is a huge ocean of eddies, which changes and evolves constantly. That is, the totality of the physically existing world can be legitimately studied as fluids, their mechanism of internal working, and their interactions with each other.

2.2 Properties of Systemic Yoyos

2.2.1 The Field Structure

Because each yoyo spins as in Fig. 2.1, other than the eddy field, which is perpendicular to the axis of rotation as shown in Fig. 2.1, there also exists a meridian field accompanying each yoyo (see Fig. 2.2). The invisible meridians go into the center of the black hole, through the narrow neck, and then out the big bang. They travel through the space and return to the center of the black hole. Somehow, we can imagine that these meridians help to hold different layers of the eddy field of the yoyo structure together. For the convenience of our communication, for any given yoyo structure, the black-hole side will be referred to as the south pole of the structure and the big bang side the north pole.

In this model, the word "spin" is used to capture the concept of angular momentum or the presence of angular momentum intrinsic to a body as opposed to orbital angular momentum of angular momentum, that is, the movement of the object about an external point. For example, the spin of the earth stands for the earth's daily rotation about its polar axis. The orbital angular momentum of the earth is about the earth's annual movement around the sun. In general, a two-dimensional object spins around a center (or a point), while a three-dimensional object rotates around a line called an axis.

Mathematically, a spin of a rigid body around a point or axis is followed by a second spin around the same point (respectively, axis), and then a third spin results. The inverse of a spin is also a spin. Thus, all possible spins around a point (respectively, axis) form a group of mathematics. However, a spin around a point or axis and a spin around a different point (respectively, axis) may result in something other than a rotation, such as a translation. In astronomy, spin (or rotation) is a commonly observed phenomenon. Stars, planets, and galaxies all spin around on their axes. In social science areas, spin appears in the study of many topics. An old saying goes as things always "go around and come around." The theory and practice of public relations heavily involve the concept of spin, where a person, such as a politician, or an organization, such as a publicly traded company, signifies his often biased favor of an event or situation. In quantum mechanics, spin is particularly important for systems at atomic length scales, such as individual atoms, protons, or electrons (Griffiths 2004).

Because systems are of various kinds and scales, the universe can be seen as an ocean of eddy pools of different sizes, where each pool spins about its visible or invisible center or axis. At this junction, one good example in our three-dimensional physical space is the spinning field of air in a tornado. In the solenoidal structure, at the same time when the air within the tornado spins about the eye in the center, the systemic yoyo structure continuously sucks in and spits out air. In the spinning solenoidal field, the tornado takes in air and other materials, such as water or water vapor on the bottom, and lifts up everything it took in into the sky, and then it continuously spays out the air and water from the top of the spinning field. At the same time, the tornado also breathes in and out with air in all horizontal directions and elevations. If the amounts of air and water taken in by the tornado are greater than those given out, then the tornado will grow larger with increasing effect on everything along its path. That is the initial stage of formation of the tornado. If the opposite holds true, then the tornado is in its process of dying out. If the amounts of air and water that are taken in and given out reach an equilibrium, then the tornado can last for at least a while. In general, each tornado (or a systemic yoyo) experiences a period of stable existence after its initial formation and before its disappearance. Similarly, for the general systemic yoyo model, it also constantly takes in and spits out materials. For the convenience of our discussion in this book, we assume that the spinning of the yoyo structures follows the left-hand rule 1 below.

Left-Hand Rule 1. When holding our left hand, the four fingers represent the spinning direction of the eddy plane, and the thumb points to the north pole direction along which the yoyo structure sucks in and spits out materials at its center (the narrow neck). (Note: it can be seen that in the physical world, systemic yoyos do not have to comply with this left-hand rule.)

As influenced by the eddy spin, the meridian directional movement of materials in the yoyo structure is actually slanted instead of being perfectly vertical. In Fig. 2.3, the horizontal vector stands for the direction of spin on the yoyo surface toward the reader and the vertical vector the direction of the meridian field, which is opposite of that in which the yoyo structure sucks in and spits out materials. Other than breathing in and out materials from the black-hole (the south pole) and big bang (the north pole) sides, the yoyo structure also takes in and gives out materials in all horizontal directions and elevations, just as in the case of tornadoes discussed earlier.

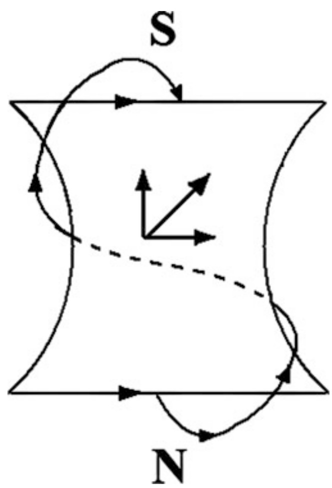


Fig. 2.3 Slanted meridians of a yoyo structure

2.2.2 The Quark Structure of Systemic Yoyos

The so-called three-jet event of the particle physics is an event with many particles in a final state that appear to be clustered in three jets, each of which consists of particles that travel in roughly the same direction. One can draw three cones from the interaction point, corresponding to the jets (Fig. 2.4), and most particles created in the reaction appear to belong to one of these cones. These three-jet events are currently the most direct available evidence for the existence of gluons, the elementary particles that cause quarks to interact and are indirectly responsible for the binding of protons and neutrons together in atomic nuclei (Brandelik et al. 1979). Because jets are ordinarily produced when quarks hadronize, the process of the formation of hadrons out of quarks and gluons, and quarks are produced only in pairs, an additional particle is required to explain such events as the three jets that contain an odd number of jets. Quantum chromodynamics indicates that this needed particle of the three-jet events is a particularly energetic gluon, radiated by one of the quarks, which hadronizes much as a quark does. What is particularly interesting about these events is their consistency with the Lund string model. And, what is predicted out of this model is precisely what is observed.

Now, let us make use of this laboratory observation to study the structure of systemic yoyos. To this end, let us borrow the term "quark structure" from Chen (2007). Because out of the several hundreds of different microscopic particles, other than protons, neutrons, electrons, and several others, most only exist momentarily, it is a common phenomenon for general systemic yoyos to be created and to disappear constantly in the physical microscopic world. All microscopic systemic yoyos can be classified (Chen 2007, p. 41) into two classes using the number of quarks involved. One class contains two-quark yoyos, such as electrons; π-, κ-, η-mesons; and others; and the other class three-quark yoyos, including protons; neutrons; Λ-, Σ-, Ω-, Ξ (Xi) baryons; etc. Here, electrons are commonly seen as without any quark. However, Chen (2007) showed that yes, they have two quarks. Currently, no laboratory experiment has produced zero-quark or n-quark particles, for natural number $n \geq 4$.

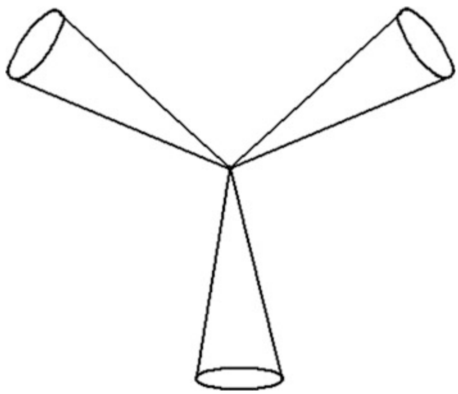


Fig. 2.4 A "snapshot" a three-jet event

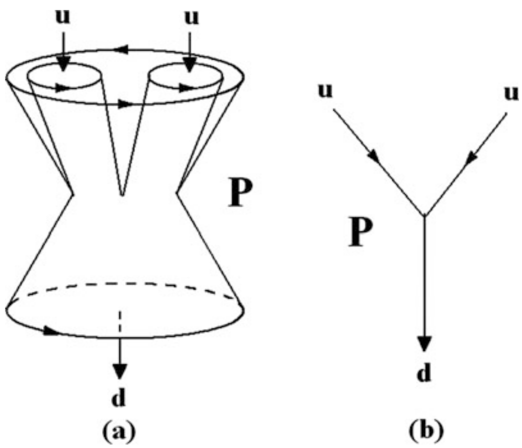


Fig. 2.5 The quark structure of a proton P

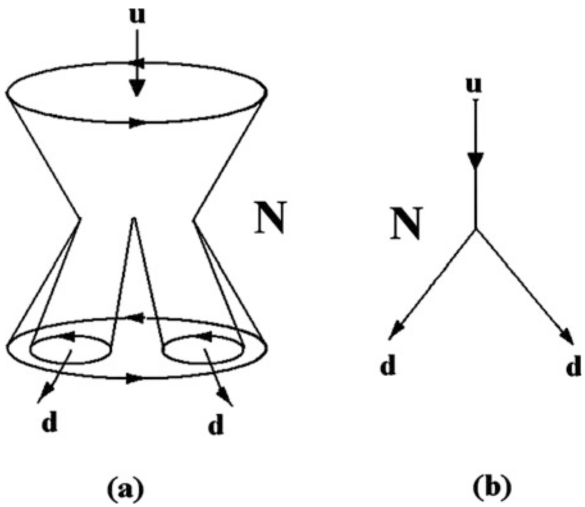


Fig. 2.6 The quark structure of a neutron N

Following Chen (2007), each spinning yoyo, as shown in Fig. 2.1, is seen as a two-quark structure, where we imagine the yoyo is cut through its waist horizontally in the middle, then the top half is defined as an absorbing quark and the bottom half a spurting quark. Now, let us study three-quark yoyos by looking at a proton P and a neutron N. At this junction, the three-jet events are employed as the evidence for the structure of three-quark yoyos, where there are two absorbing and one spurting quark in the eddy field. The proton P has two absorbing u-quarks and one spurting d-quark (Fig. 2.5), while the neutron N has two spurting d-quarks and one absorbing u-quark (Fig. 2.6). In these figures, the graphs (b) are the simplified flow charts with the line segments indicating the imaginary axes of rotation of each local spinning column. Here, in Fig. 2.5, the absorbing u-quarks stand for local spinning pools, while together they also travel along in the larger eddy field in which they are part of. Similarly in Fig. 2.6, the spurting d-quarks are regional spinning pools. At the same time when they spin individually, they also travel along in the large yoyo structure of the neutron N. In all these cases, the spinning directions of these u- and d-quarks are the same except that each u-quark spins convergently (inwardly) and each d-quark divergently (outwardly).

Different yoyo structures have different numbers of absorbing u-quarks and d-quarks. And, the u-quarks and d-quarks in different yoyos are different due to variations in their mass, size, spinning speed and direction, and the speed of absorbing and spurting materials. This end is well supported by the discovery of quarks of various flavors, two spin states (up and down), positive and negative charges, and colors. That is, the existence of a great variety of quarks has been firmly established.

Hide (1953) used two concentric cylinders with a liquid placed in the ring-shaped region between the cylinders. He placed the container on a rotating turntable subjected to heating near the periphery and cooling at the center. The turntable generally rotated counterclockwise, as does the earth when viewed from above the north pole. Even though everything in the experiment was arranged with perfect symmetry about the axis of rotation, such as no impurities added in the liquid and the bottom of the container is flat, Hide observed the flow patterns as shown in Fig. 2.7. Briefly, with fixed heating, a transition from circular symmetry (Fig. 2.7a) to asymmetries (Fig. 2.7b, then Fig. 2.7c) would take place as the rotation increased past a critical value. With sufficiently rapid but fixed rate of rotation, a similar transition would occur when the heating reached a critical strength, while another transition back to symmetry would occur when the heating reached a still higher critical strength. Also, in stage Fig. 2.7c, a chain of identical eddy motions would appear. As they travel along, they would alter their shapes in unison in a regular periodic fashion, and after many rotations of the turntable, they would regain their original shape and then repeat the cycle. Fultz and his colleagues (1959) conducted another dishpan experiment without the inner cylinder, producing similar results.

Now, if we fit Fultz's dishpan experiment to the discussion above by imagining both the top and the bottom of each yoyo as a spinning dish of fluids, then the patterns as observed in the dishpan experiment suggest that in theory, there could exist such a yoyo structure that it has n u-quarks and m d-quarks, where $n \geq 1$ and $m \geq 1$ are arbitrary natural numbers, and each of these quarks spins individually and along with each other in the overall spinning pool of the yoyo structure.

From Lin (2007, 2008), it can be seen that due to uneven distribution of forces, either internal or external to the yoyo structure, the quark structure of the spinning yoyo changes, leading to different states in the development of the yoyo. This end can be well seen theoretically and has been well supported by laboratory experiments, where, for example, protons and neutrons can be transformed into each other. When a yoyo undergoes changes and becomes a new yoyo, the attributes of the original yoyo in general will be altered. For example, when a two-quark yoyo is split into two new yoyos under an external force, the total mass of the new yoyos might be greater or smaller than that of the original yoyo. And, in one spinning yoyo, no matter how many u-quarks (or d-quarks) exist, although these quarks spin

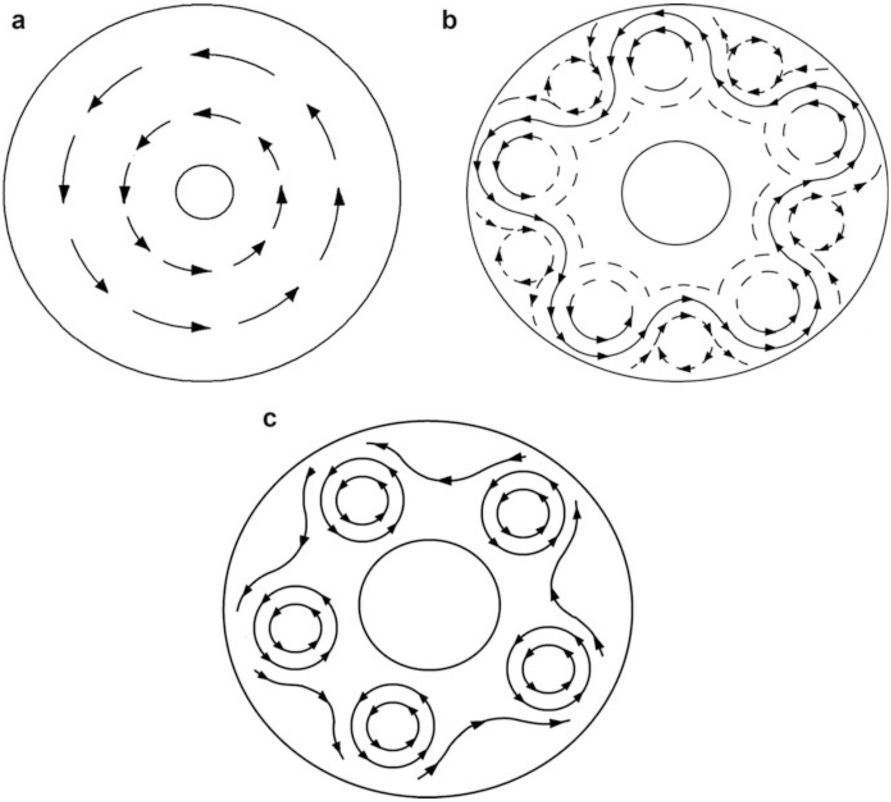


Fig. 2.7 Patterns observed in Hide's dishpan experiment. (**a**) Symmetric flow at the upper surface. (**b**) Asymmetric flow at the upper surface. (**c**) Asymmetric circular flow at the upper surface

individually, they also spin in the same direction and at the same angular speed. Here, the angular speeds of u-quarks and d-quarks do not have to be the same, which is different of what is observed in the dishpan experiment, because in this experiment everything is arranged with perfect symmetry, such as the flat bottom of the dish and perfectly round periphery.

2.3 Laws on State of Motion

Based on the discovery (Wu and Lin 2002) that spins are the fundamental evolutionary feature and characteristic of materials, in this section, we will study the figurative analysis method of the systemic yoyo model and how to apply it to establish laws on state of motion by generalizing Newton's laws of motion. More specifically, after introducing the new figurative analysis method, we will have a chance to generalize all the three laws of motion so that external forces are no longer required for these laws to work. As what is known, these laws are one of the reasons why physics is an "exact" science. And, in the rest of this book, we will show that these generalized forms of the original laws of mechanics will be equally applicable to social sciences and humanity areas as their classic forms in natural science. The presentation in this section is based on Lin (2007).

2.3.1 The First Law on State of Motion

Newton's first law says an object will continue in its state of motion unless compelled to change by a force impressed upon it. This property of objects, their natural resistance to changes in their state of motion, is called inertia. Based on the theory of blown-ups, one has to address two questions not settled by Newton in his first law: If a force truly impresses on the object, the force must be from the outside of the object. Then, where can such a force be from? How can such natural resistance of objects to changes be considered natural?

It is because uneven densities of materials create twisting forces that fields of spinning currents are naturally formed. This end provides an answer to the first question. Based on the yoyo model (Fig. 2.1), the said external force comes from the spin field of the yoyo structure of another object, which is another level higher than the object of our concern. These forces from this new spin field push the object of concern away from its original spin field into a new spin field. Because if there is not such a forced traveling, the said object will continue its original movement in its original spin field. That is why Newton called its tendency to stay in its course of movement as its resistance to changes in its state of motion and as natural. Based on this discussion and the yoyo model (Fig. 2.1) developed for each and every object and system in the universe, Newton's first law of mechanics can be rewritten in a general term as follows:

The First Law on State of Motion *Each imaginable and existing entity in the universe is a spinning yoyo of a certain dimension. Located on the outskirt of the yoyo is a spin field. Without being affected by another yoyo structure, each particle in the said entity's yoyo structure continues its movement in its orbital state of motion.*

Because for Newton's first law to hold true, one needs an external force, when people asked Newton where such an initial force could be from, he answered (jokingly?): "It was from God. He waved a bat and provided the very first blow to all things he created" (Kline 1972). If such an initial blow is called the first push, then the yoyo model in Fig. 2.1 and the stirring forces naturally existing in each "yoyo" created by uneven densities of materials' structures will be called the second stir.

2.3.2 The Second Law on State of Motion

Newton's second law of motion says that when a force does act on an object, the object's velocity will change and the object will accelerate. More precisely, what is claimed is that its acceleration $\vec{a}$ will be directly proportional to the magnitude of the total (or net) force $\vec{F}_{\text{net}}$ and inversely proportional to the object's mass m. In symbols, the second law is written:

$$\vec{F}_{\text{net}} = m\vec{a} = m\frac{d\vec{v}}{dt} \tag{2.1}$$

Even though Eq. (2.1) has been one of the most important equations in mechanics, when one ponders over this equation long enough, he has to ask the following questions: What is a force? Where are forces from and how do forces act on other objects?

To answer these questions, let us apply Einstein's concept of "uneven time and space" of materials' evolution (Einstein 1997). So, we can assume

$$\vec{F} = -\nabla S(t, x, y, z), \tag{2.2}$$

where $S = S(t, x, y, z)$ stands for the time-space distribution of the external acting object (a yoyo structure). Let $\rho = \rho(t, x, y, z)$ be the density of the object being acted upon. Then, Eq. (2.1) can be rewritten as follows for a unit mass of the object being acted upon:

$$\frac{d\vec{v}}{dt} = -\frac{1}{\rho(t, x, y, z)}\nabla S(t, x, y, z). \tag{2.3}$$

If $S(t, x, y, z)$ is not a constant, or if the structure of the acting object is not even, Eq. (2.3) can be rewritten as

$$\frac{d\left(\nabla x \times \vec{v}\right)}{dt} = -\nabla x \times \left[\frac{1}{\rho}\nabla S\right] \neq 0 \tag{2.4}$$

and it represents an eddy motion due to the nonlinearity involved. That is, when the concept of uneven structures is employed, Newton's second law actually indicates that a force, acting on an object, is in fact the attraction or gravitation from the acting object. It is created within the acting object by the unevenness of its internal structure.

By combining this new understanding of Newton's second law with the yoyo model, we get the models on how an object m is acted upon by another object M (see Figs. 2.8 and 2.9).

Now, by summarizing what can be observed in these figures, Newton's second law can be generalized as follows.

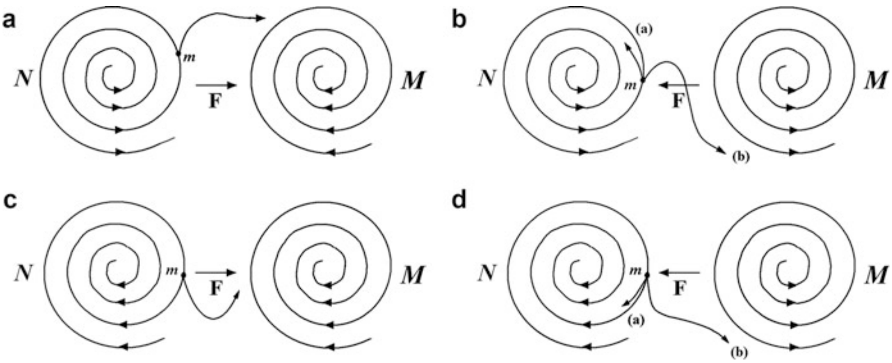


Fig. 2.8 Acting and reacting models with yoyo structures of harmonic spinning patterns. (**a**) Object *m* is located in a diverging eddy and pulled by a converging eddy *M*. (**b**) Object *m* is located in a diverging eddy and pulled or pushed by a diverging eddy *M*. (**c**) Object *m* is located in a converging eddy and pulled by a converging eddy *M*. (**d**) Object *m* is located in a converging eddy and pulled or pushed by a diverging eddy *M*

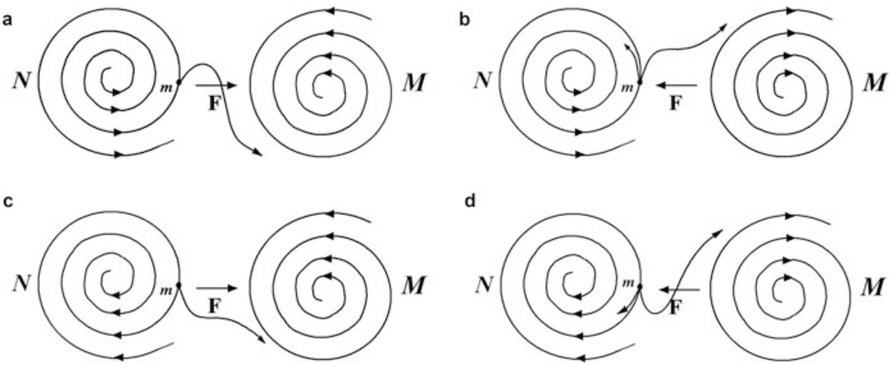


Fig. 2.9 Acting and reacting models with yoyo structures of inharmonic spinning patterns. (**a**) Object *m* is located in a diverging eddy and pulled by a converging eddy *M*. (**b**) Object *m* is located in a diverging eddy and pushed or pulled by a diverging eddy *M*. (**c**) Object *m* is located in a converging eddy and pulled by a converging eddy *M*. (**d**) Object *m* is located in a converging eddy and pushed or pulled by a diverging eddy *M*

The Second Law on State of Motion *When a constantly spinning yoyo structure M does affect an object m, which is located in the spin field of another object N, the velocity of the object m will change and the object will accelerate. More specifically, the object m experiences an acceleration $\vec{a}$ toward the center of M such that the magnitude of $\vec{a}$ is given by*

$$a = \frac{v^2}{r} \tag{2.5}$$

where r is the distance between the object m and the center of M and v the speed of any object in the spin field of M about distance r away from the center of M. And, the magnitude of the net pulling force $\vec{F}_{\text{net}}$ that M exerts on m is given by

$$F_{\text{net}} = ma = m\frac{v^2}{r} \tag{2.6}$$

2.3.3 The 3rd and 4th Laws on State of Motion

Newton's third law is commonly known as that to every action, there is an equal, but opposite, reaction. More precisely, if object A exerts a force on object B, then object B exerts a force back on object A, equal in strength but in the opposite direction. These two forces, $\vec{F}_{A-\text{on}-B}$ and $\vec{F}_{B-\text{on}-A}$, are called an action/reaction pair.

Similar to what has been done earlier, if we analyze the situation in two different angles: two eddy motions act and react to each other's spin field, and two, one spinning yoyo is acted upon by an eddy flow of a higher level and scale, then for the first situation, where two eddy motions act and react to each other's spin field, we have the diagrams in Fig. 2.10.

For objects N and M with harmonic spin fields, we have the diagrams in Fig. 2.11.

Based on the analysis of these graphs, Newton's third law can be generalized for the case of two eddy motions acting and reacting to each other's spin fields as follows:

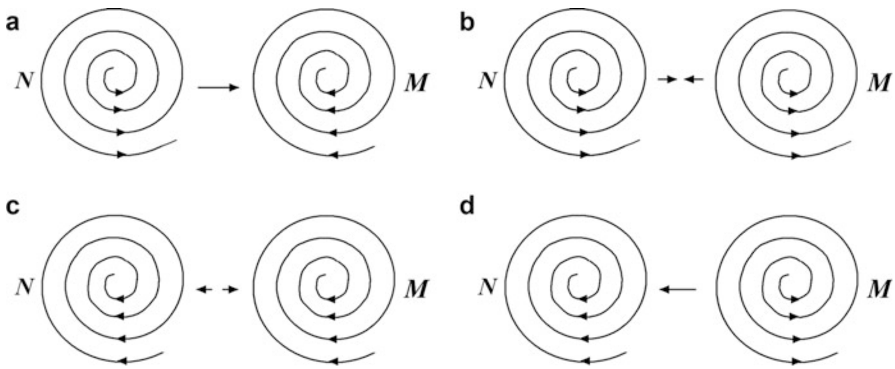


Fig. 2.10 Same scale acting and reacting spinning yoyos of the harmonic pattern. (**a**) N diverges and M converges. (**b**) Both N and M diverge. (**c**) Both N and M converge. (**d**) N converges and M diverges

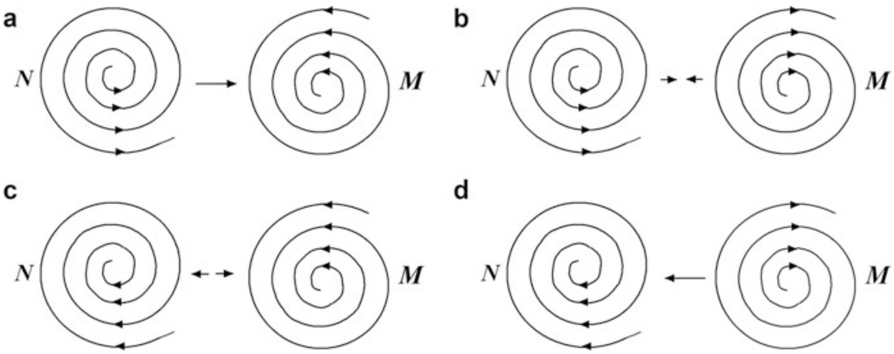


Fig. 2.11 Same scale acting and reacting spinning yoyos of inharmonic patterns. (**a**) *N* diverges and *M* converges. (**b**) Both *N* and *M* diverge. (**c**) Both *N* and *M* converge. (**d**) *N* converges and *M* diverges

The Third Law on State of Motion *When the spin fields of two yoyo structures N and M act and react on each other, their interaction falls in one of the six scenarios as shown in* Figs. 2.10a–c and 2.11a–c. *And, the following are true:*

1. *For the cases in (a) of* Figs. 2.10 and 2.11, *if both N and M are relatively stable temporarily, then their action and reaction are roughly equal but in opposite directions during the temporary stability. In terms of the whole evolution involved, the divergent spin field (N) exerts more action on the convergent field (M) than M's reaction peacefully in the case of* Fig. 2.10a *and violently in the case of* Fig. 2.11a.
2. *For the cases (b) in* Figs. 2.10 and 2.11, *there are permanent equal, but opposite, actions and reactions with the interaction more violent in the case of* Fig. 2.10b *than in the case of* Fig. 2.11b.
3. *For the cases in (c) of* Figs. 2.10 and 2.11, *there is a permanent mutual attraction. However, for the former case, the violent attraction may pull the two spin fields together and have the tendency to become one spin field. For the latter case, the peaceful attraction is balanced off by their opposite spinning directions. And, the spin fields will coexist permanently.*

That is to say, Newton's third law holds true temporarily for cases (a), permanently for cases (b), and partially for cases (c) in Figs. 2.10 and 2.11.

If we look at Newton's third law from the second angle, one spinning yoyo *m* is acted upon by an eddy flow *M* of a higher level and scale. If we assume *m* is a particle in a higher-level eddy flow *N* before it is acted upon on by *M*, then we are looking at situations as depicted in Figs. 2.8 and 2.9. Jointly, we have what is shown in Fig. 2.12, where the sub-eddies created in Fig. 2.12a are both converging, since the spin fields of *N* and *M* are suppliers for them and sources of forces for their spins. Sub-eddies in Fig. 2.12b are only spinning currents. They serve as middle stop before supplying to the spin field of *M*. Sub-eddies in Fig. 2.12c are diverging.

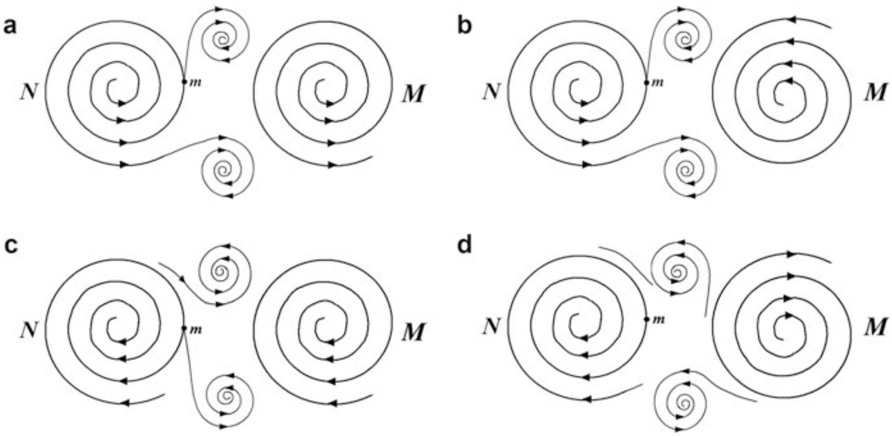


Fig. 2.12 Object *m* might be thrown into a sub-eddy created by the spin fields of *N* and *M* jointly. (**a**) Object *m* is situated as in Fig. 2.8b. (**b**) Object *m* is situated as in Fig. 2.9a. (**c**) Object *m* is situated as in Fig. 2.8c. (**d**) Object *m* is situated as in Fig. 2.9d

And, sub-eddies in Fig. 2.12d are only spinning currents similar to those in Fig. 2.12b.

That is, based on our analysis on the scenario that one object *m*, situated in a spin field *N*, is acted upon by an eddy flow *M* of a higher level and scale, we can generalize Newton's third law to the following form:

The Fourth Law on State of Motion *When the spin field M acts on an object m, rotating in the spin field N, the object m experiences equal, but opposite, action and reaction, if it is either thrown out of the spin field N and not accepted by that of M (*Figs. 2.8a, d and 2.9b, c*) or trapped in a sub-eddy motion created jointly by the spin fields of N and M (*Figs. 2.8b, c and 2.9a, d*). In all other possibilities, the object m does not experience equal and opposite action and reaction from N and M.*

2.3.4 Validity of Figurative Analysis

In the previous three subsections, we have heavily relied on the analysis of shapes and dynamic graphs. To any scientific mind produced out of the current formal education system, he/she will very well question the validity of such a method of reasoning naturally. To address this concern, let us start with the concept of equal quantitative effects. For detailed and thorough study of this concept, please consult with Wu and Lin (2002) and Lin (1998).

By equal quantitative effects, it means the eddy effects with nonuniform vortical vectorities existing naturally in systems of equal quantitative movements due to the unevenness of materials. Here, by equal quantitative movements, it means such movements that quasi-equal acting and reacting objects are involved or two or more quasi-equal mutual constraints are concerned with. What is significant about equal quantitative effects is that they can easily throw calculations of equations into computational uncertainty. For example, if two quantities x and y are roughly equal, then $x - y$ becomes a computational uncertainty involving large quantities with infinitesimal increments. This end is closely related to the second crisis in the foundations of mathematics.

Based on recent studies in chaos (Lorenz 1993), it is known that for nonlinear equation systems, which always represent equal quantitative movements (Wu and Lin 2002), minor changes in their initial values lead to dramatic changes in their solutions. Such extreme volatility existing in the solutions can be easily caused by changes of a digit many places after the decimal point. Such a digit place far away from the decimal point in general is no longer practically meaningful. That is, when equal quantitative effects are involved, we face with either the situation where no equation can be reasonably established or the situation that the established equation cannot be solved with valid and meaningful solution.

That is, the concept of equal quantitative effects has computationally declared that equations are not eternal and that there does not exist any equation under equal quantitative effects. That is why OuYang (Lin 1998) introduced the methodological method of "abstracting numbers (quantities) back into shapes (figurative structures)." Of course, the idea of abstracting numbers back to shapes is mainly about how to describe and make use of the formality of eddy irregularities. These irregularities are very different of all the regularized mathematical quantifications of structures.

Because the currently available variable mathematics is entirely about regularized computational schemes, there must be the problem of disagreement between the variable mathematics and irregularities of objective materials' evolutions and the problem that distinct physical properties are quantified and abstracted into indistinguishable numbers. Such incapability of modern mathematics has been shown time and time again in areas of practical forecastings and predictions. For example, since theoretical studies cannot yield any meaningful and effective method to foretell drastic weather changes, especially about small or zero probability disastrous weather systems, (in fact, the study of chaos theory indicates that weather patterns are chaotic and unpredictable. A little butterfly fluttering its tiny wings in Australia can drastically change the weather patterns in North America (Gleick 1987)); the technique of live report has been widely employed. However, in the area of financial market predictions, it has not been so lucky that the technique of live report can possibly applied as effectively. Due to equal quantitative effects, the movements of prices in the financial marketplace have been truly chaotic when viewed from the contemporary scientific point of view.

That is, the introduction of the concept of equal quantitative effects has made the epistemology of natural sciences gone from solids to fluids and completed the unification of natural and social sciences. More specifically, after we have generalized Newton's laws of motion, which have been the foundations on which physics is made into an "exact" science, in the previous three subsections, these new laws can be readily employed to study social systems, such as military conflicts, political struggles, economic competitions, etc.

Since we have briefly discussed about the concept of equal quantitative effects and inevitable failures of current variable mathematics under the influence of such effects, then how about figurative analysis?

As for the usage of graphs in our daily lives, it goes back as far as our recorded history can go. For example, any written language consists of an array of graphic figures. In terms of figurative analysis, one early work is the book, named *Yi Ching* (or the *Book of Changes*, as known in English (Wilhalm and Baynes 1967)). For now, no one knows exactly when this book was written and who wrote it. All known is that the book has been around since about 3000 years ago. In that book, the concept of Yin and Yang was first introduced and graphic figures are used to describe supposedly all matters and events in the world. When Leibniz (a founder of calculus) had a hand on that book, he introduced the binary number system and base p number system in modern mathematics (Kline 1972). Later on, Bool furthered this work and laid down the foundation for the modern computer technology to appear.

In our modern days, figures and figurative analysis are readily seen in many aspects of our lives. One good example is the number π. Since we cannot write out this number in the traditional fashion (in either the decimal form or the fraction form), we simply use a figure π to indicate it. The same idea is employed to write all irrational numbers. In the area of weather forecasting, figurative analysis is used each and every day in terms of weather maps. In terms of studies of financial markets, a big part of the technical analysis is developed on graphs. So, this part of technical analysis can also be seen as an example of figurative analysis.

From the recognition of equal quantitative effects and the realization of the importance of figurative analysis, OuYang invented and materialized a practical way to "abstract numbers back into shapes" so that the forecasting of many disastrous small or zero probability weather systems becomes possible. For detailed discussion about this end, please consult with Appendix D in Wu and Lin (2002) and Lin (1998). To simplify the matter, let us see how to abstract numbers π and $\sqrt{2}$ back into shapes with their inherent structures kept. In Fig. 2.13a, the exact value of π is represented using the area of a circle of radius 1. And, the precise value of $\sqrt{2}$ is

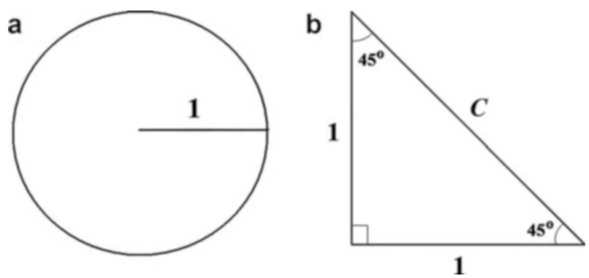


Fig. 2.13 Representing π and $\sqrt{2}$ figuratively and precisely. (**a**) The area of the circle is π. (**b**) The length of c is $\sqrt{2}$

given in Fig. 2.13b by employing the special right triangle. By applying these simple graphs, the meaning, the precise values, and their inherent structures of π and $\sqrt{2}$ are presented once for all.

2.4 Theoretical Justifications

This section looks at the theoretical foundation on why such an intuition as the yoyo model of general systems holds for each and every system that is either tangible or imaginable.

2.4.1 Blown-Ups: Moments of Transition in Evolutions

When we study the nature and treat everything we see as a system (Klir 2001), then one fact we can easily see is that many systems in nature evolve in concert. When one thing changes, many other seemingly unrelated things alter their states of existence accordingly. That is why we propose OuYang et al. (2009) to look at the evolution of a system or event of our concern as a whole. That is, when developments and changes naturally existing in the natural environment are seen as a whole, we have the concept of whole evolutions. And, in whole evolutions, other than continuities, as well studied in modern mathematics and science, what seems to be more important and more common is discontinuity, with which transitional changes (or blown-ups) occur. These blown-ups reflect not only the singular transitional characteristics of the whole evolutions of nonlinear equations but also the changes of old structures being replaced by new structures. By borrowing the form of calculus, we can write the concept of blown-ups as follows: For a given (mathematical or symbolic) model, which truthfully describes the physical situation of our concern, if its solution $u = u(t; t_0, u_0)$, where t stands for time and u_0 the initial state of the system, satisfies

$$\lim_{t \to t_0} |u| = +\infty, \tag{2.7}$$

and at the same time moment when $t \to t_0$, the underlying physical system also goes through a transitional change, then the solution $u = u(t; t_0, u_0)$ is called a blown-up solution and the relevant physical movement expresses a blown-up. For nonlinear models in independent variables of time (t) and space (x, x and y, or x, y, and z), the concept of blown-ups is defined similarly, where blown-ups in the model and the underlying physical system can appear in time or in space or in both.

2.4.2 Mathematical Properties of Blown-Ups

To help us understand the mathematical characteristics of blown-ups, let us look at the following constant-coefficient equation:

$$\dot{u} = a_0 + a_1 u + \ldots + a_{n-1} u^{n-1} + u^n = F, \quad (2.8)$$

where u is the state variable, and a_0, a_1, …, $a_{n\text{-}1}$ are constants. Based on the fundamental theorem of algebra, let us assume that Eq. (2.8) can be written as

$$\dot{u} = F = (u - u_1)^{p_1} \ldots (u - u_r)^{p_r} \left(u^2 + b_1 u + c_1\right)^{q_1} \ldots \left(u^2 + b_m u + c_m\right)^{q_m}, \quad (2.9)$$

where p_i and q_j, $i = 1, 2, \ldots, r$ and $j = 1, 2, \ldots, m$, are positive whole numbers and $n = \sum_{i=1}^{r} p_i + 2\sum_{j=1}^{m} q_j$, $\Delta = b_j^2 - 4c_j < 0$, $j = 1, 2, \ldots, m$. Without loss of generality, assume that $u_1 \geq u_2 \geq \ldots \geq u_r$, then the blown-up properties of the solution of Eq. (2.9) are given in the following theorem.

Theorem 2.1 The condition under which the solution of an initial value problem of Eq. (2.8) contains blown-ups is given by

1. When u_i, $i = 1, 2, \ldots, r$, does not exist, that is, $F = 0$ does not have any real solution
2. If $F = 0$ does have real solutions u_i, $i = 1, 2, \ldots, r$, satisfying $u_1 \geq u_2 \geq \ldots \geq u_r$
   (a) When n is an even number, if $u > u_1$, then u contains blown-up(s).
   (b) When n is an odd number, whether $u > u_1$ or $u < u_r$, there always exist blown-ups.

A detailed proof of this theorem can be found in Wu and Lin (2002, pp. 65–66) and is omitted here. And for higher-order nonlinear evolution systems, please consult with Lin (2008).

2.4.3 The Problem of Quantitative Infinity

One of the features of blown-ups is the quantitative infinity ∞, which stands for indeterminacy mathematically. So, a natural question is how to comprehend this mathematical symbol ∞, which in applications causes instabilities and calculation spills that have stopped each and every working computer.

To address the previous question, let us look at the mapping relation of the Riemann ball, which is well studied in complex functions (Fig. 2.14). This so-called Riemann ball, a curved or curvature space, illustrates the relationship between the infinity on the plane and the north pole N of the ball. Such a mapping relation connects $-\infty$ and $+\infty$ through a blown-up. Or in other words, when a dynamic point x_i travels through the north pole N on the sphere, the corresponding image x_i'

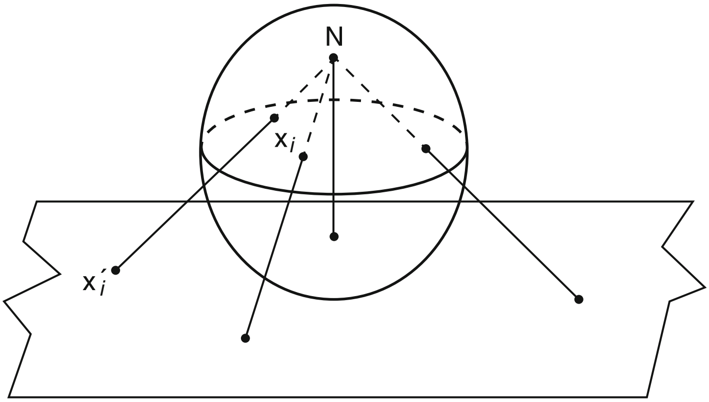


Fig. 2.14 The Riemann ball – relationship between planar infinity and three-dimensional north pole

on the plane of the point x_i shows up as a reversal change from $-\infty$ to $+\infty$ through a blown-up. So, treating the planar points $\pm\infty$ as indeterminacy can only be a product of the thinking logic of a narrow or low dimensional observ-control, since, speaking generally, these points stand implicitly for direction changes of one dynamic point on the sphere at the polar point N. Or speaking differently, the phenomenon of directionless, as shown by blown-ups of a lower dimensional space, represents exactly a direction change of movement in a higher-dimensional curvature space. Therefore, the concept of blown-ups can specifically represent implicit transformations of spatial dynamics. That is, through blown-ups, problems of indeterminacy of a narrow observ-control in a distorted space are transformed into determinant situations of a more general observ-control system in a curvature space. This discussion shows that the traditional view of singularities as meaningless indeterminacies has not only revealed the obstacles of the thinking logic of the narrow observ-control (in this case, the Euclidean space) but also the careless omissions of spatial properties of dynamic implicit transformations (bridging the Euclidean space to a general curvature space).

Summarizing what has been discussed above in this section, we can see that nonlinearity, speaking mathematically, stands (mostly) for singularities in Euclidean spaces, the imaginary plane discussed above. In terms of physics, nonlinearity represents eddy motions, the movements on curvature spaces, the Riemann ball above. Such motions are a problem about structural evolutions, which are a natural consequence of uneven evolutions of materials. So, nonlinearity accidentally describes discontinuous singular evolutionary characteristics of eddy motions (in curvature spaces) from the angle of a special, narrow observ-control system, the Euclidean spaces.

2.4.4 Equal Quantitative Effects

Another important concept studied in the blown-up theory is that of equal quantitative effects. Even though this concept was initially proposed in the study of fluid motions, it essentially represents the fundamental and universal characteristics of all movements of materials. What is more important is that this concept reveals the fact that nonlinearity is originated from the figurative structures of materials instead of nonstructural quantities of the materials.

The so-called equal quantitative effects stand for the eddy effects with nonuniform vortical vectorities existing naturally in systems of equal quantitative movements due to the unevenness of materials. And, by equal quantitative movements, it is meant to be the movements with quasi-equal acting and reacting objects or under two or more quasi-equal mutual constraints. For example, the relative movements of two or more planets of approximately equal masses are considered equal quantitative movements. In the microcosmic world, an often seen equal quantitative movement is the mutual interference between the particles to be measured and the equipment used to make the measurement. Many phenomena in daily lives can also be considered equal quantitative effects, including such events as wars, politics, economies, chess games, races, plays, etc.

Comparing to the concept of equal quantitative effects, the Aristotelian and Newtonian framework of separate objects and forces is about unequal quantitative movements established on the assumption of particles. On the other hand, equal quantitative movements are mainly characterized by the kind of measurement uncertainty that when I observe an object, the object is constrained by me. When an object is observed by another object, the two objects cannot really be separated apart. At this junction, it can be seen that the Su-Shi Principle of Xuemou Wu's panrelativity theory (1990), Bohr (N. Bohr, 1885–1962) principle and the relativity principle about microcosmic motions, von Neumann's principle of program storage, etc. all fall into the uncertainty model of equal quantitative movements with separate objects and forces.

What is practically important and theoretically significant is that eddy motions are confirmed not only by daily observations of surrounding natural phenomena but also by laboratory studies from as small as atomic structures to as huge as nebular structures of the universe. At the same time, eddy motions show up in mathematics as nonlinear evolutions. The corresponding linear models can only describe straight-line-like spraying currents and wave motions of the morphological changes of reciprocating currents. What is interesting here is that wave motions and spraying currents are local characteristics of eddy movements. This fact is very well shown by the fact that linearities are special cases of nonlinearities. Please note that we do not mean that linearities are approximations of nonlinearities.

The birth-death exchanges and the nonuniformity of vortical vectorities of eddy evolutions naturally explain where and how quantitative irregularities, complexities, and multiplicities of materials' evolutions, when seen from the current narrow observ-control system, come from. Evidently, if the irregularity of eddies comes from the unevenness of materials' internal structures and if the world is seen at the height of structural evolutions of materials, then the world is simple. And, it is so simple that there are only two forms of motions. One is clockwise rotation, and the other counterclockwise rotation. The vortical vectority in the structures of materials has very intelligently resolved the Tao of Yin and Yang of the *Book of Changes* of the eastern mystery (Wilhalm and Baynes 1967) and has been very practically implemented in the common form of motion of all materials in the universe. That is when the concept of invisible organizations of the blown-up system comes from.

The concept of equal quantitative effects not only possesses a wide range of applications but also represents an important omission of modern science, developed in the past 300 plus years. Evidently, not only are equal quantitative effects more general than the mechanic system of particles with further reaching significance, but also have they directly pointed to some of the fundamental problems existing in modern science.

In order for us to intuitively see why equal quantitative effects are so difficult for modern science to handle by using the theories established in the past 300 plus years, let us first look at why all materials in the universe are in rotational movements. According to Einstein's uneven space and time, we can assume that all materials have uneven structures. Out of these uneven structures, there naturally exist gradients. With gradients, there will appear forces. Combined with uneven arms of forces, the carrying materials will have to rotate in the form of moments of forces. That is exactly what the ancient Chinese Lao Tzu (English and Feng 1972) said: "Under the heaven, there is nothing more than the Tao of images," instead of Newtonian doctrine of particles (under the heaven, there is such a Tao that is not about images but sizeless and volumeless particles). The former stands for an evolution problem of rotational movements under stirring forces. Since structural unevenness is an innate character of materials, that is why it is named second stir, considering that the phrase of first push was used first in history (OuYang et al. 2000). What needs to be noted is that the phrases of first push and second stir do not mean that the first push is prior to the second stir.

Now, we can imagine that the natural world and/or the universe be composed of entirely with eddy currents, where eddies exist in different sizes and scales and interact with each other. That is, the universe is a huge ocean of eddies, which change and evolve constantly. One of the most important characteristics of spinning fluids, including spinning solids, is the difference between the structural properties of inwardly and outwardly spinning pools and the discontinuity between these pools. Due to the stirs in the form of moments of forces, in the discontinuous zones, there exist sub-eddies and sub-sub-eddies (Fig. 2.15, where sub-eddies are created naturally by the large eddies M and N). Their twist-ups (the sub-eddies) contain highly condensed amounts of materials and energies. Or in other words, the traditional frontal lines and surfaces (in meteorology) are not simply expansions of particles without any structure. Instead, they represent twist-up zones concentrated with irregularly structured materials and energies (this is where the so-called small-probability events appear and small-probability information is observed and collected, so such information (event) should also be called irregular information (and

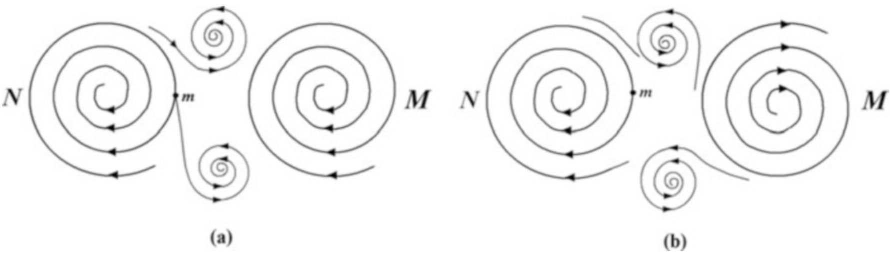
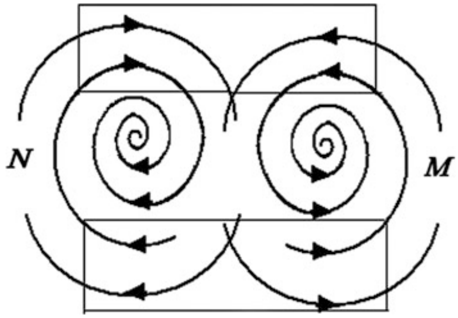


Fig. 2.15 Appearance of sub-eddies

Fig. 2.16 Structural representation of equal quantitative effects



event)). In terms of basic energies, these twist-up zones cannot be formed by only the pushes of external forces and cannot be adequately described by using mathematical forms of separate objects and forces. Since evolution is about changes in materials' structures, it cannot be simply represented by different speeds of movements. Instead, it is mainly about transformations of rotations in the form of moments of forces ignited by irregularities. The enclosed areas in Fig. 2.16 stand for the potential places for equal quantitative effects to appear, where the combined pushing or pulling is small in absolute terms. However, it is generally difficult to predict what will come out of the power struggles. In general, what comes out of the power struggle tends to be drastic and unpredictable by using the theories and methodologies of modern science.

2.5 Empirical Justifications

Continuing on what was done in the previous sections, we will in this section study several empirical evidences and observations that underline the existence of the yoyo structure behind each and every system, which either tangibly exists or is intellectually imaginable.

2.5.1 Bjerknes' Circulation Theorem

Based on the previous discussions, it is found that nonlinearity accidentally describes discontinuous singular evolutionary characteristics of eddy motions (in curvature spaces) from the angle of a special, narrow observ-control system, the Euclidean spaces (the imaginary plane). To support this end, let us now look at the Bjerknes' Circulation Theorem (1898).

At the end of the nineteenth century, V. Bjerkes (1898) (Hess 1959) discovered the eddy effects due to changes in the density of the media in the movements of the atmosphere and ocean. He consequently established the well-known circulation theorem, which was later named after him. Let us look at this theorem briefly.

By a circulation, it is meant to be a closed contour in a fluid. Mathematically, each circulation Γ is defined as the line integral about the contour of the component of the velocity vector locally tangent to the contour. In symbols, if $\vec{V}$ stands for the speed of a moving fluid, S an arbitrary closed curve, $\delta\vec{r}$ the vector difference of two neighboring points of the curve S (Fig. 2.17), then a circulation Γ is defined as follows:

$$\Gamma = \oint_S \vec{V}\delta\,\vec{r}. \tag{2.10}$$

Through some very clever manipulations, we can produce the following well-known Bjerknes' Circulation Theorem:

$$\frac{d\vec{V}}{dt} = \iint_\sigma \nabla\left(\frac{1}{\rho}\right) \times (-\nabla p)\cdot\delta\sigma - 2\Omega\frac{d\sigma}{dt}, \tag{2.11}$$

where $\vec{V}$ stands for the velocity of the circulation, σ the projection area on the equator plane of the area enclosed by the closed curve S, p the atmospheric pressure, ρ the density of the atmosphere, and Ω the earth's rotational angular speed.

The left-hand side of Eq. (2.11) represents the acceleration of the moving fluid, which according to Newton's second law of motion is equivalent to the force acting on the fluid. On the right-hand side, the first term is called a solenoid term in

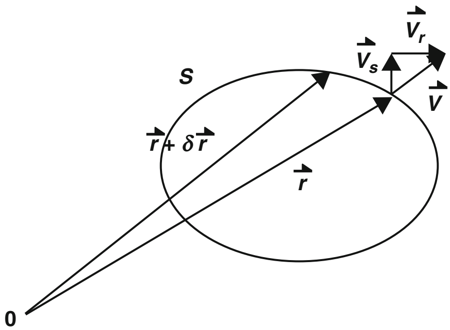


Fig. 2.17 The definition of a closed circulation

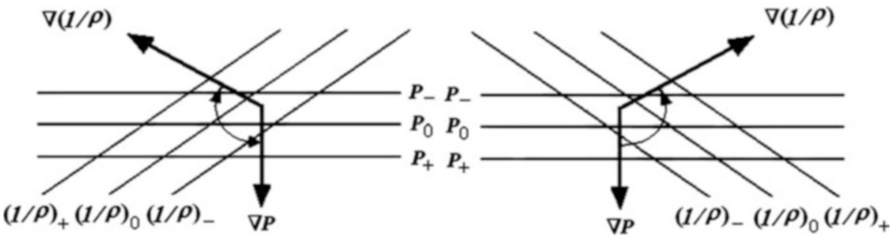


Fig. 2.18 A diagram for solenoid circulations

meteorology. It is originated from the interaction of the p- and ρ-planes due to uneven density ρ so that a twisting force is created. Consequently, materials' movements must be rotations with the rotating direction determined by the equal p- and ρ-plane distributions (Fig. 2.18). The second term in Eq. (2.11) comes from the rotation of the earth. In short, when a force is acting on a fluid, a rotation is created.

2.5.2 Conservation of Informational Infrastructure

Some branches of modern science were made "exact" by introducing various laws of conservation, even though, at the times when they were proposed, there might not have been any "theoretical or mathematical" foundations for these laws. Walking along the similar lines, Lin (1995) developed a theoretical foundation for some laws of conservation, such as the laws of conservation of matter-energy, of fundamental particles, etc., on the basis of general systems theory. By addressing some problems related to the discussions in Lin (1995), Lin and Fan (1997) systematically showed that human understanding of nature can be very much limited by our sensing organs, even though our constant attempts do help us get closer to the true state of the nature.

To form the heuristic foundation of the conservation law of informational infrastructure, let us first look at the intuitive understanding of the concept of general systems. From a practical point of view, a system is what is distinguished as a system (Klir 1985). From a mathematical point of view, a system is defined as follows (Lin 1987): S is a (general) system, provided that S is an ordered pair (M, R) of sets, where M is the set of objects of the system S and R a set of some relations on the set M. The sets M and R are called the object set and the relation set of the system S, respectively. (For those readers who are sophisticated enough in mathematics, for each relation r in R, it implies that there exists an ordinal number $n = n(r)$, a function of r, such that r is a subset of the Cartesian product of n copies of the set M.) The idea of using an ordered pair of sets to define the general system is to create the convenience of comparing systems. In particular, when two systems S_1 and S_2 are given, by writing each of these systems as an ordered pair (M_i, R_i), $i = 1$, 2, we can make use of the known facts of mathematics to show that $S_1 = S_2$, if, and only if $M_1 = M_2$ and $R_1 = R_2$. When two systems S_1 and S_2 are not equal, then with their ordered pair structures, we can readily investigate their comparisons, such as how and when they are similar, congruent, or one is structurally less than the other, and other properties between systems. For more details about this end, please consult with Lin (1999).

By combining these two understandings of general systems, we can intuitively see the following: Each thing that can be imagined in human minds is a system according to Klir's definition so that this thing would look the same as that of an ordered pair (M, R) according to Lin's definition. Furthermore, relations in R can be about some information of the system, its spatial structure, its theoretical structure, etc. That is, there should exist a law of conservation that reflects the uniformity of all tangible and imaginable things with respect to:

1. The content of information
2. Spatial structures
3. Various forms of movements, etc.

Based on this intuition of (general) systems and by looking at the available data from particle physics, field theory, astronomy, celestial mechanics, geo-physics, and meteorology, it is shown that between the macrocosm and the microcosm, between the electromagnetic interactions of atomic scale and the strong interactions of Quark's scale, between the central celestial body and the circling celestial bodies of celestial systems, between and among the large, medium, small, and micro-scales of the earth atmosphere, there exist laws of conservation of products of spatial physical quantities. In particular, it can be conjectured that there might be a more general law of conservation in terms of structure, in which the informational infrastructure, including time, space, mass, energy, etc., is approximately equal to a constant. In symbols, this conjecture can be written as follows:

$$AT \times BS \times CM \times DE = a \tag{2.12}$$

or more generally,

$$AT^a \times BS^b \times CM^g \times DE^e = a, \tag{2.13}$$

where α, β, γ, ε, and a are constants and T, S, M, E and A, B, C, D are, respectively, time, space, mass, energy, and their coefficients. These two formulas can be applied to various conservative systems of the universal, macroscopic, and microscopic levels. The constants α, β, γ, ε and a are determined by the initial state and properties of the natural system of interest.

In Eq. (2.12), when two (or one) terms of choice are fixed, the other two (or three) terms will vary inversely. For example, under the conditions of low speed and the macrocosm, all the coefficients A, B, C, and D equal 1. In this case, when two terms are fixed, the other two terms will be inversely proportional. This end satisfies all principles and various laws of conservation in the classical mechanics, including the laws of conservation of mass, momentum, energy, moment of momentum, etc. So, the varieties of mass and energy in this case are reflected mainly in changes in mass density and energy density. In the classical mechanics, when time and mass are fixed, the effect of a force of a fixed magnitude becomes the effect of an awl when the cross section of the force is getting smaller. When the space and mass are kept unchanged, the same force of a fixed magnitude can have an impulsive effect, since the shorter the time the force acts the greater density the energy release will be. When time and energy are kept the same, the size of working space and the mass density are inversely proportional. When the mass is kept fixed, shrinking acting time and working space at the same time can cause the released energy density reaching a very high level.

Under the conditions of relativity theory, that is, under the conditions of high speeds and great amounts of masses, the coefficients in Eq. (2.12) are no longer equal to 1, and Eq. (2.13) becomes more appropriate, and the constants A, B, C, D, and a and the exponents α, β, γ, and ε satisfy relevant equations in relativity theory. When time and space are fixed, the mass and energy can be transformed back and forth according to the well-known mass-energy relation:

$$E = mc^2.$$

When traveling at a speed close to that of light, the length of a pole will shrink when the pole is traveling in the direction of the pole and any clock in motion will become slower. When the mass is sufficiently great, light and gravitation deflection can be caused. When a celestial system evolves to its old age, gravitation collapse will appear and a black hole will be formed. We can imagine based on Eq. (2.12) that when our earth evolves sufficiently long, say a billion or trillion years, the relativity effects would also appear. More specifically speaking, in such a great time measurement, the creep deformation of rocks could increase and solids and fluids would have almost no difference so that solids could be treated as fluids. When a universe shrinks to a single point with the mass density infinitely high, a universe explosion of extremely high energy density could appear in a very short time period. So, a new universe is created!

If the previous law of conservation of informational infrastructure holds true, (all the empirical data seem to suggest so), its theoretical and practical significance is obvious. The hypothesis of the law contains the following facts:

1. Multiplications of relevant physical quantities in either the universal scale or the microscopic scale approximately equal a fixed constant.
2. Multiplications of either electromagnetic interactions or strong interactions approximately equal a fixed constant.

In the widest domain of human knowledge of our modern time, this law of conservation deeply reveals the structural unification of different layers of the universe so that it might provide a clue for the unification of the four basic forces in physics. This law of conservation can be a new evidence for the big bang theory.

It supports the model for the infinite universe with border and the oscillation model for the evolution of the universe, where the universe evolves as follows:

$$\ldots \rightarrow \text{explosion} \rightarrow \text{shrinking} \rightarrow \text{explosion} \rightarrow \text{shrinking} \rightarrow \ldots$$

It also supports the hypothesis that there exist universes "outside of our universe." The truthfulness of this proposed law of conservation is limited to the range of "our universe," with its conservation constant being determined by the structural states of the initial moment of "our universe."

All specific examples analyzed in establishing this law show that to a certain degree, the proposed law of conservation indeed holds true. That is, there indeed exists some kind of uniformity in terms of time, space, mass, and energy among different natural systems of various scales under either macroscopic or microscopic conditions or relativity conditions. Therefore, there might be a need to reconsider some classical theoretical systems so that our understanding about nature can be deepened. For example, under the time and space conditions of the earth's atmosphere, the traditional view in atmospheric dynamics is that since the vertical velocity of each atmospheric huge scale system is much smaller than its horizontal velocity, the vertical velocity is ignored. As a matter of fact (Ren and Nio 1994), since the atmospheric density difference in the vertical direction is far greater than that in the horizontal direction and since the gradient force of atmospheric pressure to move the atmospheric system 10 m vertically is equivalent to that of moving the system 200 km horizontally, the vertical velocity should not be ignored. The law of conservation of informational infrastructure, which holds true for all scales used in the earth's atmosphere, might provide conditions for a unified atmospheric dynamics applicable to all atmospheric systems of various scales. As a second example, in the situation of our earth where time and mass do not change, in terms of geological time measurements (sufficiently long time), can we imagine the force, which causes the earth's crust movements? Does it have to be as great as what is believed currently?

As for applications of science and technology, tremendous successes have been made in the macroscopic and microscopic levels, such as shrinking working spatial sectors, shortening the time length for energy releasing, and sacrificing partial masses (say, the usage of nuclear energy). However, the law of conservation of informational infrastructure might very well further the width and depth of applications of science and technology. For example, this law of conservation can provide a theory and thinking logic for us to study the movement evolution of the earth's structure, the source of forces or structural information which leads to successful predictions of major earthquakes, and to find the mechanisms for the formation of torrential rains and for the arrival of earthquakes (Ren 1996).

Philosophically speaking, the law of conservation of informational infrastructure indicates that in the same way as mass, energy is also a characteristic of physical entities. Time and space can be seen as the forms of existence of physical entities with motion as their basic characteristics. This law of conservation connects time, space, mass, and motion closely into an inseparable whole. So, time, space, mass, and energy can be seen as attributes of physical entities. With this understanding, the concept of mass is generalized and the wholeness of the world is further proved and the thoughts of never diminishing mass and never diminishing universes are evidenced.

2.5.3 Silent Human Communications

In this subsection, we will look at how the systemic yoyo model is manifested in different areas of life by briefly visiting relevant experimental and clinical evidences. All the omitted details can be found in the relevant references.

Based on the systemic yoyo model, each human being is a three-dimensional realization of a spinning yoyo structure of a certain dimension higher than three. To illustrate this end, let us consider two simple and easy-to-repeat experiments.

Experiment #1: Feel the Vibe

Let us imagine we go to a sport event, say a swim meet. Assume that the area of competition contains a pool of the Olympic size and along one long side of the pool there are about 200 seats available for spectators to watch the swim meet. The pool area is enclosed with a roof and walls all around the space.

Now, let us physically enter the pool area. What we find is that as soon as we enter the enclosed area of competition, we immediately fall into a boiling pot of screaming and jumping spectators, cheering for their favorite swimmers competing in the pool. Now, let us pick a seat a distance away from the pool deck anywhere in the seating area. After we settle down in our seat, let us purposelessly pick a voluntary helper standing or walking on the pool deck for whatever reason, either for her beauty or for his strange look or body posture, and stare at him intensively. Here is what will happen next:

Magically enough, before long, our stare will be felt by the person from quite a good distance; he/she will turn around and locate us in no time out of the reasonably sized and boiling audience.

By using the systemic yoyo model, we can provide one explanation for why this happens and how the silent communication takes place. In particular, each side, the person being stared at and us, is a high-dimensional spinning yoyo. Even though we are separated by space and possibly by informational noise, the stare of one party on the other has directed that party's spin field of the yoyo structure into the spin field of the yoyo structure of the other party. Even though the later party initially did not know the forthcoming stare, when her/his spin field is interrupted by the sudden intrusion of another unexpected spin field, the person surely senses the exact direction and location where the intrusion is from. That is the underlying mechanism for the silent communication to be established.

When this experiment is done in a large auditorium where the person being stared at is on the stage, the afore-described phenomenon does not occur. It is because when many spin fields interfere the field of a same person, these interfering fields actually destroy their originally organized flows of materials and energy so that the person who is being stared at can only feel the overwhelming pressure from the entire audience instead of from individual persons.

This easily repeatable experiment in fact has been numerously conducted by some of the high school students in our region. When these students eat out in a restaurant and after they run out of topics to gossip about, they play the game they call “feel the vibe.” What they do is to stare as a group at a randomly chosen guest of the restaurant to see how long it takes the guest to feel their stares. As described in the situation of swim meet earlier, the chosen guest can almost always feel the stares immediately and can locate the intruders in no time.

Experiment #2: She Does Not Like Me!

In this case, let us look at the situation of human relationship. When an individual A has a good impression about another individual B, magically, individual B also has a similar and almost identical impression about A. When A does not like B and describes B as a dishonest person with various undesirable traits, it has been clinically proven in psychology that what A describes about B is exactly who A is himself (Hendrix 2001).

Once again, the underlying mechanism for such a quiet and unspoken evaluation of each other is based on the fact that each human being stands for a high-dimensional spinning yoyo and its rotational field. Our feelings toward each other are formed through the interactions of our invisible yoyo structures and their spin fields. So, when person A feels good about another person B, it generally means that their underlying yoyo structures possess the same or very similar attributes, such as spinning in the same direction, both being either divergent or convergent at the same time, both having similar intensities of spin, etc. When person A does not like B and lists many undesirable traits B possesses, it fundamentally stands for the situation that the underlying yoyo fields of A and B are fighting against each other in terms of either opposite spinning directions, or different degrees of convergence, or in terms of other attributes. For a more in depth analysis along a line similar to this one, please consult with Part 4: The Systemic Yoyo Model: Its Applications in Human Mind, of this book.

Such quiet and unspoken evaluations of one another can be seen in any working environment. For instance, let us consider a work situation where quality is not and cannot be quantitatively measured, such as a teaching institution in the United States. When one teacher does not perform well in his line of work, he generally uses the concept of quality loudly in day-to-day settings in order to cover up his own deficiency in quality. When one does not have honesty, he tends to use the term honesty all the time. It is exactly as what Lao Tzu (exact time unknown, Chap. 1) said over 2000 years ago: “The one who speaks of integrity all the time does not have integrity.”

When we tried to repeat this experiment with local high school students, what is found is that when two students A and B, who used to be very good friends, turned away from each other, we ask A why she does not like B anymore. The answer is exactly what we expect: “Because she does not like me anymore!”

Part I
Systemic Modeling of Economic Entities and Processes

Chapter 3
Systemic Representation of Economic Organizations

Jeffrey Yi-Lin Forrest, Yirong Ying, Zaiwu Gong, Baohua Yang, Jesus Valencia, and Qiaoxing Li

Contents

Recent financial events since the 1990s, such as the Southeast Asian financial crisis, the South American financial crisis, the US subprime mortgage crisis, etc., caused abnormal changes to the monetary systems of the affected countries, leading to economic recessions and losses of wealth (Rickards 2012). That helps to make people ask the following question: is there a new method that can effectively be

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employed to address problems related to the movement of money, while providing measures needed to counter potential financial crises facing various economies? And this chapter attempts to address this question by laying down the necessary foundation.

This chapter utilizes the methodology of systems research to describe economic activities and processes and establishes dynamic equations for the systemic development of economies. Consequently, a general expression is developed in terms of systemic control equations for various economic activities. The significance of this result is that it provides a new way to investigate the characteristics of money movements from the angle of systems research and a systemic methodology for further exploring the laws that govern the functions of money in various economies so that potential financial crises could be more effectively countered.

3.1 Introduction

Each economic system is definitely dynamic. It should be possible that such systems can be investigated by using the methods of dynamic systems developed for the study of systems of the natural science. For instance, it should be possible to describe the dynamic state of any economic system by using relevant factor variables, such as the consumer price index (CPI), employment rate, inflation, etc. At the same time, the ultimate state (output) of the economy could also be expressed by utilizing some indices. For example, the national output could be described to a certain degree by the gross domestic product (GDP); and the ultimate output of an enterprise could be depicted through the company's profits. In other words, the development state of an economy could be described by using several variables, while the ultimate state (output) of the economy could also be written in terms of related indices. Of course, all these variables and indices are inevitably affected by other environmental factors, such as the current fiscal and monetary policies. For related discussions, please consult with (Forrest 2014).

In the study of natural science, investigations of dynamic systems are often done by using the language of mathematics on the basis of the laws of conservation, such as the laws of mass conservation and/or energy conservation, Newtonian second law of motion, the first law and the second law of thermodynamics, etc. These laws are employed to investigate how fast an object moves, the characteristics of motion of the object itself, and the interaction between the object and its environment, etc. The ultimate goal of these studies is generally about how the movement of the object could be controlled (Wang and Wang 1995). Based on the principle of natural science, it is natural to believe that there must be certain fundamental laws that govern the development of economic systems. For example, if one can describe each of the fundamental laws that govern the dynamics of economic systems by using the language of mathematics, then he will be able to establish the mathematical model for each specific dynamic economic system. By employing the mathematical model, he can investigate the laws that govern the development of the economic system and the relationship between input variables from the outside world and the state variables of the economic system. In fact, similar to the mathematical models established in natural science for the study of dynamic systems, the mathematical models of economic systems can often be presented in the form of systems of differential equations.

In particular, based on (Forrest et al. 2013a, b), the purpose of this chapter is to show how each economic system can be described by using the concept of state space, which can then be employed to establish the functional relationship between the inputs and outputs of an economic system. Therefore, one is able to, by using methods of the well-established control theory, investigate the influence of money movement within an economy on the internal state characteristics of the economy, to design mechanisms to stabilize the movement of money within the economy in order to reduce the effect of sudden capital flights and sudden capital inflow to its lowest level possible.

This chapter is organized as follows: Section 3.2 presents the reason why movements of money can be seen as similar to those of fluids and how such idea has been widely used in the literature. Section 3.3 considers how to describe the investments in innovative competitiveness as a dynamic system. Section 3.4 looks at the problem of economic development and explores a way to describe such a problem as a dynamic system. Section 3.5 studies the problem of consistency between fiscal and monetary policies and the state of the economy. Section 3.6 peeks into such as a particularly small economic entity as the production stock of a company. Section 3.7 concludes this work by introducing a general expression for the dynamics of an economic system.

3.2 The Relevant Systemic Intuition

The fundamental concept behind the result that each economic system can be investigated by using differential equations is that the movement of money can be seen as flows of fluids. So, in this section, we first look at the yoyo model to see why systemically the evolution of any system can be theoretically treated as changes in the state of fluids. After that, we look at how in the existing literature, the concept of treating money movement as flows of fluids has been widely employed.

When the study of systems is done from the angle of whole evolution (Wu and Lin 2002), the yoyo model arises: each system or object considered in a study is a multidimensional entity that "spins" about its "invisible" axis. If we fathom such a spinning entity in our three-dimensional space, we will have a structure as shown in Fig. 3.1a. The side of black hole sucks in all things, such as materials, information, energy, etc. After funneling through the "short narrow neck," all things are spit out in the form of a big bang. Some of the materials, spit out from the end of big bang, never return to the other side and some will (Fig. 3.1b). More specifically, what this model says is that each physical entity in the universe, be it a tangible or an

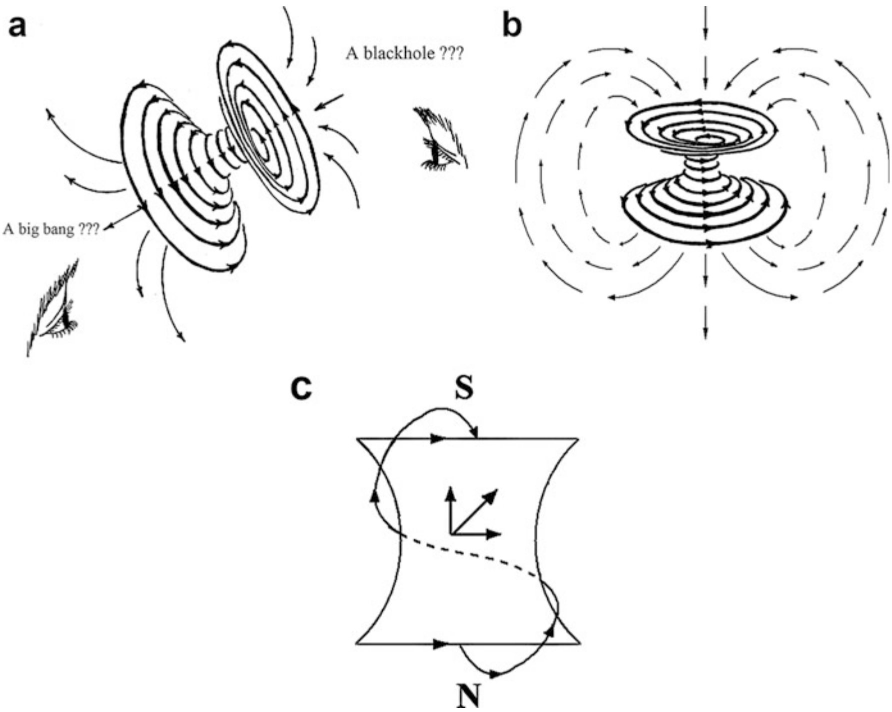

Fig. 3.1 The eddy motion model of the general system

intangible object, a living being, an organization, a culture, a civilization, etc., can all be seen as a kind of realization of a certain multidimensional spinning yoyo with an invisible spin field around it. It stays in a constant spinning motion as depicted in Fig. 3.1a. If it does stop its spinning, it will no longer exist as an identifiable system. What Fig. 3.1c shows is that due to the interactions between the eddy field, which spins perpendicularly to the axis of spin, of the model, and the meridian field, which rotates parallel to axis of spin, all the materials returning to the black-hole side travel along a spiral trajectory. To limit the length of this presentation, please consult with (Lin and Forrest 2011) regarding the theoretical and empirical reasons why such a model exists for each and every system.

What this yoyo model shows based on various understandings of the concept of systems is that when an economy is seen as the totality of various economic systems, each of which is an economic entity, the entirety of the economy is really an ocean of yoyo fields pushing against each other. What connect the interacting yoyo fields are different kinds of flows of money.

To this end, the existence of money reduces the cost of trades, while making the entire society more efficient. That is why money has been commonly accepted as the standard of value and that is how money acquires its absolute liquidity and permeates throughout the entire economic system. Because of the money's characteristic of liquidity, people also use the state of movement of money to judge and to evaluate the performance of their economies. Therefore, when regulating an economic system, the policy makers often employ monetary policies or fiscal policies to alter the amount of money in circulation and how fast money is circulated within the economy in order to achieve the goal of regulating the performance of the economic system. In other words, when investigating the macroscopic regulation and control of an economic system, we can describe the regulation effects on the economic system by using the monetary and/or fiscal policy inputs and the relevant economic performance indices.

Socioeconomic systems are complex, while each complex system is dynamic. So, socioeconomic systems can be effectively investigated by using the methods of dynamic systems. For relevant discussions on systems and systems research, please consult with (Lin 1999). As a physical object of complex systems research of the dynamics of economic developments, currency (or money) should also be considered as one of the most commonly existing materials of relevant systems (Keynes 1930).

As for treating flows of capital as those of fluids, traces of such thoughts have appeared in the classic modern theories of international capital flows. If we look at the economic phenomena of capital flows across national borders, for example, there have been some observations and research works done on such phenomena. In particular, the earlier economists had noticed the unidirectional flows of capital from capital-rich nations toward capital-poor nations. For example, in "On the Principles of Political Economy and Taxation," David Ricardo (1817) explained that what stimulates capital to flow away from England to foreign countries is the law of comparative advantage (Gui and Liu 2001). That is to say, capital flows from countries where the marginal productivity of capital is relatively low to countries where the marginal productivity of capital is relatively high, because such movements of capital are beneficial to the capitalists and consumers of the nations involved (Gui and Liu 2001). Ricardo supported international capital flow and believed that excessive taxations should be eliminated in order to encourage across border capital flows. This description of capital flow from nations with relatively low marginal productivity to nations of relatively high marginal productivity is very similar to that in fluid dynamics, where fluids flow from places of high potential to places of low potential. Both situations describe almost the same principle behind the flows. However, due to differences of capital preference in the international credit markets, the flow of capital between nations is generally not unidirectional. While summarizing the professional achievements of Bertil Ohlin, Samuelson (1982) described two kinds of endogenous capital flows. By using factor flow model, it shows that better rate of return guides the flow of capital. The better rate of return is originated from the rate differences that exist in the international credit markets and the large amounts of earnings for direct foreign investments. In terms of the difference in returns, flows of capital help to make rates of return to reach equilibrium. It is similar to how mobility of labor helps to even out wage differences. That is the so-called factor flow model. In terms of direct foreign investments, Ohlin (Samuelson 1982) believed that even though the difference in rates might be small or the overall level of rates is relatively low, the characteristics of capital and the risk preference of investors would determine the direction and the amount of flows of capital. Additionally, it is also a major contribution of Ohlin to look at the flows of international capital from the angle of the balance of international payments. He first introduced the concept of purchasing power and believed that changes in the purchasing power alter the supply and demand functions of the domestic money through balancing the international trade, and changes in the domestic money supply and demand ultimately cause the international capital to move.

After World War II, international capital has been moving around the world unprecedentedly in terms of both scale and speed and greatly affected the world economy. On the basis of earlier studies, economists have developed various new theories on international capital flows, such as the flow rate theory developed in the 1950s and 1960s, the monetary analysis theory developed in the 1970s and 1980s, and the transaction costs theory developed in the 1990s. The flow rate theory maintains that differences in rates of return can cause capital to move, while monetary analysis theory claims that the monetary policies that were introduced to balance international payments and the regulations that were established to influence the domestic credit determine the flow of international capital. The transaction costs theory on the other hand thinks that the important factors that affect capital to move across national borders are the expenses of various trades (Gui and Liu 2001). In the following, let us glance through these theories and compare their differences.

1. The flow rate theory. This theory emphasizes on the relationship between capital flows and the level of interest rates. James Meade (1951) established a model, also known as a Keynesian model, to illustrate the flow rate theory. According to this theory, rising foreign interest rate could increase the export of the domestic capital; as long as the foreign interest rate stays at a relatively high level when compared to that of the domestic interest rate, the outflow of capital would continue. Conversely, if the domestic interest rate is higher than the foreign rate, then foreign capital would flow into the country. Within the framework of the flow rate theory, Mundell (1972) believes that the flow of capital is determined by the level of interest rate: relatively high domestic interest rate can increase the amount of net inflow of capital and decrease the amount of net outflow of capital. (Fleming 1972) further believed that the flow of international capital is more sensitive to the interest rate within a floating exchange rate system than in a fixed exchange rate system.
2. The monetary analysis theory. This theory maintains that the essence underneath the flow of international capital is a phenomenon of currency; it is determined by changes in the reserves and the domestic monetary policy. Different from the flow rate theory, the monetary analysis theory believes that increasing total output and/or rising price level can escalate the demand for money so that the international reserve is improved; conversely, rising interest rate can dampen the quantity of money demanded, worsening the balance of international payments. When this formula is applied to analyze the flow of international capital, its

conclusion is inconsistent with those obtained from the model of the flow rate theory. Even so, (Johnson 1972, 1977) of the monetarist school still provided a quantitative model that is convenient for the currency analysis of international capital flows. (Förster et al. 2014) initiated the investigation of problems related to international capital flows from the angle of dynamics.

3. The transaction costs theory. Since the 1990s, the trend of globalization of financial markets has become increasingly apparent. The flows of international capital have shown some new characteristics, such as much larger scales than before, multidirectional, securitized, etc. All of these new characteristics are difficult to understand with the existing theories. When compared to the flow rate theory, the model of transaction costs theory claims that the flows of international capital are not only affected by the differences of domestic and foreign interest rates but also constrained by the transaction costs of domestic and foreign investments. Under the assumption that the market is imperfect, the flows of international capital in terms of their directions of movement appear in four different forms: inflow, outflow, nondirectional, and static (not moving). Both Williamson (1995) and Di (1999) established their transaction costs theory, which is capable of explaining the phenomena of globalization of international capital flows.

From the angle of fluid dynamics, speed, energy, and pressure represent some of the most important concepts of fluids. Then, in the studies of money movements, are there corresponding concepts?

- Speed

The main focus of the dynamic studies of a moving object is the magnitude of speed and the direction of the movement. Starting with the speed of circulation of money, economists investigated the mechanism of how to regulate the movement of money and how to avoid financial crises in order to ultimately resolve the problem of steady growth of the domestic wealth and to successfully materialize the national strategy and national goals. The finance of a large nation is different from that of a small country, which has been widely recognized by economists. Currency is the general representation of value; the movement of one nation's money has to affect the movements of money of the surrounding nations and needs to be accepted by these nations and even the world. Therefore, in order to understand how a nation's currency expands beyond its border and how to materialize its national strategy and goals, it is necessary to investigate the laws that govern the movement of money, which is the study of the dynamic laws of the monetary system in order to materialize the purpose of regulating the movement of money.

By defining the speed of circulation for money, (Luo 2010) introduced a dynamic model to describe the movement of money. On top of that model, the author proved that each movement of money follows a main circular direction and possesses the nature of continuous media. That confirms the truthfulness of the hypothesis of Irving Fisher, Francois Quesnay (1759), and others that the movement of money is like that of fluids. Additionally, (Luo 2010) derived a model to describe how money moves across national borders on the basis of energy and provided a specific method to regulate movements of money by employing the theory and methods on how to control movements in continuous media, i.e., to regulate along the border, while showing that it would be useless to only regulate the movement of money within the continuous media of money.

- Energy

From the angle of energy and its functions, (Zhang 2009a, b) identified circulations of money as flows of energy within the economic system, where the direction and magnitude of movement determine the rise and fall of the nominal economic variables in each sectors. The direction and magnitude, to certain extent, also govern the rise and fall of the virtual and the actual economies. Therefore, it is practically important to perfect, within the existing accounting system of the national economy, the methods of how to monitor, measure, analyze, and regulate money flows between the actual economy and the virtual economy and between different markets of the virtual economy in order to reveal how risks appear, be magnified, and spread. Zhang (2009) discussed a specific method to analyze input-output tables of money flows for the ultimate purpose of developing a complete observation system of money flows.

- Pressure

As for the concept of pressure under which money appears when money is moving, there is still not any rigorous definition. Hall et al. (2013) considered the pressure created by a kind of currency movement, that is, the pressure of the US dollar on other three currencies, Japanese yen, Chinese yuan, and British pound during the time period from 2000 to 2009. In particular, conversion factors required to estimate the pressure on these currencies are computed by employing a time-varying coefficient regression. Then, they used their measures of currency pressure to assess deviations of exchange rates from their market- equilibrium levels. For the yen, the currency pressure suggests undervaluation during the initial part of the estimation period, during which the Bank of Japan sold yen in the foreign exchange market. They also find persistent undervaluation of the yuan throughout the estimation period with the undervaluation peaking at about 20% in 2004 and 2007. For the pound, their results indicate a low pressure, suggesting a mainly free-floating currency, throughout the sample period. These results appear consistent with the policies pursued by the central banks of the particular currency nations in question.

3.3 Investments in Innovative Competitiveness

Innovation has been the most recognized birthplaces for wealth growth for economies from around the world in the era of knowledge economies. Within each specific time period, investments in certain particular economic element have led wealth growth. For example, when there was not enough land, land reclamation could lead to growth in wealth; when there was a shortage of labor, an increase in human resources could help create wealth; when there was insufficient capital, inputs of additional money could make the society and individuals acquire extra wealth (i.e., scarcity causes prices to rise and consequently attracts investment). On the other hand, if the supply of these wealth elements is excessive in materializing extra wealth, additional investments in these elements become less important in generating additional wealth. Therefore, after the industrial revolution, the central role of land in generating wealth is replaced by capital; while within the current knowledge-based society, the central role of capital in generating wealth is gradually replaced by the emerging innovation and creativity.

At the end of the twentieth century, by vigorously pursuing after the creation of innovative capability, the wealth of the United States gained rapid growth. For example, during the first 4 years of Clinton's white house, American economy grew on the average of 2.55%, creating a miracle in the nation's history. The annual *World Competitiveness Yearbook*, published by the International Institute for Management Development in 1998, reveals that America's strength in technology is far ahead of the rest of the world; if the United States is used as the benchmark, then Japan only reaches 89.3% of the mark, Germany only 72.12%, and France merely 69.43%; and in the new round of intellectual revolution centered around information technology, the United States has left Europe, Japan, and the rest of the world further behind itself.

Generally speaking, the innovative competitiveness of an economy consists mainly of the competitiveness of the basic production facilities, the research and development (R & D), the service area, marketing, etc. In order to increase the innovative competitiveness of an economy, capital investment in each of the basic component areas of the competitiveness needs to be assured.

It is a gradual process for sources of innovative competitiveness to appear and for the competitiveness to grow and to accumulate. It is relatively easier to increase the innovative competitiveness of production facilities by purchasing new equipment and by gaining experience. That explains why developing countries have almost always focused on their initial efforts on introducing advanced technology from developed countries. What is relatively more difficult is an increase in the innovative competitiveness in such areas as service and marketing, because any increase in innovative competitiveness in these areas requires changes in the fundamental concepts of management and service without involving too many of technological obstacles. In comparison, increasing the innovative competitiveness in the area of introducing new products is most difficult. What is required here is not only an accumulation of innovative experiences and innovative talents within the economy but also groundbreaking capability of thinking and developing of original knowledge. Such capability is difficult to acquire. Because within any period of time the amount of capital available for investment in increasing the innovative competitiveness within the economy is limited, how to describe the movement of capital between different areas of innovative competitiveness of the economy is a prerequisite for reaching the goal of maximizing the contribution of the capital in the growth of innovative competitiveness.

For a chosen economy, change in its innovative competitiveness can be approximately described as follows:

$$\frac{dP}{dt} = d(D - S) \tag{3.1}$$

where D represents the amount of money needed to increase the innovative competitiveness of the economy, S is the money actually supplied for such a purpose, P is the innovative competitiveness of the economy (which really means the power of money in maintaining and growing the innovative competitiveness), $d < 0$ is a constant, and t stands for time.

From Eq. (3.1), it follows that the rate of change in the innovative competitiveness of the economy is directly proportional to the difference between the amount of money needed for increasing the competitiveness and the actual amount of money that is supplied for such purpose. When other parameters are kept unchanged, if the actual amount of money supplied for the purpose of improving the innovative competitiveness is increased drastically and satisfies $S > D$, then the rate of change of the innovative competitiveness of the economy will be positive.

For any given economic system, capital flows between the components that make up the innovative competitiveness of the economy. To coordinate the development of the innovative competitiveness of the economy, there is a need to effectively direct the movement of capital within the economic system. Assume that at time moment t, the economic system contains k departments, denoted U_1, $U_2, \cdots, U_k$, respectively, that make up the system's innovative competitiveness. Assume that the system's aggregate demand for money for the purpose of improving the system's innovative competitiveness is D, while the individual departments' demands for money are, respectively, D_1, D_2, ..., D_k. If the proportions of the individual departments' demands for money against the aggregate demand are $\alpha_1, \alpha_2, \cdots, \alpha_k$, satisfying $\sum_{i=1}^{k} \alpha_i = 1$, then we have the following:

$$D = D_1 + D_2 + \cdots + D_k = \sum_{i=1}^{k} \alpha_i D (i = 1, 2, \cdots, k) \tag{3.2}$$

Assume that the actual capital supplies of the economic system for the individual departments are, respectively, $S_1, S_2, \cdots, S_k$, and the actual innovative competitiveness of the individual departments is, respectively, $P_1, P_2, \cdots, P_k$.

By analyzing the established Eqs. (3.1) and (3.2), it follows that a model that describes the development of the innovative competitiveness of the economy can be given as follows:

$$\begin{cases} \dfrac{dP_1}{dt} = d_{11}(D_1 - S_1) + d_{12}(D_2 - S_2) + \cdots + d_{1k}(D_k - S_k) + \sum_{j=1}^{p} e_{1j}u_j \\ \dfrac{dP_2}{dt} = d_{21}(D_1 - S_1) + d_{22}(D_2 - S_2) + \cdots + d_{2k}(D_k - S_k) + \sum_{j=1}^{p} e_{2j}u_j \\ \vdots \\ \dfrac{dP_k}{dt} = d_{k1}(D_1 - S_1) + d_{k2}(D_2 - S_2) + \cdots + d_{kk}(D_k - S_k) + \sum_{j=1}^{p} e_{kj}u_j \end{cases} \tag{3.3}$$

where both d_{it} and e_{ij} are constants, while u_j stands for the external policies that affect the improvement of the economic system's innovative competitiveness, (i, $t = 1, 2, \ldots, k; j = 1, 2, \ldots, p$). By using the symbols of matrices, we can obtain

$$\dot{P} = Dx + Eu \tag{3.4}$$

where $P = [P_1 \ P_2 \ldots P_n]^T$, $\dot{P} = \left[\dfrac{dP_1}{dt} \dfrac{dP_2}{dt} \ldots \dfrac{dP_n}{dt}\right]^T$ stands for the Newtonian symbol for derivatives, $D = [d_{it}]_{k \times k}$ the coefficient matrix of the variable $(D_i - S_i)$, $E = [e_{ij}]_{k \times p}$, and$j = 1, 2, \ldots, p$ the coefficient matrix of the external policy variables u_j.

If we assume that a linear relationship exists between the innovative competitiveness function $P = [P_1, P_2, \cdots, P_3]^T$ of the individual departments of the economic system and the differences between the demands and actual supplies of money of the economic system, then we obtain

$$P = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_k \end{bmatrix} = R_{k\times k} \begin{bmatrix} D_1 - S_1 \\ D_2 - S_2 \\ \vdots \\ D_k - S_k \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_k \end{bmatrix} \tag{3.5}$$

where $R_{k \times k}$ is a constant square matrix and $[\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_k]^T$ a term of random errors of non-zero means.

Accordingly, by applying mathematical expectations, the previous equation can be rewritten as follows:

$$P = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_k \end{bmatrix} = R_{k\times k} \begin{bmatrix} D_1 - S_1 \\ D_2 - S_2 \\ \vdots \\ D_k - S_k \end{bmatrix} + \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_k \end{bmatrix} \tag{3.6}$$

where $E(\varepsilon_i) = c_i \neq 0, i = 1, \cdots, k$.

Substituting this equation into Eq. (3.4) gives

$$R_{k\times k}\dot{x} = Dx + Eu \tag{3.7}$$

where $R_{k \times k}$ is an invertible matrix.

Assume that change in the innovative competitiveness of each individual department of the economy is completely affected by the difference between the demand and supply of money of the economic system and policies external to the system. Then we have

$$\dot{x} = Ax + Bu \tag{3.8}$$

where $A = R^{-1}D$ and $B = R^{-1}E$. If an index $y = [y_1, y_2, \ldots, y_k]^T$ that represents the innovative competitiveness of different departments of the economic system is seen as the degrees of satisfaction of the individual departments toward the economic system, then we can obtain the following model for the innovative competitiveness of the economic system:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases} \tag{3.9}$$

In this model, the differences x_i between the demands for money of the individual departments that compose the innovative competitiveness of the economic system and the corresponding supplies of money by the system to the individual departments determine the state of the system in Eq. (3.9). These differences are referred to as the state variables of the economy. The external factors u that influence the innovative competitiveness are referred to as the control variable or the input variable of the system in Eq. (3.9), while the index y of the innovative competitiveness of the departments is referred to as the output variable of the system in Eq. (3.9). This equation is referred to as the state equation of the innovative competitiveness of the economy, and $y = Cx + Du$ is the output equation.

3.4 The Development Problem of an Economy

Along with the flows of money within an economy, input of additional human labor, and innovations, the amount of wealth produced within the economy grows constantly. Let us use R to represent the wealth created within the economy, which for our purpose is the aggregate income. With changes in fiscal and monetary policies, the amount of wealth created within the economy fluctuates, showing different forms of "economic movements." For example, loose fiscal and monetary policies encourage rapid growth of wealth, while tight policies tend to make the speed of wealth creation slow down. Generally speaking, with the development of the society, growth in investment, new development in technology, and improvement in innovation capabilities, the value created within the economy tends to potentially increase over time. Let us refer the origin of momentum for such potential tendency of increase to as the expected growth momentum of the economic system and denote it by μ_E.

As anything in life, there is always resistance to change in the process of creating wealth. For example, economic weaknesses can appear when the economy is in recession; monopolistic markets can result along with frictions and protectionism in international trade, corruption, etc. During economic recessions, the actual income and expected income for the near future generally decrease so that the current spending will be lowered. Because of their negative economic outlook, investors will generally reduce their investments. Along with decreasing consumption and reduced investments, the development of the economy and the creation of wealth are directly affected. When there are monopolies in the economic system, these monopoly enterprises generally influence the speed of development of the economy. When there are frictions and protectionism in international trades, they tend to cause large-scale production declines, worker layoffs, factory closeouts, etc., causing the economic system to experience setbacks. For example, when some European nations started their investigation procedures and took restriction measures a few years ago against some of the textile products imported from China, they eventually applied restrictions on seven textile products which caused nearly US$2 billion losses for China. If we assume that US$15,000 export per day of Chinese textile products represents one employment opportunity, then the loss affected nearly 140,000 jobs in the textile industry. And the amount of US$0.67 billion involved in the antidumping investigations of the European Union against imported shoes from China impacted the employment of nearly 50,000 workers of the footwear industry in China (Koulischer and Struyven 2014).

Therefore, within an economic system, wealth creation depends not only on the system's own momentum of growth but also on the resistances that exist both within and outside the system. If fiscal and monetary policies are held constant, then the development of the economic system can be described by

$$M\frac{d^2R}{dt^2} + \mu_M\frac{dR}{dt} = \mu_E \tag{3.10}$$

where M stands for the money that is circulating within the economic system, R the return of the system when the amount of money in circulation within the system is M, μ_M the coefficient of resistance experienced by the development of the economic system, and μ_E the expected momentum of development of the system, which is a variable related to the applied fiscal and monetary policies.

Assume that when the external macro policies stay the same and the expected economic growth is constant, the state of development of the economic system is completely determined by the value R created by the system and the rate of change $\frac{dR}{dt}$ of this value. If we let $R = x_1$ and $x_2 = \frac{dx_1}{dt}$, then we have the state system representation of the economic system as follows:

$$\begin{cases} \dfrac{dx_1}{dt} = x_2 \\ \dfrac{dx_2}{dt} = -\dfrac{\mu_M}{M}x_2 + \dfrac{\mu_E}{M} \end{cases} \tag{3.11}$$

with $y = x_1$ being the output equation. The matrix form of this system can be written as follows:

$$\begin{bmatrix} \dfrac{dx_1}{dt} \\ \dfrac{dx_2}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\dfrac{\mu_M}{M} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{1}{M} \end{bmatrix} u \tag{3.12}$$

where $u = \mu_E$.

3.5 Consistency Between Fiscal/Monetary Policies and the Performance of the Economy

In order to protect the healthy growth of the economic system and to reduce the interference of the outside world, fiscal and monetary policies (Bernanke 2007) are often employed to regulate the amount of money in circulation and how fast the circulation is to be for the purpose of materializing the predetermined macroeconomic targets, as measured by such indices as the development speed of the economy, inflation, rate of employment, etc. By fiscal policy, it means such a principle that it is introduced to guide the fiscal activities of the government so that the predetermined political, economic, and social tasks of the time could be accomplished. The aggregate demand of money is regulated through fiscal spending and tax policies. Increasing taxes and reducing spending represent “tight” fiscal policies. They can lower the aggregate demand for money of the society and are not beneficial for investments. Conversely, although “loose” fiscal policies are advantageous for investments, they tend to cause the societal demand for money to rise, which could readily lead to inflation. Monetary policies represent various tools used by the central bank to regulate the supply of money in order to materialize its predetermined objectives. These policies further influence the policy measures that influence the macroeconomic operations of the economic system. Monetary policies consist of mainly credit policies and interest rate policies. Credit contraction and raising interest rates represent “tight” monetary policies, which could suppress the aggregate demand of the society for money, restrict investments and short-term economic development. Conversely, “loose” monetary policies could expand the aggregate demand of the society for money and are conducive to investments and near-term economic development. However, “loose” monetary policies could easily cause inflation to rise.

Changes in monetary policies directly affect the supply of money, the amount of money in circulation, and the speed of circulation of money within the economic system. They are mainly reflected through changes in the amount of wealth created within the system. When the return on money in circulation increases, the circulation speed of money goes higher within the economic system. When the return of the economic system is fixed, the more money is in circulation within the economic system, the slower the circulation speed would be within the system. Hence, we can use $V_c = K\frac{dR}{dM}$ to represent the circulation speed of money within the economic system, where R stands for overall return of the economic system, M is the amount of money in circulation within the system, and K is a coefficient.

The source of money within the economic system consists mainly of the profits that were not distributed or consumed (referred to as surplus profits) and bank loans, while the amount of bank loans is most likely affected by the lending rates and the expected return on investments within the economic system. The currency expenditure approach of the economic system mainly includes:

- Cash balances, which are mainly spent on consumer goods, labor, and physical capital goods.
- Investments, which include mainly productive investments and financial investments; the former are largely used for expanding the production scales and the research and development of new products, while the latter are essentially used in the financial markets.
- Savings, which are mainly reflected in the bank account balances of business firms.

Within a period of time, the accumulation (the supply of money) and expenditure (the demand for money) of money within the economic system should satisfy the following: the sum of last time period's surplus of profit and bank loans is equal to the sum of the current cash balances, investment expenditure, and savings of businesses.

If the fiscal and monetary policies under which the economic system is currently in are maintained, then when the future return, as expected by the economic system, is roughly the same as the banks' interest rate of savings, there would be no motivation for the economic system to take out additional bank loans for further investment expansion. That is when the supply and demand of money of the economic system are maintained stably and when the circulation speed of money within the economic system stays constant and the performance of the economy is maintained at an ideal stable state from the angle of the policy makers. When the expected future return deviates from the interest rate of bank savings, the equilibrium of the supply and demand of money of the economic system is broken. The circulation speed of money within the economic system starts to change, leading to changes in the state of development of the economic system. If the expected future return is greater than the interest rate of bank savings, the economic system tends to expand its scale of investment by taking out additional bank loans while reducing the amount of savings deposited in banks. During such a time, the demand for money of the economic system increases, and the circulation of money speeds up as indicated by growing amount of investment and the prosperity of the market. If the future return, as expected by the economic system, is smaller than the interest rate of bank savings, the system tends to experience surpluses of capital, increase in bank savings, and decreasing investment. During such a time, the demand for money of the economic system lowers and the circulation speed of money slows down, which are shown as increasing bank deposits and low economic growth or stagflation.

As a matter of fact, changes in the circulation speed of money within the economic system have significant impacts on the state and performance of the macroscopic economy. For instance, overinvestment could cause such phenomena as unrestraint construction, surplus of production capability, irrational economic structure, etc., to appear. Hence, the external environment of the economic system would regulate the circulation speed and direction of money within the economic system based on the observed index of the economic performance by appropriately adjusting fiscal and monetary policies in timely fashion so that the overall economy is maintained within a relatively controllable, stable state. If the economic system is optimistic about future prospects, investment will increase along with growing demand for money, rising circulation speed of money, and improving performance of the economy. Accordingly, the regulators would employ monetary policies, such as increasing the deposit and lending rates for banks, raising the banks' reserve ratio, etc., to make, on one hand, the cost of money more expensive, and on the other hand, to reduce the banks' money supply. Such monetary policies tend to alter the expected return of the economic system, while lowering the system's demand for money, slowing down the circulation speed of money, so that the economic development could be adjusted to an appropriate level. On the contrary, if the investment of the economic system decreases while banks' deposits increase drastically, the performance of the economy would be in doldrums. In this case, the supply of money of the economic system would grow higher, while the demand for money and the circulation speed of money drop. People would not want to make new investments and would cut back on spending, leading to economic contraction. During such a time, the regulators would utilize such monetary policies as lowering the deposit and lending rates for banks, reducing the banks' reserve ratio, etc., to reduce the cost of money and to increase banks' supply of money so that the return as expected by the economic system would be altered. Consequently, the demand for money would rise, and the circulation of money would speed up, so that the economic development would rise to a reasonable level.

That is to say, economic development is always influenced by the demand and supply of money. Such influence items, on one hand, are from the supply and demand capability of money within the economic system, while, on the other hand, they are from the monetary and fiscal policies of the external environment. When these two forces, one internal and the other external to the economic system, work together, they change the circulation speed of money and make it eventually reach an ideal state of equilibrium. Such joint effect we use $g(S-D)\bigoplus f(S,D,P)$ to denote, where $g(S-D)$ stands for the force that powers changes in the circulation of money as a function of the difference between the supply and demand of money and $f(S,D,P)$ the acting force that policies act on the amount of money in circulation within the economic system. So, any change in the circulation speed of money within the economic system can be expressed as follows:

$$M\frac{dV_c}{dt} = g(S - D) \bigoplus f(S, D, P) \tag{3.13}$$

where S stands for the supply of money, M the amount of money in circulation within the economic system, D the demand for money, $g(S - D)$ the force that powers changes in the circulation speed of money within the economic system as a function of the difference between the supply and demand of money, and $f(S, D, P)$ the acting force that policies exert on the amount of money in circulation within the economic system.

In this model, the money supply S can be M_1 or M_2 or any other index of money supply. That is to say, what is described by the value of S is the aggregate amount of money issued by the central bank of the economic system. Within the currently existing financial systems, in theory the value of S is not constrained by any external conditions. The amount of money M in circulation can be seen as the difference between the supply S and the amount of money in circulation outside the domestic economic system. The latter amount can include those held by foreign governments and financial groups and direct overseas' investments by domestic citizens and companies. For example, a large proportion of the money supply S issued by the Federal Reserve, the central bank of the United States, is circulating outside the United States as an international currency and as a reserve currency of many banks from across the world. So, in terms of the domestic economy of the United States, the values of S and M can be very different. However, for most of the developing countries, their money supply S and the amount of money M in circulation with their domestic economic system might very well be the (almost) same. It is because for developing countries, their currencies are not likely to be used directly in international trades or as foreign reserves by other countries. On the contrary, such a developing country could mostly likely prohibits its currency to go beyond its national border in order to prevent itself from shocks of the international finance. In this case, for this developing country, its supply of money S is equal to its amount of money M in circulation within its economic system.

Changes in fiscal and monetary policies alter the demand for investment of the economic system. For example, changes in the interest rate could cause changes in the cost of money and the supply and demand of money so that by adjusting interest rate regulated could be the performance of the economic system, which could further affect the amount of value the economic system creates. When the marginal rate of return of capital is fixed, the magnitude of investment is determined by the interest rate. Changes in interest rate affect investments and lead to changes in the value created by the economic system because of the multiplier effect. When an inflation gap occurs in the economy that is overheating, the money is circulating within the economic system at an excessive speed. By raising the interest rate, it could suppress the investment scale of the economic system, slow down the circulation speed of money, and eliminate the inflation gap so that the quantity of the value created by the economic system could be pulled down. When the economy experiences a tight gap (i.e., the supply of money is greater than the demand) and recession, the money tends to circulate too slowly within the economic system. By reducing interest rate, it could stimulate investments, speed up the circulation of money, and eliminate the tight gap so that the economic system is encouraged to create additional value.

Therefore, the drive, as expected by the economic system, and the push, as generated by changes in fiscal and monetary policies, for economic development jointly determine changes in the value created within the economic system. Because such effect is not expressible by using elementary algebraic operations, let us describe the change in the value created within the economic system as follows:

$$M\frac{d^2R}{dt^2} + \mu_M\frac{dR}{dt} = \mu_E \bigoplus f(S, D, P) \tag{3.14}$$

where M stands for the amount of money in circulation within the economic system, R the return of the economic system when the amount of money in circulation is M, S the supply of money, D the demand for money, μ_M the coefficient of resistance existing in the development of the economic system, μ_E the development momentum as expected by the economic system, and $f(S, D, P)$ the acting force that policies exert on the circulation speed of money within the economic system.

When a fiscal or monetary policy is introduced for the purpose of lowering the speed of economy development, that is, reducing the circulation speed of money, the acting force $f(S, D, P)$ of the policy takes a negative value; when a fiscal or monetary policy is utilized to stimulate the economic development, that is, to increase the circulation speed of money, then the acting force $f(S, D, P)$ of the policy takes a positive value.

During a time period when the fiscal and/or monetary policy changes, the market expectations of the economic return also change, which in turn affects the use allocation of money allocated for payments in the economic system. Hence the circulation speed of money within the economic system changes accordingly, affecting the indices of the economic performance, such as the employment rate, deflation or inflation, rise or fall of the GDP, the level of wages, etc. All these indices show how the introduction of new policies affects the performance of the economy, and conversely they dictate how the policies should be adjusted, because the ultimate goal of utilizing fiscal and monetary policies is economic development and relative stability of inflation and the rate of inflation. However, during the implementation of any policy, there is a time effect, where the policy is almost always implemented with a time delay. This delay stands for the time difference between the time when the central bank decides on the employment of the policy to the time when the expected effect of the policy is observed.

Because of this time effect of policies, the effectiveness of monetary policies is greatly affected. If the time delay of a monetary policy is limited and can be predicted, then the policy can play its expected role. It is because no matter how long the time delay is, as long as it is within a certain definite range, the central bank can adopt a particular monetary policy that will influence the economic situation of a certain future time period based on the predicted time delay. However, if the distribution of monetary policies' time delay is not even with large deviations, then because of the unpredictability of the time delay, the adopted monetary policy might start to play out its roles at inappropriate times so that the economic and financial circumstance could very well be worsened. For example, if the central bank could not predict the time delay of its monetary policies, then it could very possibly adopt a tightening policy during an economic boom; and because of the existence of time delay with the adoption of monetary policies, the effect of the tightening policy began to show when the economy had already started to contract. In this case, the countercyclical monetary policies the central bank employed would lose their effectiveness. Not only so, these policies could also help unconsciously to strengthen the magnitude of economic cycles, making the domestic economy more unstable. Such changes also show how policies could sometimes be adopted ahead of their appropriate times or adopted with major delay. So, investigating the problem of consistency between policy design and economic development can help avoid the adverse effects of either adopting monetary policies ahead of their appropriate times or reacting to economic performance with too much delay.

Based on our discussion above, we can establish the following differential equation model for policy adjustment and change:

$$J\frac{d^2\varphi(t-\tau)}{dt^2}+C_P\frac{d\varphi(t-\tau)}{dt}=F(R,L,IF,\cdots,t) \tag{3.15}$$

where φ stands for the magnitude of the policy adjustment, J the inertia coefficient of the policy adjustment, C_P the coefficient of resistance of the policy adjustment, R the return of the economic system, L the employment rate, UP the unemployment rate, IF the inflation, and WC the change in wages. Then we obtain the following state equation for the economic development and policy effect:

$$\begin{cases} M\dfrac{dV_c}{dt}=g(S-D)\bigoplus f(S,D,P) \\ M\dfrac{d^2R}{dt^2}+\mu_M\dfrac{dR}{dt}=\mu_E\bigoplus f(S,D,P) \\ J\dfrac{d^2\varphi(t-\tau)}{dt^2}+C_P\dfrac{d\varphi(t-\tau)}{dt}=F(R,L,IF,\cdots,t) \end{cases} \tag{3.16}$$

3.6 The Storage System of Manufactured Products

Let us consider the storage system of some manufactured products. Assume that the inventory of the products in the kth month is $x(k)$, the production of the products of the same month is $u(k)$, and the number of units of the products sold during the month is $S(k)$. Then these three quantities are related as follows: the inventory of the following month is equal to the current-month inventory plus the current-month production minus the current-month sales. That is, symbolically, we have

$$x(k+1) = x(k) + u(k) - S(k) \tag{3.17}$$

In this system, the storage $x(k)$ stands for the state variable, the production $u(k)$ the control variable, and the sales $S(k)$ the disturbance variable. The state representation of this storage system consists of a difference equation.

3.7 Changes in the State of an Economic System

As a conclusion, we can see that the previous four particular case analyses illustrate for any given economic system how the state variable(s) could be selected and how the state representation of the system should be established. Theoretically speaking, the state of an economic system at time moment t is completely described by all the relevant economic factor variables. All these relevant economic factor variables are collectively referred to as the state vector. The existing literature in economics and finance clearly shows that this state vector must be finite dimensional; how the dimensionality could potentially be very high. At the same time, the state of the economic system is affected constantly by human factors, which include the monetary policies adopted by the central bank, the fiscal policies of the central government, etc. These policies more or less influence the state of the economic system. So, in theory we can treat monetary and fiscal policies as input variables that regulate the economic system. In general, we have the following theoretical concept:

Definition 3.1 For a given economic system, the state vector at the initial time moment t_0 and the state vector, as a vector of variables, at any time moment $t > t_0$ can jointly determine the unique output vector of n variables of the economic system. Assume that the state vector of the economic system at the initial time moment t_0 is $x(t_0) = [x_1(t_0), x_2(t_0), \cdots, x_n(t_0)]^T$, and the state vector and the input vector at time t are, respectively, $x(t) = [x_1(t), x_2(t), \cdots, x_n(t)]^T$ and $u(t) = [u_1(t), u_2(t), \cdots, u_n(t)]^T$, and $y(t) = [y_1(t), y_2(t), \cdots, y_n(t)]^T$ is the output vector at time t. Then the development of the state of the economic system can be described as follows:

$$\begin{cases} \dfrac{dx}{dt} = f(x, u, t) \\ y = g(x, u, t) \end{cases} \tag{3.18}$$

where the first equation depicts the relationship at time t between the state vector and the input vector of the system, and the second equation illustrates the relationship at time t between the output vector, input vector, and the state vector of the system. In general, the functions f and g can be linear or nonlinear. Based on the case studies of the previous sections and series expansions of mathematics, we can employ linear functions f and g to approximately describe the laws of development for the economic system at time t. That is, approximately we can use the following system of linear equations to represent the state of the economic system at time t.

$$\begin{cases} \dfrac{dx}{dt} = A(t)x(t) + B(t)u(t) \\ y = C(t)x(t) + D(t)u(t) \end{cases} \tag{3.19}$$

where A , B , C , D are matrices of appropriate dimensions. Such an abstract systemic expression of economic systems is referred to as a time-dependent linear economic system. When A , B , C , D are all constant matrices, this model is referred to as either a constant coefficient linear economic system or a non-time-dependent linear economic system.

As for a discrete time, non-time-dependent linear economic system, its state equation and the output equation are given as follows:

$$\begin{cases} x(k+1) = Ax(k) + Bu(k) \\ y(k) = Cx(k) + Du(k) \end{cases} \tag{3.20}$$

which can be denoted as system (A, B, C, D). And when D is zero matrix, we will omit it and denote this system (A, B, C).

The constant-coefficient linear system in Eq. (3.19) is depicted by the spin field of the yoyo model in Fig. 3.2, where the state vector $x(t)$ represents the internal spin structure of the system and connects the input vector $u(t)$ and the output vector $y(t)$.

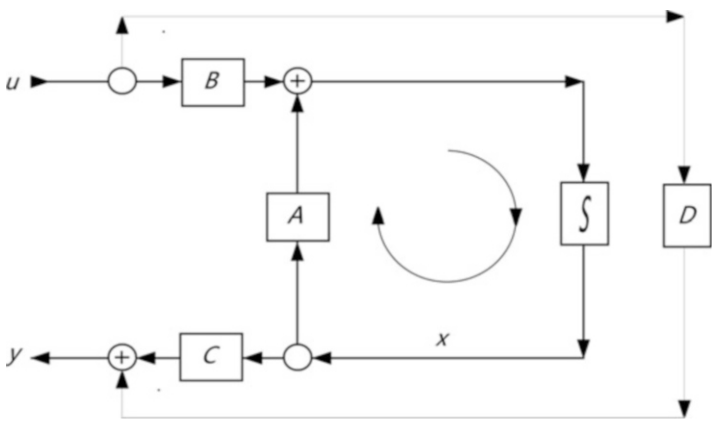

Fig. 3.2 Flow chart of a linear economic system

3.8 Some Concluding Remarks

What is shown in this chapter through looking at several typical examples of economic entities is that the methodology of systems research can be naturally employed to describe economic activities and processes. The significance of this conclusion is that this work paves the way for us to investigate money movements by using results and methods of systems research. And our consequent works confirm this end very positively: the laws that govern the functions of money in various economies can be theoretically established so that potential financial crises could be more effectively countered.

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Chapter 4
Order Reduction of Dynamic Monetary Systems

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This chapter develops a control-theory model for the movement of money within an economic system based on changes in purchasing power of a currency by analyzing how the purchasing power changes within the economic system, and it details with the problem of how our method of reducing the order of the original control-theory model can be utilized to obtain models of reduced order that resemble the original model while still processing such important properties as observability and controllability.

This chapter employs the systemic yoyo model and the thinking logic and methods of control theory to investigate how to reduce the dimensionality of the established control-theory modal and the properties of the models of reduced dimensions.

Considering the problem of having to deal with a huge number of variables in the analysis, this chapter studies the practical needs and theoretical existence for reducing the dimensionality of the control-theory model established for the currency movement within the economic system and then develops a particular method to practically reduce the dimensionality of the modal. It provides a straightforward, effective tool for policy decision-makers to evaluate in advance the effectiveness of their policies that will be potentially adopted to counter currency wars.

The South American financial crises, the Southeast Asian financial crises, and other crises that occurred since the 1990s had made these regions lose their financial achievements acquired through many years of hard work within a short period of time. These crises and their devastating aftermath also made people recognize a new form of assault: currency wars. So, arises a natural question that challenges the monetary authorities from around the world: how can potential currency wars be effectively dealt with? To this end, this chapter will provide the necessary insights for designing counter measures against the potential attacks of currency wars.

4.1 Introduction

Having wealth means the right and convenience of making use of the labor of others. That drives some people to acquire excess amounts of wealth through using all possible means, including wars, in order to establish their "master" status within their organizations, regions, and/or international relations. The history has shown that since the beginning of time, quite a few empires had established their dominant positions in the international relations, be they political, economic, or military, by acquiring extraordinary amounts of wealth through various forms of wars. However, with the development of modern technology, in particular, the development of modern weaponry, it has become more difficult for any nation to loot and transfer wealth by directly employing military conflicts and wars. At the same time, in the modern world, money is not only a symbol of wealth but also a new means and a concealed weapon to loot a nation or region and to make wealth transfers. For example, such crises as the 1994 Mexican financial crisis, 1997 Southeast Asian financial crisis, 1998 Russian currency and financial crises, 1999 Brazilian currency and financial crises, 2001 Argentine currency and financial crises, etc., all seem to show traces of looting and transfer of wealth from these involved nations and regions through the form of currencies (Forrest et al. 2013a).

Because owning money implies the power to purchase assets, to enjoy the labor of others, and to acquire comfort, it makes money flow like fluid between nations and regions. When money moves within an economic system at a certain speed in a certain amount, the money can help the economic system maintain a level of vitality, while promoting economic development, enriching the culture, and improving life quality. However, if a large amount of capital flows either into or out of an economic system within a short period of time, the large-scale, sudden movement of capital would most likely create chaos in the otherwise orderly operation of the economic system, causing economic depression or malaise. What is also likely to occur with the sudden, large-scale outflow of capital is a transfer of wealth from the economic system within a very short period of time that the system has accumulated through hard work in the past years or even decades. This kind of wealth transfer through the use of capital will we refer to as a currency war. So, the problem of how to prevent and how to counter potential currency wars has become a problem facing each and every economic system.

By using systemic yoyo model and the thinking logic and methods of control theory, this chapter will develop a control-theory model to describe the movement of money within an economic system, explore methods on how to reduce the dimensionality of the modal, and investigate the properties of the models of reduced dimensions. It is expected that this chapter will provide the necessary insights for designing counter measures against the potential attacks of currency wars.

The rest of this chapter is organized as follows: Section 2 shows how we can construct a control-theory model to describe the movement of money within an economic system; Section 3 presents by using case analyses, the practical need for reducing the order of the control-theory model developed for the movements of money within an economic system; Section 4 employs the general systems approach to show the actual existence of reduced order models for the movements of money within an economic system; in Section 5, we look at a particular method of order reduction for the control-theory model of monetary movements; Section 6 investigates the error involved in order reductions; Section 7 looks at the relationship between the transfer functions of the original and the reduced order systems; Section 8 considers the observability and controllability of the models of reduced orders; Section 9 studies the selection of the order reduction vector q; Section 10 uses a particular example to show how the theory constructed in this chapter could be practically employed. Then, Section 11 concludes the presentation of this chapter.

4.2 The Control-Theory Model for Money Movement

Dornbusch (1976) represents the initial research on flows of international capital on the basis of Mundell-Fleming model (Kim 2001; Siebrand et al. 1988; Rafiq 2013). On the basis of Meade's thought of internal and external equilibrium (Skidelsky 2015) and the elasticity theory of income and expenditure (Vine et al. 2014), Dornbusch introduced foreign trades and capital flows into his IS-LM analysis, emphasized on that decisions on exchange rates and macroscopic control must be made by considering flows of capital, and believed that it is impossible to simultaneously achieve exchange rate stability, independence of monetary policies, and free movement of capital.

The problem of controlling capital flow is often closely related to the occurrence of currency crises. Many theorists maintain that the free movement of international capital, specifically the free movement associated with fixed exchange rate system, has been a trigger of the currency crises of the recent years. Therefore, these scholars believe that controlling the free movement of capital across national borders can lower the probability for currency crises to occur (Dungey et al. 2015). However, unfortunately, these theoretical results have not obtained empirical support. In recent years, many countries have employed the method of controlling capital movements in order to shield their domestic financial systems from the adverse effects of foreign financial crises. What is resulted from the controls seems to suggest that the health of the domestic financial system is mainly affected by foreign financial crises instead of the control of the capital movement. For example, Kaplan and Rodrik (2001) investigated the case of capital flow control in Malaysia and discovered that the control did not play an obvious role in the recovery of Malaysian economy; instead, the control actually made the financial crises worse. Glick and Hutchison (2005) studied the relationship between currency stability and capital flow control of developing countries. Their results also indicate that such controls play a very minor role in stabilizing currencies.

Since 2006, because of various reasons, Chinese economic growth has been clearly strengthened. The stock market bubble, constantly rising prices, excess liquidity, large amounts of nonproducing loans in the financial system, adverse operation conditions in the state-owned enterprises, etc. have made China particular vulnerable against currency crises. In response to this situation, Guo and Zhou (2003) considered the effects of system's stability on macroeconomic variables under different controls of capital movements and varied degrees of control. Their work indicates that within a flexible exchange rate system loosing up control on capital movements can help the economy to evolve from a state of saddle point stability to that of global stability. Zhou and Guo (2004) further studied the effect of capital movement control on equilibrium: how the domestic fixed exchange rate system can be protected by controlling capital movement in order to maintain the stability of the exchange rate of Renminbi (RMB). From the effect of the implemented capital movement control in China, it is found that in the short term, it is effective but ineffective for the long term. Wang et al. (2009) empirically looked at whether or not controlling capital movement could help suppress currency crises by using panel logit models.

Like how fluids move and exist in nature, money permeates each and every corner of the economic system and circulates within and between various organizational forms, from individuals to families to business firms, through purchasing and selling behaviors. Such constant transfer makes money flow continuously. Such fluidity of money also represents how economic units make their decisions that constitute the process of movement from receiving to paying out. However, the speed of movement from receiving to paying out is often affected by the current purchasing power of the money and the expected purchasing power in the near future. If the purchasing power of money is strong, economic units will be more willing to store and hold additional money; if the purchasing power of money drops, then economic units will be more willing to reduce the amounts of money they hold in order to possibly avoid loss in their purchasing power. However, the purchasing power of a currency is associated with the supply and demand of the currency within the economic system, with the monetary and fiscal policies, and with other factors.

If we use D to represent the demand for money of the economic system, S the supply of money of the system, and u the policy factors of the system, such as the adopted monetary policy, fiscal policy, etc., then a change in the purchasing power of money within the economic system can be described as follows:

$$\frac{dP}{dt} = k(D - S) + cu \tag{4.1}$$

where t stands for time, $k > 0$ is a constant, and $c \neq 0$ is also a constant.

Equation (4.1) indicates that the purchasing power of the currency within an economic system is related to the supply and demand of money and policy factors. If k, c, and u stay constant, then when the supply S of money within the economic system is greater than the demand D for money of the system, then the purchasing power P of the currency decreases. That is, the inflation of the economic system goes higher with the increasing supply of money within the system.

As a matter of fact, the economy of a general economic system is made up of a large number of individuals, families, business enterprises, and other organizational forms of businesses. If D_i and S_i represent the demand and supply of money of the ith economic organization, where $i = 1, 2, \cdots, n$, and n stands for the total number of economic organizations that exist in the economic system, then the model in Eq. (4.1) for the purchasing power of money can be rewritten as follows:

$$\begin{cases} \dfrac{dP_1}{dt} = k_{11}(D_1 - S_1) + k_{12}(D_2 - S_2) + \cdots + k_{1n}(D_n - S_n) + \sum_{m=1}^{q} c_{1m}u_m \\ \dfrac{dP_2}{dt} = k_{21}(D_1 - S_1) + k_{22}(D_2 - S_2) + \cdots + k_{2n}(D_n - S_n) + \sum_{m=1}^{q} c_{2m}u_m \\ \vdots \\ \dfrac{dP_n}{dt} = k_{n1}(D_1 - S_1) + k_{n2}(D_2 - S_2) + \cdots + k_{nn}(D_n - S_n) + \sum_{m=1}^{q} c_{nm}u_m \end{cases} \tag{4.2}$$

where k_{it} and c_{im} are constants, while u_m stands for a monetary, fiscal, and other relevant policy factor adopted within the economic system, $(i, t = 1, 2, \cdots, n;$ $m = 1, 2, \cdots, q)$.

By making use of matrix symbols, Eq. (4.2) can be simplified into

$$\dot{P} = Kx + Cu \tag{4.3}$$

where $P = [P_1, P_2, \cdots, P_n]^T$, $\dot{P} = \left[\frac{dP_1}{dt}, \frac{dP_2}{dt}, \cdots, \frac{dP_n}{dt}\right]^T$ stands for the symbol of Newtonian derivatives, $K = [k_{it}]_{n \times n}$ the coefficient matrix of the variable vector $x = [D_1 - S_1, D_2 - S_2, \cdots, D_n - S_n]^T$, and $C = [c_{ik}]_{n \times q}$ the coefficient matrix of the vector $u = [u_1, u_2, \cdots, u_q]^T$ of policy variables.

If the relationship within the economic system between the purchasing power function $P = [P_1, P_2, \cdots, P_n]^T$ and the differences $x = [D_1 - S_1, D_2 - S_2, \cdots, D_n - S_n]^T$ of demands and supplies of money within the system is linear, that is, the following holds true:

$$P = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} = R_{n \times n} \begin{bmatrix} D_1 - S_1 \\ D_2 - S_2 \\ \vdots \\ D_n - S_n \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix} \tag{4.4}$$

where $R_{n \times n}$ is a constant square matrix and $\varepsilon = [\varepsilon_1\ \varepsilon_2 \cdots \varepsilon_n]^T$ a random error terms with nonzero means. So, by taking mathematical expectations, the previous equation becomes

$$P = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} = R_{n \times n} \begin{bmatrix} D_1 - S_1 \\ D_2 - S_2 \\ \vdots \\ D_n - S_n \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} \tag{4.5}$$

where $E(\varepsilon_i) = b_i \neq 0, i = 1, 2, \cdots, n$.

Based on how the previous model for the purchasing power within the economic system is constructed, substituting Eq. (4.5) into Eq. (4.3) leads to

$$R_{n \times n}\dot{x} = Kx + Cu \tag{4.6}$$

where $R_{n \times n}$ is assumed to be invertible, which implies that the number of economic entities used in our analysis is the minimum in the sense that none of the entities can be seen as a linear combination of other entities.

By letting $A = R^{-1}K$ and $B = R^{-1}C$, Eq. (4.6) can be rewritten as follows:

$$\dot{x} = Ax + Bu. \tag{4.7}$$

Similar to how consumer price index (CPI), employment rate, inflation, etc. are used to represent the performance of an economy, let us employ the purchasing power $y = [y_1, y_2, \cdots, y_n]^T$ of money of individual economic organizations within the economic system to measure the respective contributions of the individual economic organizations to the circulation of money with the economic system. Then we obtain the following control-theory model for the movement of capital within the economic system:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \, . \\ x(t_0) = x_0 \end{cases} \tag{4.8}$$

Equation (4.8) indicates that by using the state variable x to absorb the positive and negative effects of the monetary, fiscal, and other policy factors within the economic system, the state of movement of the capital within the economic system can be determined. Here, both the internal mechanism x of how money circulates within the economic system and the policy variable u jointly work on the effect of money within the economic system, that is, the degrees of satisfaction of individual economic organizations about how the money circulates. Accordingly, the input space describes all the policy factors, including the relevant monetary policies, fiscal policies, and other policies, while the output space lists all possible effects, the purchasing power of money of the individual economic organizations, of the policy factors on the movement of money within the economic system.

As a matter of fact, because the state variable x in Eq. (4.8) has already absorbed the effects of various policies within the economic system, it can determine the state of movement of money within the system. So, the purchasing power index $y = [y_1, y_2, \cdots, y_n]^T$ that measures the state of movement of money of individual economic organizations can be simplified as a direct consequence of employing the state variable x. That is, Eq. (4.8) can be simplified into the following:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \\ x(t_0) = x_0 \end{cases} \tag{4.9}$$

where $x(t) \in R^{n \times 1}$, $u(t) \in R^{r \times 1}$, $y(t) \in R^{n \times 1}$, $A_{n \times n}$, $B_{n \times r}$, and $C_{n \times n}$ are all real-valued matrices. The control-theory system in Eq. (4.9) that describes the movement of money can be simply written by using the abbreviated form $\{A, B, C\}$.

Based on what is presented above, it follows that for any given economic system, a control-theory model in the form of Eq. (4.9) for describing the movement of money within the system can be established. As soon as such a system of motion is constructed, a tool that can be used to measure the movement of money within the economic system becomes available so that relevant strategies can be designed to regulate the movement of money and the consequent effects of the implemented strategies can be evaluated. For relevant discussions, please consult with (Forrest et al. 2013b).

4.3 Needs for Reducing the Dimensionality of the Capital Movement Model

As what has been discussed earlier, a control-theory model can be established to describe the movement of money within an economic system. Assume that the system representation as in Eq. (4.9) has been developed for our study of the movement of money. However, due to the large number of economic entities, such as individuals, families, commercial firms, and other forms of organizations, which exist in an economic system, the number of state variables involved in the model in Eq. (4.9) would be at least in the thousands. That is, the state vector x would be very high dimensional. That would make it difficult for policy makers to accurately measure the state of movement of money and to appropriately design the adequate regulation policies. On the other hand, in practical works, people have been employing relatively a few variables to describe the performance of the economic system, For example, some investors use the state of the stock market of the economic system to reflect how well the economy is doing; some others use the purchasing managers' index to represent how well the manufacture sector of the economic system is doing.

As a matter of fact, the economy of a nation is made up of countless entities and business organizations. When the economic performance of most these entities goes up, it implies that the overall economy is rising as a whole. Conversely, the overall economy is in period of recession. Because the stock market of a nation stands for such a platform that gathers most of the great business firms of the country, when the profits of these firms rise, a direct consequence will be an upward swing of the stock market. When the growth of the firms' profits gradually slows down, it will be reflected in the stock market by a process of falling from a high level. That is why some investors believe that the stock market is a barometer of the economy and can directly reflect to a great degree the economic situation of the country. Figures 4.1 and 4.2, respectively, show the relationships between the changes of the US stock

Fig. 4.1 The US stock market and the nominal GDP

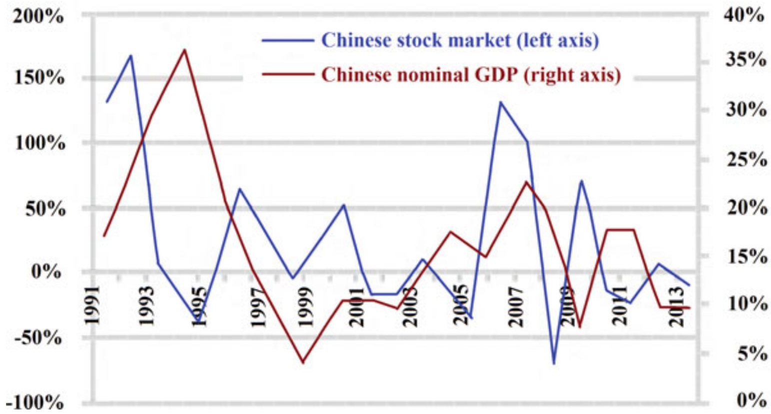

Fig. 4.2 Changes in Chinese stock market and the nominal GDP

market and the US macroeconomic outputs and the changes between Chinese stock market and Chinese macroeconomic outputs. From these figures, it follows that the annual movements of the stock markets are somehow correlated to the fluctuations of the nominal GDP, although the trends of movement in the stock markets seem to appear 1 year ahead of those of the nominal GDP: if the stock markets move downward, so did the corresponding GDPs with similar patterns of fluctuation.

Other than the stock market of an economic system that can be employed to describe the macroeconomic health of the system, for economic sectors, local and regional economic systems, similar relationships also exist. For example, to measure the performance of the manufacturing sector, the purchasing managers' index (PMI) is established.

The PMI generally stands for that of the United States. It is often seen as the "examination table" of the US manufacturing sector and is an important parameter regarding the manufacturing sector of the United States reported by the ISM, the Institute for Supply Management, the world's largest and most authoritative professional organization focusing on purchasing management, supply management, logistics management, and other relevant areas. This PMI is a comprehensive index that measures the state of eight different areas of the manufacturing sector: output, new orders, prices of products, stocks, employment, suppliers' delivery, new export orders, and import. It is calculated as a composite of five survey indices as follows:

$$\begin{aligned}\text{PMI} &= \text{new orders} \times 30\% + \text{output} \times 25\% + \text{employment} \times 20\% \\ &\quad + \text{suppliers}' \text{ delivery times} \times 15\% + \text{stocks of purchases} \times 10\%\end{aligned}$$

Although PMI does not index much, it indeed covers many aspects of economic activities and comprehensively reflects the overall situation and trend of the economy. An analysis of the historical data indicates that the PMI index and GDP are highly correlated and changes in PMI seem to appear several months ahead of those of GDP. For example, during the past 40 plus years, the peak values in the PMI index of the US manufacturing sector could lead the business climax as much ahead as 6 months, while the lows could also lead the business lows by a few months.

Therefore, the PMI index has become an important tool employed by and an indispensable piece of information disseminated by the Federal Reserve, the Wall Street, Dow Jones Newswires, Thomson Reuters, and other economy media. Currently, over 20 countries, including China, England, Japan, etc., from around the world have established their country-specific PMI systems. More broadly, similar indices have been developed for the Eurozone and the world as an important parameter for evaluating the world economic performance and as a barometer that measures changes in the world economy.

From what is discussed above, it follows that when one needs to describe the state of development of a particular economic system, he could select an appropriate "part" to approximately represent the whole, where the approximate representation maintains a high degree of congruency with the original economic system. Correspondingly, a natural question arises: for the movement of the currency of an economic system, is there also an appropriate "part" that could approximately describe the state of movement of the currency within the system? Theoretically speaking, this question is equivalent to whether or not there are matrices $G_{m \times n}$, $F_{m \times m}$, and $\Gamma_{m \times r}$ and a linear transformation $z = Gx$ so that the control-theory system, as given in Eq. (4.9), can be simplified into that in Eq. (4.10).

$$\begin{cases} z = Fz + \Gamma u \\ y_m = Hz \\ z(t_0) = Gx_0 \end{cases} \tag{4.10}$$

where $z(t) \in R^{m \times 1}$, $u(t) \in R^{r \times 1}$, and $y_m(t) \in R^{m \times 1}$, satisfying $m < n$, $FG = GA$, $\Gamma = GB$, and $HG = C$. If such a simplified representation does exist, then we call the system in Eq. (4.10) a system of reduced order (or dimension) of the control-theory system of the currency movement in Eq. (4.9).

Generally speaking, although such simplified systems do exist, which is similar to the situations that changes in the stock market and the PMI index can be employed to approximately reflect the performance of the macroeconomic system, how in practical applications can one find such desirable transformation $z = Gx$? Following that question, we would naturally ask: Is such transformation unique? If there is more than one such transformation, then what could be the relationship between these multiple transformations? Only after all these open questions are settled, each such system of reduced order as that given in Eq. (4.10) that approximately describes the original control-theory system of the currency movement would become practically valuable.

As a matter of fact, just as the cases that stock market, the PMI, and other indices can be employed to approximate the state of development of the macroeconomic system, for many circumstances there is not any accurate transformation $z = Gx$ that can be used to produce the desired system of reduced order for the control-theory system of the currency movement as in Eq. (4.10). Instead, one has to select an approximate transformation $z \approx Gx$ to reduce and simplify the control-theory system in Eq.(4.9) that describes the currency movement. So, the question becomes that for any given economic system, how can one select the appropriate "part" to approximately describe the whole and how can the degree of congruency between the "part" and the original whole be measured? Additionally, can the established "partial system" still possess the good economic characteristics that are important for the regulation of the original whole, such as the characteristics as controllability, observability, and others?

In order to simply our presentation, in the following we will only consider the problem of order reduction of single input and single output currency movement systems. That is, we only look at the following system of currency movement:

$$\begin{cases} \dot{x} = Ax + bu \\ y = cx \\ x(t_0) = x_0 \end{cases} \tag{4.11}$$

where $A \in R^{n \times n}$, $x(t)\,, b\,, c \in R^n$, and $u(t)\,, y(t) \in R$.

As for the problem of order reduction of multiple input and multiple output currency movement systems, we will illustrate the relevant details partially later in this chapter. In the following, we will mainly focus on how to construct systems of desired lower dimension that approximate the original currency movement system, at what degrees of congruency the approximate systems would be with the original system, and what properties the approximate systems would inherit from the original system.

4.4 Existence of Reduced Order Systems for Currency Movement

The previous section presents the practical need for order reduction models in the investigation of economic systems through more or less case analyses. Riding on the back of this analysis, this section presents a general systems theoretical result that shows the existence of such order reductions models.

In particular, each financial unit in an economy can be modeled by using the concept of centralized and centralizable systems. (Hall and Fagen 1956) initially introduced the concept of centralized systems. Specifically, a system is centralized if one object or a subsystem of the system plays a dominant role in the system's operation. The leading part can be thought of as the center of the system, since a small change in it would affect the entire system, causing considerable changes across the entire spectrum. Lin (1989) applied the concept of centralized systems to the study of some phenomena in sociology, where several interesting results were obtained, including an argument on why there must be a few people in each community who dominate over others.

Mathematically, a system (Lin 1987) is an ordered pair of sets, $S = (M, R)$, such that M is the set of all objects of the system and R a set of some relations defined on M. The sets M and R are known as the object and relation set of S, respectively. Here, each $r \in R$ is defined as follows: there is an ordinal number $n = n(r)$, as a function of r, known as the length of the relation r, such that $r \subseteq M^n$, where

$$M^n = \underbrace{M \times M \times \ldots \times M n \;\text{ times} = \{f : n \to M \,\text{is a mapping}\}}$$

is the Cartesian product of n copies of the object set M.

A system $S = (M, R)$ is trivial, if $M = R = \varnothing$. Given two systems $S_i = (M_i, R_i)$, $i = 1, 2$, S_1 is a partial system of S_2 if either (1) $M_1 = M_2$ and $R_1 \subseteq R_2$ or (2) $M_1 \subset M_2$, and there exists a subset $R' \subseteq R_2$ such that $R_1 = R' | M_1 = \{f$: f is a relation on M_1 and there is $g \in R'$ such that f is the restriction of g on $M_1\}$. In symbols, we have

$$R' \mid M_1 = \{f : g \in R'(f = g|M_1)\},$$

where $g \mid M_1 \equiv g \cap M_1^{n(g)}$.

A system $S = (M, R)$ is called a centralized system, if each object in S is a system and there is a nontrivial system $C = (M_C, R_C)$ such that for any distinct elements x and $y \in M$, say, $x = (M_x, R_x)$ and $y = (M_y, R_y)$, then $M_C = M_x \cap M_y$ and $R_C \subseteq R_x / M_C \cap R_y / M_C$. The system C is known as a center of S. The following holds true:

Theorem 4.1 (Lin 1988a). *Assume ZFC. Suppose that $S = (M, R)$ is a system such that $|M|$, the cardinality of M, $\geq c$, where c is the cardinality of the set of all real numbers, and that each object in S is a system with finite object set. If there exists such an element that belongs to at least c objects in M, there then exists a partial system B of S with an object set of cardinality $\geq c$ and B forms a centralized system.*

One interpretation of this result is that as long as an economy is seen as a system, where different parts of the economy are closely connected by various relationships, and some special monetary or fiscal policies exist such that each of these policies transcends through a great number of the parts of the economy, then in this economy, at least one center (or a set of policies) will appear and influences the development of an overwhelming part of the economy. And, when dictated by nature, such as severely uneven distribution of resources and uneven flows of money and credit, the effects of various policies will naturally fluctuate from one level to another. In the process of fluctuation of policy effectiveness, this theorem indicates that many sets of policies along with their fields of effectiveness could be removed without greatly affecting the underlying structure of the economy. This theoretical result might be the explanation for the phenomenon that the effectiveness of different policies changes alternatively over time through different stages of economic development.

Let $S_i = (M_i, R_i)$, $i = 1, 2$, be two systems and h: $M_1 \to M_2$ a mapping. Define two classes $\hat{M}_i$, $i = 1, 2$, and a class mapping $\hat{h} : \hat{M}_1 \to \hat{M}_2$ by using the transfinite induction as follows:

$$\hat{M}_i = \cup_{n \in Ord} M_i^n, i = 1, 2,$$

and for each $x = (x_0, x_1, \ldots, x_\alpha, \ldots) \in \hat{M}_1$,

$$\hat{h}(x) = (h(x_0), h(x_1), \ldots, h(x_\alpha), \ldots) \in \hat{M}_2,$$

where Ord is the class of all ordinals.

For each relation $r \in R_1$, $\hat{h}(r) = \{h(x) : x \in r\}$ is a relation on M_2 with length $n(r)$. Without confusion, h will be used to indicate the class mapping $\hat{h}$ and is seen as a mapping from the system S_1 into the system S_2, denoted $h: S_1 \to S_2$. When h: $M_1 \to M_2$ is surjective, injective, or bijective, the mapping h: $S_1 \to S_2$ is also seen as surjective, injective, or bijective, respectively.

The systems S_i, $i = 1, 2$, are similar if there is a bijection h: $S_1 \to S_2$ such that $h(R_1) = \{h(r) : r \in R_1\} = R_2$. The mapping h is known as a similarity mapping from S_1 onto S_2. A mapping h: $S_1 \to S_2$ is termed to as a homomorphism from S_1 into S_2 if $h(R_1) \subseteq R_2$.

A system $S = (M, R)$ has n levels (Lin 1989), where n is a fixed whole number, if

(i) Each object $S_1 = (M_1, R_1)$ in M is a system, called the first-level object system of S.
(ii) If $S_{n\text{-}1} = (M_{n\text{-}1}, R_{n\text{-}1})$ is an $(n - 1)$th-level object system of S, then each object $S_n = (M_n, R_n) \in M_{n\text{-}1}$ is a system, called the nth-level object system of S.

For a graphic representation of this concept, see Fig. 4.3.

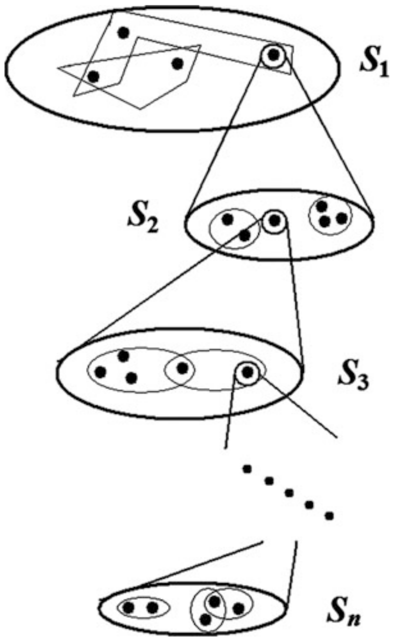

Fig. 4.3 A graphical representation of an n-level system

A system S_0 is n-level homomorphic to a system A, where n is a fixed natural number, if there exists a mapping h_{S0}: $S_0 \to A$, known as an n-level homomorphism, satisfying the following:

1. The systems S_0 and A have no nonsystem kth-level objects, for each $k < n$.
2. For each object S_1 in S_0, there exists a homomorphism h_{S1} from the object system S_1 into the object system $h_{S0}(S_1)$.
3. For each $i < n$ and each ith-level object S_i of S_0, there exist level object systems S_k, for $k = 0, 1, \ldots, i - 1$, and homomorphisms h_{Sk}, $k = 1, 2, \ldots, i$, such that S_k is an object of the object system $S_{k\text{-}1}$ and h_{Sk} is a homomorphism from S_k into $h_{S_{k-1}}(S_k)$, for $k = 1, 2, \ldots, i$.

A system S is centralizable (Lin 1999), if it is 1-level homomorphic to a centralized system S_C under a homomorphism h: $S \to S_C$ such that for each object m in S, the object systems m and $h(m)$ are similar. Each center of S_C is also known as a center of S.

Theorem 4.2 (Lin 1999). *A system $S = (M, R)$ with two levels is centralizable, if and only if there exists a nontrivial system $C = (M_C, R_C)$ such that C is embeddable in each object S_1 of S; that is, C is similar to a partial system of S_1.*

This result provides the theoretical foundation for checking whether or not an economy that is in a chaotic state would soon become organized or ready to grow again out of a meltdown. When this theorem is mapped over to the current economic state of a specific economy, one would be able to tell whether a particular set of a few economic policies is going to potentially work or not. That is, this theorem provides a theoretical framework for telling whether a high-dimensional economic system, where the performance of the system is affected by a huge number of factors, can be reduced to a system of lower order, where the performance of the system is influenced by only a few factors or policies.

4.5 Method for Order Reduction of Currency Movement Systems

Just as how a weighted average of the Dow component stocks and how a weighted average of the Standard and Poor 500 component stocks are employed to describe the performance of the stock markets, many scholars have been interested in selecting an appropriate low-order "component" vector z in their process of developing an approximate linear transformation $z \approx Gx$ so that the original currency movement system can be more or less adequately described. Along this line of thinking logic, many methods of order reduction have been developed (Wilhelmus et al. 2008; Benner et al. 2005; Antoulas et al. 2001; Gugercin 2002; Freund 2003). However, these methods only provided detailed computational schemes without considering the potential errors between the original system and the obtained systems of reduced orders. As a contribution of this chapter to the existing literature, we investigate a new method of order reduction of the original system of currency movement from the angle of optimizing the involved error based on the already established methods. Additionally, we analyze the relationship between the original system and new systems of much reduced orders and study the properties the reduced systems.

The method of Krylov subspaces is one of the most frequently employed methods for order reduction of systems (Freund 2003). In particular, Krylov subspaces are generated by a given matrix A and a given vector b, where the kth Krylov subspace $\kappa_k(A, b)$ is generated by the following k column vectors:

$$\kappa_k(A,b) = span\{b, Ab, A^2b, \cdots, A^{k-1}b\}$$

where A is an constant $n \times n$ matrix, b an $n \times 1$ vector (also known as the initial vector), and k a fixed positive constant. The vectors $b, Ab, A^2b, \cdots, A^{k-1}b$ are referred to as the base vectors. Our work here on how to reduce the order of the original currency movement system is mainly based on the idea of Krylov subspaces.

As a matter of fact, when one needs to reduce the order of the original currency movement system of the economic system, he generally does not know which initial vector q he should use in order to produce the ideal system of reduced order. Hence, let us also start with an unknown row vector q as our initial vector. For a fixed positive whole number $k(k < n)$, we will use the state matrix A of the currency movement system in Eq. (4.11) to design the base vectors $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ and the reduced order matrix G_k in order to produce our needed system of reduced order of Eq. (4.11), where

$$G_k = \begin{pmatrix} q \\ qA \\ \vdots \\ qA^{k-2} \\ qA^{k-1} \end{pmatrix}. \tag{4.12}$$

For the row vector qA^k, the following equation generally does not hold true:

$$qA^k = -\alpha_0 q - \alpha_1 qA - \cdots - \alpha_{k-2} qA^{k-2} - \alpha_{k-1} qA^{k-1} \tag{4.13}$$

In fact, only when the set $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ of vectors forms a maximal linear independent set of vectors within $\{q, qA, qA^2, \cdots, qA^{k-1}, qA^k\}$, Eq. (4.13) will hold true. So, when Eq. (4.13) does not hold true, let us assume that the coefficients $(\alpha_0, \alpha_1, \cdots, \alpha_{k-2}, \alpha_{k-1})$ are the solution of the minimum norm error of Eq. (4.13). Then we have

$$qA^k \approx -\alpha_0 q - \alpha_1 qA - \cdots - \alpha_{k-2} qA^{k-2} - \alpha_{k-1} qA^{k-1} \tag{4.14}$$

which can be rewritten as $(\alpha_0, \alpha_1, \cdots, \alpha_{k-2}, \alpha_{k-1})G_k \approx -qA^k$ so that we have

$$(\alpha_0, \alpha_1, \cdots, \alpha_{k-2}, \alpha_{k-1}) \approx -qA^k G_k^+ \tag{4.15}$$

where G_k^+ stands for the generalized inverse of G_k. So, from Eq. (4.15), we can obtain

$$G_k A = \begin{pmatrix} qA \\ qA^2 \\ \vdots \\ qA^{k-1} \\ qA^k \end{pmatrix} \approx \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \ddots & & \\ 0 & 0 & 0 & \cdots & 0 & 1 \\ -\alpha_0 & -\alpha_1 & -\alpha_2 & \cdots & -\alpha_{k-2} & -\alpha_{k-1} \end{pmatrix} \begin{pmatrix} q \\ qA \\ \vdots \\ qA^{k-2} \\ qA^{k-1} \end{pmatrix} = F_k G_k \tag{4.16}$$

where

$$F_k = \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \ddots & & \\ 0 & 0 & 0 & \cdots & 0 & 1 \\ -\alpha_0 & -\alpha_1 & -\alpha_2 & \cdots & -\alpha_{k-2} & -\alpha_{k-1} \end{pmatrix}.$$

Assume that $Z_k = G_k x$, $b_k = G_k b$, and $c_k G_k = c$, where c_k is a k-dimensional vector. Then the original system in Eq. (4.11) can be transformed into

$$\begin{cases} \dot{Z}_k \approx F_k Z_k + b_k u \\ Y = c_k Z_k \\ Z(t_0) = G_k x_0 \end{cases} \tag{4.17}$$

which stands for an approximate reduced order system of the original currency movement system Eq. (4.11) with G_k being the reduced order matrix satisfying $F_k G_k \approx G_k A$, $b_k = G_k b$, and $c_k G_k = c$.

From how Eq. (4.17) is constructed, it follows that as long as the row vector q is known, for any chosen positive whole number k, the reduced order matrix G_k can be obtained by using the matrix A from the currency movement system Eq. (4.11). And then the system in Eq. (4.17) of reduced order is produced.

On the other hand, if Eq. (4.13) holds true, then the system in Eq. (4.17) will be accurate. That is, we have

$$\begin{cases} \dot{Z}_k = F_k Z_k + b_k u \\ Y = c_k Z_k \\ Z(t_0) = G_k x_0 \end{cases}.$$

So, if we want to obtain a reduced order system for the original currency movement system in Eq. (4.11) with a high degree of accuracy, then how to choose the row vector q is very important. To this end, a natural question arises as follows: what criterion should we use to measure whether or not a reduced order system is of high quality or a high degree of accuracy? Generally, what is often used as the criterion for evaluating measurements and the degree of congruency with the original system is the error. So, let us also make use of the concept of error to judge whether or not a reduced order system of the original currency movement system in Eq. (4.11) is of high quality. That is, an order reduction is considered high quality if the system of reduced order as in Eq. (4.17) has the minimum deviation from the original currency movement system.

4.6 Error Analysis for Reduced Order Currency Movement Model

From the process of how the order or dimension of the model in Eq. (4.11) of the currency movement within an economic system can be reduced, it follows that the source of error, if any, of the model of reduced order in Eq. (4.17) is mainly from the approximate linear representation of the vector qA^k in terms of the set of vectors $\{q, qA, qA^2, \cdots, qA^{k-1}\}$.

In fact, according to Eq. (4.14), we can obtain the following expression for the error that is created during the process of order reduction of the original currency movement model:

$$\left\| qA^k + \alpha_0 q + \alpha_1 qA + \cdots + \alpha_{k-2} qA^{k-2} + \alpha_{k-1} qA^{k-1} \right\|. \tag{4.18}$$

And from Eq. (4.16), we can also obtain the following expression for the error that is created during the order reduction:

$$\| G_k A - F_k G_k \|. \tag{4.19}$$

In the following, let us analyze the relationship between Eqs. (4.18) and (4.19).

A. The row vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly independent.

If the vectors in$\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly independent, then from algebra, it follows that the coefficients $(\alpha_0, \alpha_1, \cdots, \alpha_{k-2}, \alpha_{k-1})$ of the solution of the least sum of squared norms of Eq. (4.14) must be unique.

On the other hand, the matrix $G_k A$ and the set of row vectors $\{qA, qA^2, \cdots, qA^{k-1}, qA^k\}$ can be expressed (approximately) as linear combinations of the row vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$; and the expressions are unique. That means that Eq. (4.15) holds true and the equation $F_k = G_k A G_k^+$ is satisfied. That is, the errors expressed, respectively, in Eq. (4.18) and Eq.(4.19) are the same. So, we have

$$\| G_k A - F_k G_k \| = \left\| qA^k + \alpha_0 q + \alpha_1 Aq + \cdots + \alpha_{k-2} qA^{k-2} + \alpha_{k-1} qA^{k-1} \right\|. \tag{4.20}$$

B. The row vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly dependent.

In this case, it means that the order of the minimal polynomial of the matrix A in the currency movement system in Eq. (4.11) is smaller than the positive whole number k. Without loss of generality, let us assume that the order of the minimal polynomial of A is m, satisfying $m < k$. From the properties of the minimal polynomials of matrices, it follows that the vectors in the set $\{q, qA, qA^2, \cdots, qA^{m-1}\}$ are linearly independent and the vector qA^m can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{m-1}\}$. So, qA^k can also be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{m-1}\}$. That is, the vectors in the set $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly dependent. Therefore, Eq. (4.13) holds true.

Because the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly dependent, it means that each row vector $qA^i, i = 1, 2, \cdots, k$, in the matrix G_kA, can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ and the expression of the linear combination is not unique. So, the solutions of the least sum of squared norms, each of which corresponds to each individual linear combination, can together form a matrix F_k. Let us denote each solution that is different of the solution F_k of Eq. (4.16) as $\tilde{F}_k$. That is, there is at least one additional solution $\tilde{F}_k$ to Eq. (4.16) that is different from F_k, satisfying $\tilde{F}_k = G_kAG_k^+$. From the conclusion that the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly dependent, it follows that

$$\left\|qA^k + \alpha_0 q + \alpha_1 Aq + \cdots + \alpha_{k-2} qA^{k-2} + \alpha_{k-1} qA^{k-1}\right\| = \|G_kA - F_kG_k\| = 0.$$

That implies that if one chooses Eq. (4.16) to obtain matrix F_k in his process of reducing the order of the original system, then the minimum error of the order reduction is 0, and the following inequality holds true:

$$\|G_kA - F_kG_k\| \le \left\|G_kA - \tilde{F}_kG_k\right\|.$$

From the previous analyses of the two listed cases, it follows that one can also obtain matrix F_k by using Eq. (4.10). On the other hand, when the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly dependent, one can directly choose the vectors in $\{q, qA, qA^2, \cdots, qA^{m-1}\}$ to form the reduced order matrix G_m for the currency movement system in Eq. (4.11). By doing so, he cannot only obtain a high-quality lower dimensional approximation for that in Eq. (4.11) but also make the order of the new system in Eq. (4.17) lower.

So, for the convenience of discussion, we will simply assume that the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly independent so that the error of the reduced order system in Eq. (4.17) will be determined by Eq. (4.20). If we use the 2-norm to measure the magnitude of Eq. (4.20), then Eq. (4.20) can be rewritten as follows:

$$\|G_kA - FG_k\|_2 = \left\|qA^k + \alpha_0 q + \alpha_1 Aq + \cdots + \alpha_{k-2} qA^{k-2} + \alpha_{k-1} qA^{k-1}\right\|_2, \tag{4.21}$$

while the magnitude of the value in Eq. (4.21) can be understood as the distance between the vector qA^k and the subspace $L(q, qA, qA^2, \cdots, qA^{k-1})$. That is, we have

$$d_k = \sqrt{\frac{G(q, qA, \cdots, qA^{k-1}, qA^k)}{G(q, qA, \cdots, qA^{k-2}, qA^{k-1})}} = \sqrt{\frac{|G_{k+1}G_{k+1}^T|}{|G_k G_k^T|}}, \tag{4.22}$$

That means that the error of the reduced order system in Eq. (4.17) when compared to the currency movement system in Eq. (4.11) can be obtained from the following equation:

$$\begin{aligned} e_k &= \|G_k A - F G_k\|_2 \\ &= \|qA^k + \alpha_0 q + \alpha_1 A q + \cdots + \alpha_{k-2} qA^{k-2} + \alpha_{k-1} qA^{k-1}\|_2 \\ &= \sqrt{\frac{|G_{k+1}G_{k+1}^T|}{|G_k G_k^T|}}. \end{aligned} \tag{4.23}$$

Hence, for any chosen positive whole number $k(k < n)$, we can compute d_k through using Eq. (4.23), and correspondingly an order can be introduced to all the models of reduced dimensions according to the magnitudes of d_k's, each of which corresponds to the order k of the model of reduced dimension. So, the decision-maker can choose the desired dimension k and the corresponding model of reduced order based on the pre-determined regulation on the movement of currency.

From the previous error analysis of models of reduced order, it follows that when one reduces the order of the original currency movement system, he cannot only obtain a model of his desired dimension but also measure the error between the original system and that of the reduced order. So, the method of order reduction, as introduced here, can greatly improve the accuracy of the reduced order model when applied to regulate the currency movement of a large-scale complex economic system.

4.7 Relationship Between the Transfer Functions of the Original and Reduced Order Models

When the positive whole number $k(k < n)$ used for order reduction and the row vector q are chosen, it is ready to obtain the reduced order matrix G_k, which consists of the row vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$. From the row vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$, one can expand into a base of the n-dimensional Euclidean space. Assume that the base matrix that consists of the expanded base vectors is $G = \begin{pmatrix} G_k \\ Q \end{pmatrix}$. Then by using the transformation $\bar{X} = GX$, the system in Eq. (4.11) can be rewritten as follows:

$$\begin{cases} \dot{\bar{X}} = GAG^{-1}\bar{X} + Gbu \\ Y = cG^{-1}\bar{X} \end{cases}. \tag{4.24}$$

Because the following holds true

$$GA = \begin{pmatrix} G_k \\ Q \end{pmatrix} A = \begin{pmatrix} G_k A \\ Q\,A \end{pmatrix} \approx \begin{pmatrix} F_k G_k \\ Q\,A \end{pmatrix} = \begin{pmatrix} F_k & 0 \\ A_2 & A_3 \end{pmatrix} \begin{pmatrix} G_k \\ Q \end{pmatrix} = \begin{pmatrix} F_k & 0 \\ A_2 & A_3 \end{pmatrix} G,$$

we have $GAG^{-1} \approx \begin{pmatrix} F_k & 0 \\ A_2 & A_3 \end{pmatrix}$.

Let $Gb = \begin{pmatrix} G_k b \\ Qb \end{pmatrix} = \begin{pmatrix} b_k \\ b_0 \end{pmatrix}$ and $cG^{-1} = (c_k\ c_0)$. Assume $c_0 = 0$; that is, the row vector c is a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$, which can be satisfied readily. Let us decompose the state vector $\bar{X}$ into two parts Z_k and X_0, that is, $\bar{X} = \begin{pmatrix} Z_k \\ X_0 \end{pmatrix}$. Then the system in Eq. (4.24) can be rewritten as follows:

$$\begin{cases} \begin{pmatrix} \dot{Z}_k \\ \dot{X}_0 \end{pmatrix} \approx \begin{pmatrix} F_k & O \\ A_2 & A_3 \end{pmatrix} \begin{pmatrix} Z_k \\ X_0 \end{pmatrix} + \begin{pmatrix} b_k \\ b_0 \end{pmatrix} u \\ Y = (c_k\ c_0) \begin{pmatrix} Z_k \\ X_0 \end{pmatrix} \end{cases}. \tag{4.25}$$

By employing the operations of block matrices, the system in Eq. (4.25) can be split into two systems as follows:

$$\begin{cases} \dot{Z}_k \approx F_k Z_k + b_k u \\ Y = c_k Z_k \end{cases} \tag{4.26}$$

and

$$\begin{cases} \dot{X}_0 = A_2 Z_k + A_3 X_0 + b_0 u = A_3 X_0 + f(t) + b_0 u \\ Y_0 = c_0 X_0 = 0 \end{cases} \tag{4.27}$$

where the system in Eq. (4.26) stands for an approximate system of reduced dimension of the original currency movement system in Eq. (4.11), while the system in Eq. (4.27) represents the state variables disregarded in the process of order reduction of the original currency movement system in Eq. (4.11). Notice that this latter system does not have any output. That is, the reduced order system in Eq. (4.26) has completely "absorbed" the output vector of the original currency movement system in Eq. (4.11). Therefore, from the strategic angle of regulating the currency movement, it can be seen that the decision-makers only need to design their strategies based on the system's expression given in Eq. (4.26), while the effect of the strategies will be the same as that as if the strategies were designed based on the original system in Eq. (4.11).

Additionally, because the system in Eq. (4.24) is the result of an isomorphic transformation of the original system in Eq. (4.11), while isomorphic transformations do not alter the transfer function of the system, the transfer functions of the systems in Eqs. (4.11) and (4.24) are the same. That is, we have $H(s) = c(sI - A)^{-1} b$. Because the transfer function of the system in Eq. (4.26) is $H_k(s) = c_k(sI - F_k)^{-1} b_k$, the following equation holds true:

$$\begin{aligned} H(s) &= c(sI - A)^{-1}b \approx (c_k \ \ 0)\begin{pmatrix} (sI - F_k) & O \\ -A_2 & (sI - A_3) \end{pmatrix}^{-1}\begin{pmatrix} b_k \\ b_0 \end{pmatrix} \\ &= (c_k \ \ 0)\begin{pmatrix} (sI - F_k)^{-1} & O \\ -(sI - A_3)^{-1}A_2(sI - F_k)^{-1} & (sI - A_3)^{-1} \end{pmatrix}\begin{pmatrix} b_k \\ b_0 \end{pmatrix} \\ &= c_k(sI - F_k)^{-1}b_k. \end{aligned}$$

What this equality implies is that the transfer function of the reduced order system in Eq. (4.26) is approximately equal to that of the original system in Eq. (4.11). In other words, the eigenvalues of the matrix F_k of the reduced order system are approximately equal to those of the matrix A of the original system.

For the original system, the magnitudes of the eigenvalues of the matrix A play a decisive role in the stability of the system when the system suffers from a disturbance. For example, if the real parts of the eigenvalues of A are all smaller than 0, then after experiencing disturbances, the system in Eq. (4.11) will still be convergent. Conversely, if the matrix A has at least one eigenvalue whose real part is positive, then when experiencing disturbances the system in Eq. (4.11) will become divergent. Now, because the eigenvalues of F_k are approximately equal to those of A, it follows that if the deviation of the reduced order system from the original system is small, then when the original system in Eq. (4.11) is stable, the reduced order system in Eq. (4.26) is also stable.

4.8 Observability and Controllability of Reduced Order Systems

One area, which has not been well studied in modern control theory, involves such currency movement system that is observable and controllable; however, its stability is uncertain. To this end, one fundamental problem that needs to be first resolved is for a given reduced order system of the original currency movement system, is it observable?

The observability of many systems in nature has been well confirmed. For example, the observability of mechanical systems is established by O'Sullivan-Greene et al. (2014) and Kawano and Ohtsuka (2013), electronic network systems by Dehghani et al. (2014), space flight systems by Wang and Xia (2015), Zhang and Zhang (2015), and Rashidi et al. (2015), robot systems by Bejarano and Zheng (2014), Boukhobza and Hamelin (2013), and Bejarano et al. (2013), biological systems by Rivadeneira and Moog (2015) and Zhou (2015), etc. Tian (2013) developed his generalized delta operator system for the purpose of describing general continuous and general discrete systems uniformly, while he also investigated the observability (and other properties) of the generalized delta operator system. However, in this work, Tian only presented two numerical examples without providing any practical meanings.

A system is said to be controllable, provided the system can evolve from a state of a prior time moment to an expected state at a later moment. In order to establish the concept of controllability of the general system, one needs to consider two important points (Zhou et al. 2002a): the impact of the external environment on the system and the measurement of an evaluation function on the controllability of the system. The most fundamental problem in the research of controllability is how to make the system of concern to evolve from a state to an expected state within the given constraint. When a mathematical model is established for the process of interest, the first step of analysis is to specify what is possible and what is impossible under the conditions of constraint (Casti 1987). On the basis of the Mesarovic and Takahara's model of systems, Lin (1987) established a general model of systems of multi-relations. Generally speaking, conditions under which a general system is controllable are developed for models of abstract systems without considering any specific background information of realistic systems. That is why such studies can be applicable to any realistic systems. In the following, let us illustrate this point by using the example of reducing the dimension of the control-theory model of currency movement within an economic system.

Because currency can be utilized as a weapon of war to launch attack on another economic system, any economic system should be prepared at all time for potential attacks on its currency. To this end, the prepared economic system needs to possess the following two basic capabilities:

- At any given time moment, the economic system knows the systemic state of operation of its currency movements, and whether or not the operational state is within the pre-determined range.
- When the economic system is under attack of some currency tools, it can foretell whether or not its adopted countermeasures could make the system return to the pre-determined target range.

In technical terms, these two basic capabilities imply whether or not the system in Eq. (4.11) or the reduced order system in Eq. (4.26) can either materialize a certain objective or track a given goal. In order to realize this purpose, we must first analyze the controllability of the system. In other words, can we make the output y (t) of the system equal to a pre-determined value (a target value) within a certain time range by altering the input value u (the adopted policy vector) into the system of the currency movement? Because of the output $y(t)$ is equal to a linear combination of the internal state $x(t)$, $Y = c_k Z_k$, to materialize the goal of obtaining the output of the system to equal the pre-determined value, we need the state Z_k of the reduced order system in Eq. (4.26) to be controllable. Additionally, after observing the system for a period of time, specifically, after we have observed the output $y(t)$

of the reduced order system in Eq. (4.26) for a period of time, can we acquire a good knowledge about the state Z_k of the system? The answer to this question has everything to do with the observability of the system.

Based on the previous analysis, it follows that the transfer function of the reduced order system in Eq. (4.26) is approximately equal to that of the original system in Eq. (4.11). That implies that the reduced order system possesses a similar stability as the original system. If additionally the reduced order system possesses better qualities, such as observability and controllability, then the system of lower dimension could be seen as an ideal tool for designing strategies to counter currency wars. So, in the following, we investigate the observability and controllability of the system of reduced order in Eq. (4.26).

Result 1 The currency movement system in Eq. (4.26) of reduced order is controllable.

From the knowledge of control theory, it follows that a sufficient and necessary condition for a linear control system to be controllable is that the rank of the control matrix $U = [B|AB|A^2B| \cdots |A^{n-1}B]$ is n, where matrices A and B are, respectively, the coefficient matrix of the state vector and that of the input vector of the control system and n the order of the state vector (Grimme 1997; Bai 2002). That is, for our purpose here, we only need to show that in terms of the currency movement system in Eq. (4.26) of reduced order, the rank of the matrix $U = \left[b_k|F_kb_k|F_k^2b_k|\cdots|F_k^{k-1}b_k\right]$ is k.

Proof Because the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly independent, that is,

$$\alpha G_k = \alpha \begin{bmatrix} q \\ qA \\ \vdots \\ qA^{k-1} \end{bmatrix} = 0 \text{ if and only if } \alpha = 0.$$

$$\text{Since } b_k = G_k b = \begin{bmatrix} qb \\ qAb \\ \vdots \\ qA^{k-2}b \\ qA^{k-1}b \end{bmatrix} \text{ and } F_k = \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \ddots & & \\ 0 & 0 & 0 & \cdots & 0 & 1 \\ -\alpha_0 & -\alpha_1 & -\alpha_2 & \cdots & -\alpha_{k-2} & -\alpha_{k-1} \end{pmatrix}, \text{ we have}$$

$$U = \begin{bmatrix} qb & qAb & qA^2b & \vdots & qA^{k-1}b \\ qAb & qA^2b & qA^3b & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ qA^{k-2}b & qA^{k-1}b & \vdots & \vdots & \vdots \\ qA^{k-1}b & \sum_{i=1}^{k} \alpha_{i-1}qA^{i-1}b & \vdots & \vdots & \end{bmatrix}.$$

So, to show the rank of U is k, we only need to check whether or not the row vectors or column vectors of U are linearly independent. That is,

$$\begin{cases} k_1qb + k_2qAb + \cdots + k_{k-1}qA^{k-2}b + k_kqA^{k-1}b = 0 \\ k_1qAb + k_2qA^2b + \cdots + k_{k-1}qA^{k-1}b + k_k\sum_{i=1}^{k}\alpha_{i-1}qA^{i-1}b = 0 \\ \vdots \\ k_1qA^{k-1}b + \cdots = 0 \end{cases}. \tag{4.28}$$

Since

$$\begin{aligned} &k_1qb + k_2qAb + \cdots + k_{k-1}qA^{k-2}b + k_kqA^{k-1}b \\ &\quad = \left[k_1q + k_2qA + \cdots + k_{k-1}qA^{k-2} + k_kqA^{k-1}\right]b = 0 \end{aligned} \tag{4.29}$$

and because b stands for the coefficient matrix of the control vector (the policy vector) in the currency movement system in Eq. (4.11), while any change in the control vector affects the state vector of the currency movement system, especially during the time of dealing with a currency attack, (the orderly state of the currency movement within the economic system is mainly maintained through adopting relevant monetary and fiscal policies), it follows that $b \neq 0$. Additionally, because different policies would exert different effects on the state vector of the currency movement system, it is reasonable to see that b can be any nonzero vector. Therefore, Eq. (4.29) holds true for any $b \neq 0$. So, we have

$$k_1q + k_2qA + \cdots + k_{k-1}qA^{k-2} + k_kqA^{k-1} = 0. \tag{4.30}$$

Because the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly independent, a sufficient and necessary condition for Eq. (4.30) to hold true is $k_1 = k_2 = \cdots = k_k = 0$. So, the system of equation in Eq. (4.28) holds true if and only if $k_1 = k_2 = \cdots = k_k = 0$. That is, the column vectors of U are linearly independent. Hence, the rank of the control matrix $U = \left[b_k | F_k b_k | F_k^2 b_k | \cdots | F_k^{k-1} b_k\right]$ of the currency movement system in Eq. (4.26) of reduced order is k. That is, the system in Eq. (4.26) is controllable. QED

Result 2 The currency movement system of reduced order in Eq. (4.26) is observable.

From the knowledge of control theory, it follows that a sufficient and necessary condition for a linear control system to be observable is that the rank of the observability matrix $V = [C^T | A^T C^T | (A^T)^2 C^T | \cdots | (A^T)^{n-1} C^T]^T$ is n, where A and C are, respectively, the coefficient matrix of the state vector of the control system and the coefficient matrix of the output vector, and n the order of the state vector (Grimme 1997; Bai 2002). So, in terms of the currency movement system in Eq. (4.26) of reduced order, we only need to show that the rank of the matrix $V = [C^T | A^T C^T | (A^T)^2 C^T | \cdots | (A^T)^{k-1} C^T]^T$ is k.

Proof The observability matrix $V = [C^T | A^T C^T | (A^T)^2 C^T | \cdots | (A^T)^{k-1} C^T]^T$ of the system in Eq. (4.26) can be rewritten as follows:

$$V = \left[C^T|A^TC^T|\left(A^T\right)^2C^T|\cdots|\left(A^T\right)^{k-1}C^T\right]^T = \begin{bmatrix} c_k \\ c_kF_k \\ c_kF_k^2 \\ \vdots \\ c_kF_k^{k-1} \end{bmatrix}$$

where $c = c_kG_k = c_k \begin{bmatrix} q \\ qA \\ \vdots \\ qA^{k-2} \\ qA^{k-1} \end{bmatrix}$ and $F_k = \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \ddots & & \\ 0 & 0 & 0 & \cdots & 0 & 1 \\ -\alpha_0 & -\alpha_1 & -\alpha_2 & \cdots & -\alpha_{k-2} & -\alpha_{k-1} \end{pmatrix}$.

In the following, let us analyze the relationship between the state vector matrix F_k of the currency movement system of reduced order in Eq. (4.26) and the row vectors of the matrix V that is made up of the output vector matrix c_k.

For any real numbers $g_1, g_2, \cdots, g_k$, we have

$$\begin{aligned} &g_1c_k + g_2c_kF_k + \cdots + g_{k-1}c_kF_k^{k-2} + g_kc_kF_k^{k-1} \\ &\quad = c_k\left[g_1E + g_2F_k + \cdots + g_{k-1}F_k^{k-2} + g_kF_k^{k-1}\right] = 0. \end{aligned} \tag{4.31}$$

Because c is the coefficient matrix of the output vector of the currency movement system in Eq. (4.11), and for any economic system its currency movement system does produce outputs while different policies in general produce different output vectors, it is reasonable to assume that c is nonzero. Since $c_k = cG_k^+$, where G_k^+ stands for the generalized inverse matrix of G_k and $G_k \neq 0$, it follows that c_k is an arbitrary nonzero vector.

From Eq. (4.31), it follows that

$$g_1E + g_2A + \cdots + g_{k-1}A^{k-2} + g_kA^{k-1} = 0.$$

So, for any nonzero vector q, we have

$$\begin{aligned} &q\left[g_1E + g_2A + \cdots + g_{k-1}A^{k-2} + g_kA^{k-1}\right] \\ &\quad = g_1q + g_2qA + \cdots + g_{k-1}qA^{k-2} + g_kqA^{k-1} = 0. \end{aligned}$$

Since the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ are linearly independent, we have

$$g_1 = g_2 = \cdots = g_k = 0.$$

Because the row vectors of the observability matrix

$$V = \begin{bmatrix} c_k \\ c_kF_k \\ c_kF_k^2 \\ \vdots \\ c_kF_k^{k-1} \end{bmatrix}$$

of the system in Eq. (4.26) are linearly independent, that is, the rank of V is $r(V) = k$, it follows that the currency movement system of reduced order in Eq. (4.26) is observable. QED

What is shown above indicates the fact that the currency movement system of reduced order in Eq. (4.26) has not only eigenvalues that are roughly the same as those of the original system but also such properties as controllability and observability that are difficult to confirm with the original system. All these great properties make the method of order reduction developed in this paper more advantageous and useful than any other method of order reduction available in the literature. Hence, the reduced order system, obtained in this paper, of the original currency movement system of the economic system is not only an ideal tool for countering potential currency wars but also readily acceptable by decision-makers.

4.9 Selecting the Order Reduction Vector *q*

Based on what has been presented earlier, we can see that although the reduced order system for the currency movement of the economic system, as constructed in this paper, possesses such great properties as observability, controllability, etc., its construction is based on the selection of the order reduction vector q. As a matter of fact, the selection of this vector is closely related to the purposes and the strategies of control and the preference of the strategies of the decision-makers. That is similar to the situation that when one wants to describe the stock market, he needs to select different stocks.

For example, let us look at the Dow Jones Industrial Average index, the Standard and Poor 500, and other indices of the stock markets of the United States. The Dow Jones Industrial Average is the oldest stock index of the world. It was initially started by Charles Dow, a cofounder of Dow Jones & Company, in 1884. The very first group of companies, considered in the Dow Jones Industrial Average, consisted of the stocks of 11 representative railway corporations, arithmetically averaged. Starting in 1897, the index was divided into two large classes: industrial and transportation, where the price average index for the industrial included the stocks of 12 companies, while the price average index for the transportation had stocks of 20 companies. In 1929, the Dow Jones stock price average index included additionally utilities stocks with the stocks of a total of 65 companies included. Currently, the Dow Jones stock price average index consists of four components. The first is the average of the prices of industrial stocks. The 30 representative large industrial and commercial companies included in this average could broadly reflect the price level of the entire US industrial and commercial stocks. This index is the commonly known Dow Jones Industrial Average. The second component is the price index for transportation stocks. It includes the stocks of 20 representative transportation companies, eight of which are railway transportation companies, eight airliners, and four road freight companies. The third component is the price index of utility stocks, which consists of the stocks of 15 gas companies and electricity companies. The fourth component is the comprehensive price index, which is obtained by combining the 65 stocks of the previous three components. Although this comprehensive index provides a direct representation of the quality stocks of the stock market, what is commonly cited presently is the first component – the price average index of industrial stocks.

The Standard and Poor's introduced the P&P 500 index in its current form in 1957. Initially, the index was made up of 425 industrial stocks, 15 railway stocks, and 60 utility stocks. Since July 1, 1976, the index has been composed of 400 industrial stocks, 20 transportation stocks, 40 utility stocks, and 40 financial stocks. It is calculated by using weighted average and by using 1941 and 1942 as the base period, for which the index is presumed to be 10, where the weight of a stock is determined by the stock's market capitalization. Because this index is calculated by using the prices of most of the common stocks traded on the New York Stock Exchange, it can flexibly adjust to price fluctuations caused by issuance of new shares, stock dividends, stock splits, etc. And due to its greater sample size, better representation, better continuity, and other important characteristics, when compared to the Dow Jones Industrial average, S & P 500 has been more widely used than the Dow Jones Industrial Average.

Similar to the situation that based on the characteristics of different time periods different base stocks are used to calculate the relevant index, when selecting the order reduction vector for the currency movement system, different decision-makers in different times will use different reduction order and different order reduction vector depending on their specific decision objectives. Although many aspects of the order reduction effort can vary, there are common characteristics in decision-makers' selections of their order reduction vectors. For example, all decision-makers would like to obtain their systems of reduced order to have high degrees of accuracy. So, in the following, we consider how to select an appropriate order reduction vector in order to produce a model of lower dimension with high degree of accuracy.

As a matter of fact, in the process of reducing the order of the original currency movement system, we require that the coefficient matrix c of the output vector of the original system can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$. So, a natural and simple choice for the order reduction vector q is $q = c$. However, doing so cannot guarantee that the resultant system of reduced order is of high degree of accuracy (Gao and Xu 2009). Hence, the next best method to determine the order reduction vector q is through establishing optimization models.

In order to develop an optimization model for the purpose of selecting the order reduction vector q, let us first analyze the effect of the order of the minimal polynomial of the matrix A of the original system on the order reduction vector q. Assume that the minimal polynomial of the coefficient matrix A of the state vector of the original currency movement system is $\varphi(\lambda)$ and that the order of $\varphi(\lambda)$ satisfies $\partial\varphi(\lambda) = m_1 < n$. Then, we can obtain the order reduction matrix G_{m_1} by using Eq. (4.4) so that the dimension of the reduced order system is m_1 with error 0. Of course, based on what is discussed earlier, we can also obtain reduced order models of dimension less than m_1. Hence, without loss of generality, in the following discussion, we can assume the order of the minimal polynomial $\varphi(\lambda)$ of the matrix A satisfies $\partial\varphi(\lambda) = n$.

Assume that there is a vector q such that the minimal polynomial of the coefficient matrix A of the state vector of the original currency movement system based on the vector q is $\varphi_2(\lambda)$, satisfying $\partial\varphi_2(\lambda) = m_2 < m_1 < n$. Then for any chosen positive whole number $k(k \le m_2 < m_1 < n)$, we can obtain matrix G_k through Eq. (4.12) and reduced order system (4.26) of dimension k, where the error of order reduction can be obtained by using Eq. (4.18) or Eq. (4.19).

From the previous discussions on the error of transfer functions, it follows that if the coefficient matrix c of the output vector of the original system can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$, then the error of order reduction can be decreased. So, we can determine the order reduction vector q by solving the following optimization model.

Optimization Model 1 For any chosen matrix $A \in R^{n \times n}$ such that the order of its minimal polynomial is $\partial\varphi(\lambda) = n$, any row vector $c \in R^{1 \times n}$, and any positive whole number $k(k < n)$, finds a unit row vector $q \in R^{1 \times n}$ such that c can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$. If we let

$$G_k = \begin{pmatrix} q \\ qA \\ \vdots \\ qA^{k-2} \\ qA^{k-1} \end{pmatrix} \text{ and } G_{k+1} = \begin{pmatrix} q \\ qA \\ \vdots \\ qA^{k-1} \\ qA^{k} \end{pmatrix},$$

then the unit row vector $q \in R^{1 \times n}$ also satisfies

$$\min \frac{\left|G_{k+1}G_{k+1}^T\right|}{\left|G_kG_k^T\right|}. \tag{4.32}$$

As a matter of fact, for an arbitrary linear currency movement system, the eigenvalues of the coefficient matrix of the state variable, which are also the extreme values of the system, are very important in the analysis of the system's stability. And, the real parts of different eigenvalues also play different roles in the evolution of the state vector of the currency movement. So, when it is necessary and desirable to retain some of the good properties of the original currency movement system when obtaining a reduced order system, such as keeping certain extreme values of the original currency movement system, we can construct another optimization model for producing the desirable order reduction vector q as follows.

Optimization Model 2 For any chosen matrix $A \in R^{n \times n}$ such that the order of its minimal polynomial is $\partial\varphi(\lambda) = n$, any row vector $c \in R^{1 \times n}$, and any positive whole number $k(k < n)$, assumes that $\{\lambda_0, \lambda_1, \cdots, \lambda_{k-2}, \lambda_{k-1}\}$ are the extreme values of the original system that are to be retained by the reduced order system in Eq. (4.26), satisfying

$$(\lambda-\lambda_0)(\lambda-\lambda_1)\cdots(\lambda-\lambda_{k-2})(\lambda-\lambda_{k-1})=\alpha_0+\alpha_1\lambda+\cdots+\alpha_{k-2}\lambda^{k-2}+\alpha_{k-1}\lambda^{k-1}+\lambda^k.$$

Find a unit row vector $q\in R^{1\times n}$ such that the vector c can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$ and the following equation holds true:

$$q\left(\alpha_0E+\alpha_1A+\cdots+\alpha_{k-2}A^{k-2}+\alpha_{k-1}A^{k-1}+A^k\right)=0. \tag{4.33}$$

If such a vector $q\in R^{1\times n}$, satisfying the previous condition cannot be found, then let

$$G_k=\begin{pmatrix} q \\ qA \\ \vdots \\ qA^{k-2} \\ qA^{k-1} \end{pmatrix} \text{ and } Q_{k+1}=\begin{pmatrix} c \\ q \\ qA \\ \vdots \\ qA^{k-1} \end{pmatrix}$$

and find a unit vector $q\in R^{1\times n}$ satisfying simultaneously the following two conditions:

$$\min\frac{\left|Q_{k+1}Q_{k+1}^T\right|}{\left|G_kG_k^T\right|} \tag{4.34}$$

and

$$\min\left\|q\left(\alpha_0E+\alpha_1A+\cdots+\alpha_{k-2}A^{k-2}+\alpha_{k-1}A^{k-1}+A^k\right)\right\|. \tag{4.35}$$

Although the method of system's order reduction described above is valid for systems of single input and single output, it is also as a matter of fact applicable for the order reduction of systems of multiple inputs and multiple outputs. In particular, for a multiple-input-multiple-output system, we have the following optimization model, from which we can determine the order reduction vector $q\in R^{1\times n}$ for our purpose of reducing the dimension of the original system.

Optimization Model 3 For any given matrix $A\in R^{n\times n}$, $C=\left(c_1^T, c_2^T, \cdots, c_r^T\right)$, $c_i\in R^{1\times n}(i=1,2,\cdots,r)$, and positive whole number $k(k<n)$, find a unit row vector $q\in R^{1\times n}$ such that for each vector $c_i\in R^{1\times n}(i=1,2,\cdots,r)$, qA^k can be written as a linear combination of the vectors in $\{q, qA, qA^2, \cdots, qA^{k-1}\}$. If such a vector $q\in R^{1\times n}$ that satisfies the previous two conditions simultaneously cannot be found, let

$$G_k = \begin{pmatrix} q \\ qA \\ \vdots \\ qA^{k-2} \\ qA^{k-1} \end{pmatrix} \text{ and } Q_{k+1}^i = \begin{pmatrix} c_i \\ q \\ qA \\ \vdots \\ qA^{k-1} \end{pmatrix}, (i = 1, 2, \cdots, r),$$

and find a unit vector $q \in R^{1 \times n}$ that satisfies the following two conditions simultaneously.

$$\min \frac{\left| Q_{k+1}^i \left(Q_{k+1}^i\right)^T \right|}{\left| G_k G_k^T \right|}, i = 1, 2, \cdots, r \tag{4.36}$$

and

$$\min \left\| q\left(\alpha_0 E + \alpha_1 A + \cdots + \alpha_{k-2} A^{k-2} + \alpha_{k-1} A^{k-1} + A^k\right) \right\|. \tag{4.37}$$

4.10 An Example of Application

Assume that the control-theory model of the currency movement within a regional economic system is given as follows:

$$\begin{cases} \dot{x} = \begin{pmatrix} 0 & -2 & 0 & 0 & 0 \\ 3 & -5 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2 & -2 \\ 0 & 0 & 3 & -5 & -5 \\ 0 & 0 & -7 & 6 & -1 \end{pmatrix} x + \begin{pmatrix} 1 \\ 0 \\ 2 \\ 1 \\ 5 \end{pmatrix} u \\ y = (0\ 1\ 0\ 1\ 0)x \end{cases}. \tag{4.38}$$

Then, we can obtain the eigenvalues or extreme points of the system in Eq. (4.38) as follows: −2.0000; −3.0000; −2.2654; −1.8673 ± 3.8798i.

If we like to reduce the currency movement system in Eq. (4.38) to a system of dimension 4, we will illustrate in the following the differences in the order reduction vectors q, the reduced order matrices F_4, and the corresponding errors e_4 of the resultant systems of reduced dimension. For the sake of convenience of computation, we will not unitize the chosen order reduction vectors q.

1. Let $c = q$ and $q = c$. Then the eigenvalues of the reduced order system (F_4) are −1.8712 ± 3.8885i, −2.9066, and −2.1172, where

$$F_4 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \\ -114.5963 & -116.5824 & -43.5766 & -8.7662 \end{pmatrix}, b_4 = \begin{pmatrix} 1 \\ -21 \\ 134 \\ -231 \end{pmatrix},$$
$$c_4 = (1\ 0\ 0\ 0),$$

with the controllability matrix

$$U = \begin{pmatrix} 1 & -21 & 134 & -231 \\ -21 & 134 & -231 & -1480.64 \\ 134 & -231 & -1480.64 & 9830.245 \\ -231 & -1480.64 & 9830.245 & -10078.1 \end{pmatrix}$$

the observability matrix

$$V = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

and the error $e_4 = 1.5868$.

2. Let $c = q + qA$ and $q = c(E+A)^{-1}$. Then the eigenvalues of the reduced order system (F_4) are $-1.8418 \pm 3.8974i$, -2.8541, and -2.0989, where

$$F_4 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \\ -111.3149 & -114.1033 & -42.8177 & -8.6367 \end{pmatrix}, b_4 = \begin{pmatrix} -4.05 \\ 5.05 \\ -26.05 \\ 160.05 \end{pmatrix},$$
$$c_4 = (1\ 1\ 0\ 0),$$

with the controllability matrix

$$U = \begin{pmatrix} -4.05 & 505 & -26.05 & 160.05 \\ 505 & -26.05 & 160.05 & -392.299 \\ -26.05 & 160.05 & -392.299 & -1054.55 \\ 160.05 & -392.299 & -1054.55 & 10542.72 \end{pmatrix},$$

the observability matrix

$$V = \begin{pmatrix} 1 & 0 & 0 & -111.315 \\ 1 & 1 & 0 & -114.103 \\ 0 & 1 & 1 & -42.8177 \\ 0 & 0 & 1 & -7.6367 \end{pmatrix},$$

and the error $e_4 = 1.2855$.

3. Let $c = 2q + qA - qA^2$ and $q = c(2E + A - A^2)^{-1}$. Then the eigenvalues of the reduced order system (F_4) are $-1.8289 \pm 3.8723i$, -2.8320, and -2.0941, where

$$F_4 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \\ -108.7621 & -112.0345 & -42.2887 & -8.5839 \end{pmatrix}, b_4 = \begin{pmatrix} -1.30 \\ 1.45 \\ -2.15 \\ 21.75 \end{pmatrix},$$
$$c_4 = (2\ 1\ -1\ 0),$$

with the controllability matrix

$$U = \begin{pmatrix} -1.3 & 1.45 & -2.15 & 21.75 \\ 1.45 & -2.15 & 21.75 & -116.838 \\ -2.15 & 21.75 & -116.838 & 166.3192 \\ 21.75 & -116.838 & 166.3192 & 2620.731 \end{pmatrix},$$

the observability matrix

$$V = \begin{pmatrix} 2 & 0 & 108.7621 & -208.74 \\ 1 & 6 & 112.0345 & -1929.93 \\ -1 & 6 & 44.2887 & -586.512 \\ 0 & -3 & 9.5838 & -75.9571 \end{pmatrix},$$

and the error $e_4 = 0.2946$.

4. Let $c = q + qA + qA^2 + qA^3$ and $q = c(E + A + A^2 + A^3)^{-1}$. Then the eigenvalues of the reduced order system (F_4) are -1.8687 ± 3.7945, -2.7780, and -2.0836, where

$$F_4 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \\ -103.5510 & -108.6072 & -41.8482 & -8.5990 \end{pmatrix}, b_4 = \begin{pmatrix} -1.1920 \\ 2.2294 \\ -2.8580 \\ 2.8206 \end{pmatrix},$$
$$c_4 = (1\ 1\ 1\ 1),$$

with the controllability matrix

$$U = \begin{pmatrix} -1.192 & 2.2294 & -2.858 & 2.8206 \\ 2.2294 & -2.858 & 2.8206 & -23.3483 \\ -2.858 & 2.8206 & -23.3483 & 162.2776 \\ 2.8206 & -23.3483 & 162.2776 & -428.73 \end{pmatrix},$$

the observability matrix

$$V = \begin{pmatrix} 1 & 1 & 786.884 & -2536.54 \\ 1 & 1 & 721.7551 & -1873.51 \\ 1 & 1 & 210.3973 & -303.342 \\ 1 & -262.605 & 24.4956 & -0.2404 \end{pmatrix},$$

and the error $e_4 = 0.1884$.

If we like to reduce the original system of currency movement to a three-dimensional system, then we have the following resultant three-order systems.

5. Let $c = 19q + 14qA - qA^2$ and $q = c(19E + 14A - A^2)^{-1}$. Then the eigenvalues of the reduced order system (F_3) are $-1.0417 \pm 1.9988\mathrm{i}$ and -2.2671, with

$$F_3 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 \\ -11.5178 & -9.8038 & -4.3505 \end{pmatrix}, b_3 = \begin{pmatrix} -0.3529 \\ 0.4474 \\ -1.4405 \end{pmatrix},$$
$$c_3 = (19\ 14\ -1),$$

the controllability matrix

$$U = \begin{pmatrix} -0.3529 & 0.4474 & -1.4405 \\ 0.4474 & -1.4405 & 5.9453 \\ -1.4405 & 5.9453 & -16.8957 \end{pmatrix},$$

the observability matrix

$$V = \begin{pmatrix} 19 & 11.5178 & -211.357 \\ 14 & 28.8038 & -168.387 \\ -1 & 18.3505 & -51.0301 \end{pmatrix},$$

and the error $e_3 = 1.7349$.

6. Let $c = 29q + 14qA - 2qA^2$ and $q = c(29E + 14A - 2A^2)^{-1}$. Then, the eigenvalues of the reduced order system (F_3) are $-1.5162 \pm 0.5693\mathrm{i}$ and -0.2238, with

$$F_3 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 \\ -0.5871 & -3.3016 & -3.2562 \end{pmatrix}, b_3 = \begin{pmatrix} -0.6838 \\ 1.1377 \\ -2.4515 \end{pmatrix},$$
$$c_3 = (24\ 14\ \ -2),$$

the controllability matrix

$$U = \begin{pmatrix} -0.6838 & 1.1377 & -2.4515 \\ 1.1377 & -2.4515 & 4.6278 \\ -2.4515 & 4.6278 & -7.6431 \end{pmatrix},$$

the observability matrix

$$V = \begin{pmatrix} 24 & 1.1742 & -12.0428 \\ 14 & 30.6032 & -66.5495 \\ -2 & 20.5124 & -36.1893 \end{pmatrix},$$

and the error $e_3 = 1.2808$.

7. Let $c = 90q + 14qA - 2qA^2$ and $q = c(90E + 14A - 2A^2)^{-1}$. Then, the eigenvalues of the reduced order system (F_3) are $-0.8552 \pm 2.9684\mathrm{i}$ and -3.3679, with

$$F_3 = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 \\ -32.1382 & -15.3028 & -5.0782 \end{pmatrix}, b_3 = \begin{pmatrix} 0.0672 \\ -0.2745 \\ 0.6045 \end{pmatrix},$$
$$c_3 = (90\ 14\ -2),$$

the controllability matrix

$$U = \begin{pmatrix} 0.0672 & -0.2745 & 0.6045 \\ -0.2745 & 0.6045 & -1.0288 \\ 0.6045 & -1.0288 & -4.7961 \end{pmatrix},$$

the observability matrix

$$V = \begin{pmatrix} 90 & 64.2764 & -776.343 \\ 14 & 120.6056 & -305.384 \\ -2 & 24.154 & -2.0654 \end{pmatrix},$$

and the error $e_3 = 0.6469$.

From the results of the previous reduced order systems of the original control-theory model of currency movement within an economic system in Eq. (4.38), it follows that for a given order k of reduction, different choice of the order reduction vector q leads to a different system of the desired dimension with different error of approximation. For example, when the system in Eq. (4.38) is reduced to one of dimension 4 and if the order reduction vector is $q = c$, that is, the results in case analysis (1), then the error of approximation of the reduced order system is the maximum among all the reduced order systems. This result confirms what is predicted in the analysis of the previous sections of this chapter. When comparing the reduced third-order system in case analysis (7) with those of the reduced fourth-order systems in case analyses in (1) and (2), it follows that if an adequate order reduction vector q can be found, one cannot only reduce the original system into a much lower dimensional system of order k but also obtain a much more adequate reduced order system with small error e. Of course, in terms of the decision-makers of monetary and fiscal policies, it is much easier for them to design control strategies for a third-order system than a fourth-order system, while it is also much easier to directly observe and measure the effects of their policies adopted for a third-order system than those of a fourth-order system.

4.11 Conclusions

As a symbol of wealth, money has become not only a legal means to acquire the fruits of labor of other people but also a financial weapon that can be employed to "attack" a nation or a geographic region (Forrest 2014). Just as what was said by Sun Tze in his well-received military book, *The Art of War* (Duncan Baird, III Rep Edition, 2012): before troops and horses start to move, supplies are mobilized first. That means that a nonstopping supply of military materials is the foundation for launching and sustaining a conventional war and that the stability of the financial market of a modern economic system is the foundation for the nation or region to counter potential conflicts and disputes. Hence, if at the very moment when a potential conflict or dispute starts to occur, the financial system of the attacking party could be made unstable so that it loses the "supplies" necessary for launching the perceived conflict or dispute, and then the conflict or dispute could be avoided at least temporarily. Additionally, although not every nation would employ the means of currency war to resolve conflicts or disputes with other countries, each nation and region should still be prepared for such a possibility that a hostile entity could launch a currency war against the nation.

That is, when it is confirmed that a hostile entity has launched a financial or currency war, how to effectively counter the attack has become a challenge facing the national monetary authority and financial markets. Based on this logic of thinking, this chapter provides a method on how to construct a theoretical representation for the system of currency movement within an economy. However, considering the complexity involved in the established system, if the system completely describes the realistic movement of money, there is a natural need to simplify the system by lowering its dimension to a manageable level. To this end, this chapter provides a detailed method on how to reduce the order of the established system of currency movement with the basic characteristics of the original system kept. Because the system of reduced order still has the good properties of the general control system, such as controllability and observability, this chapter provides an ideal tool for decision-makers to design effective strategies to counter potential currency wars so that the initial passive defense of the economic system that is under siege could be transformed to an active defense.

Similar to the existence of many tools available for financial and/or investment decision-making, there are also many different tools that could be employed to design strategies to counter potential currency wars. What is presented in this chapter represents only one of such tools and is a piece of fundamental research. What is left open for future consideration includes the analysis of what properties of the available tools could produce the stable effect of self-defense.

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Chapter 5
Estimating the State of Economy Through Observers

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Contents

The reality of an economic system is very complicated. Any efficient regulation of the economy requires constantly updating the knowledge regarding the state of the economic development. However, many aspects of the economy are not easily observable and/or not readily measurable. This chapter addresses the problem of how the policy maker could reliably reconstruct the unobservable and

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immeasurable state variables of the economy by using various state feedback and output feedback mechanisms.

By using methods of systems thinking and control theory, this chapter looks at how to design and use state observers, how state observers can be attached to feedback controllers, and how dynamic compensators can be employed to develop meaningful economic policies in order to make the economic performance approach the desired targets.

The complexity of economic systems makes it impossible for policy makers to fully understand the evolution of economic performance indices. That makes the characteristics of the economic system indeterminate and requires policy makers to renew their understanding of the objects of regulation through repeated measurements of their reconstructed system. By doing so, they will adjust their adopted policies in order to make the performance of the economy approach the desired optimality. To this end, this chapter reveals its theoretical and practical significance.

5.1 Introduction

Stable development of the economic system, especially, the stable development of the currency system, is the foundation for the healthy operation of the economy. Hence, the policy makers always have certain particular requirements regarding some of the characteristics of the economic system, such as the stability of the economic system, an orderly operation of the economy, etc. However, because each economy tends to be open and interact with the outside world, that makes the economic operation of the system often disturbed by various factors from different angles, causing it very difficult for the evolution of the economic system to meet the expected demands of the policy makers. Therefore, the policy makers need to adjust the control variables of the economic system to offset or eliminate the interferences of the outside world on the originally orderly operating economy so that the state of economic operation would possibly reach the expected outcomes. Currently, the most commonly employed method is to design feedback control rules of some particular form to guarantee that the resultant closed-loop economy will possess the expected characteristics. For example, William Phillips in 1954 published an article, entitled "stabilization policy in a closed economy," and in 1957 published another article, entitled "stabilisation policy and the time-forms of lagged responses," in The Economic Journal of Royal Economic Society. These two articles reflected Keynesian policy method for economic adjustments by using the control theory's block diagrams with time delay and pointed out that in order to effectively and stably regulate the economic system, one has to employ a PID controller on the expenditure of the government applied to adjust the economy.

As a matter of fact, among all the control strategies developed for economic systems, the feedback control methods consist mainly of state feedback strategies and output feedback strategies, where the information of the state variables and output variables of the economic system is respectively employed. In the existing literature, all the solutions to the problem of economic control, such as the pole placement, asymptotic tracking, disturbance repression, optimal control of linear quadratic forms, etc., are materialized through employing the state feedback of the economic system. This fact shows the superiority of state feedback strategies. However, by state it represents a group of variables that are endogenous to the economic system. Because some of the state variables cannot be directly measured, or because some of the measurements of these state variables are limited in terms of practical use and feasibility, the real-life application of most state feedbacks of the economic system becomes either difficult or impossible to materialize. Therefore, we face a dilemma between the irreplaceable nature of state feedbacks of the economic system and the practical difficulty of implementation. One way to get around this dilemma is to reconstruct the state of the economic system and then to materialize the state feedback of the economic system, as demanded by the policy makers of the economic system, by substituting the actual state of the economic system by the reconstructed state. Hence, how to successfully construct an observer of the system's state and how to estimate the unknown state variables of the economic system with relative accuracy become an important problem in the study of effective management of the economic system.

The theory of observers was initiated and developed for exactly the purpose of revolving the afore-described dilemma between the characteristic irreplaceability of state feedbacks of economic systems and the difficulty of implementation of such feedbacks. In the early 1960s, Luenberger (1964) was the first to introduce the concept of state observers and to establish ways to construct these observers so that he successfully resolved the problem of being unable to make direct measurement of the state variables by employing the idea of reconstructing the state variables. Specifically speaking, designing an observer of the economic system, or known as the reconstruction of the state, is to reconstruct an economic system by making use of the directly measurable information of the original system, such as the input and output, as the input information of the new system so that under a set of rules the output information of the newly reconstructed system is equivalent to the state of the original system. This new system that is used to reconstruct the immeasurable state is referred to as an observer of the original economic system. In other words, each observer of the economic system is a dynamic model that produces estimates for the variables that cannot be practically measured directly based on what can be actually measured out of the original system. As a matter of fact, since Luenberger (1964) first studied the design of observers of linear systems, the investigations along this line have been becoming more mature and complete; and the relevant results have been widely employed in the studies of the control problems of economic systems for estimating the known information (Sadaka et al. 2009; Fu et al. 2004; Hao 2006; Cui and Zhang 2008; Darouach 2009).

Observers of economic systems can be classified into two categories in terms of their functionalities: state observers and functional observers. If an observer's output becomes asymptotically equivalent to the state of the original system, then the observer is known as a state observer. If the output of the observer is asymptotically becoming equivalent to a function of the state of the original system, then the observer is known as a functional observer. Generally speaking, the dimension of a functional observer of the original economic system is lower than that of a state observer. And for state observers, they can further be divided based on their structures into either full order observers or lower-order observers. If the dimension of an observer is the same as the original system, then the observer is known as full order; and if the dimension of the observer is smaller than that of the original system, then the observer is known as lower order. Evidently, in terms of their structures, lower-order observers tend to be simpler than full order observers. Based on the deep theoretical understanding of observers, more attention has been devoted to the study of the feedback control problem by using observers (Franks 2009; Chen and Patton 1999; Yang and Liu 2009; Li et al. 2008; Darouach 2009). By feedback control based on observers, it means that on top of an available observer, we design a rule of feedback control so that the system of concern becomes stable and possesses some other desirable properties (Chen and Wang 2000; Wang et al. 2005). The essence here is to construct a controller that can guarantee the stability of the closed-loop economic system, while some of the indices of the economic system are smaller or equal to some pre-determined threshold values.

In the control-theory model of the actual economic system, experiencing external disturbances and containing indeterminate factors are unavoidable. So, the problem of how to maintain the system's stability under the influence of external disturbances and endogenous uncertainties, while making sure that the system also satisfies certain requirements of performance, has caught a major attention in the world of learning. In other words, a major attention has been directed to the study of how to control the indeterminate, dynamic economic system that is at the same time disturbed by the outside environment. Evidently, if it is possible to efficiently estimate the disturbance, it would become easier for us to design an effective controller for the economic system. For example, by accurately estimating the disturbance, we can readily construct a state observer and controller that can effectively cancel the disturbance. In fact, if an observer can also simultaneously estimate the factors of uncertainty, then the observer is referred to as an adaptive observer or a robust observer (Carroll and Lindorff 1973).

For a linear economic system, its adaptive observer can be described by using a first-order differential equation based on the input and output information of the system, where the parameters can be adjusted. After having produced the adaptive/state estimate law, it can guarantee that the state error equation is uniformly stable at the origin if no further conditions are imposed on the system. If the economic system is stable, then it can guarantee that the estimation error of the state will converge to zero. The parameters of the observer can also be adjusted by using the law of stable adjustment so that the error between the outputs of the observer and the system converges to zero.

Because the evolution of the actual economic system is affected by many variables, various kinds of nonlinearity, variations of time, different forms of uncertainties, and many other characteristics, and because practical applications of theoretical control have to consider such factors as timeliness, effectiveness, economy, and others, many complicated computational schemes of modern control theory, developed on the optimization of performance indices by using mathematical models, cannot be readily and effectively employed to the study of complex economic systems. In order to overcome the aforementioned inconsistency between theory and practice, considering the evolutionary characteristics of economic systems, people have looked at such methods that without requiring accurate theoretical modeling, they still provide high-quality controls. They are methods of control based on predictions. The technique of predictive control was initially proposed by Richalet (1978). It considers the practical needs of economic policy decision-making and produces good results. Because of this reason, significant progress has been made in terms of its theory and applications, and various new computational schemes of predictive control are developed continuously. However, in many control problems of the actual economy, the complexity of the objects of control and the existence of various uncertainties have adversely affected the effectiveness of the control system. That indicates that in the design of the control system, there is an absolute need to consider systemic uncertainties. In the 1990s, some methods of robust control were introduced into predictive control. Such a method that deals with the uncertainty of the modeling within the framework of predictive control such that the controlled system reaches asymptotic stability is referred to as robust predictive control (Zafiriou 1990). This method combines the advantages of how robust control deals with uncertainties and of the rolling optimization of predictive control and leads to a whole series of computational control schemes that possess great robustness, operational feasibility, and tracking performance.

Because of the complexity inherently existing with economic systems, it makes it difficult for decision makers to fully understand the evolution of the state variables. That is, the decision makers do not entirely grasp the characteristics of the economy. In other words, the characteristics of the economic system are indeterminate. Under such circumstances, ordinary methods of regulation would not generally reach their expected results. Therefore, within the operational process of the control system, the decision maker has to renew his/her understanding and grasping of the objects of control through repeated measurements of the characteristics of the objects from the angle of the reconstructed system. Based on the renewed knowledge of the objects of control, and by comparing what is newly observed with the expected characteristics, he/she will adjust his/her adopted economic policies so that the performance of the economy will reach or approach the desired optimality according to the pre-determined standards. Therefore, only by accurately reconstructing the state variables of the economic system in order to asymptotically approach the original system's state variables, the decision maker can materialize his/her expected outcome. In the following, we will provide a detailed procedure and method on how to reconstruct an economic system.

This chapter is organized as follows: In Sect. 2, after introducing the challenge of observing and measuring the performance of an economy, we look at the problem of how to design state observers. In Sect. 3, we formally post the problem of importance and establish our main result. Section 4 investigates a method of how to design observers. Section 5 looks at how to lower the order of observers.

Section 6 looks at the problem of how to determine the location of the observer's poles. And this chapter is concluded in Sect. 7.

5.2 Design of Observers

A so-called shadow economy, also known as a underground economy, stands for the totality of all the economic activities that are not registered with the government, do not pay income taxes, and whose outputs and incomes are not considered in the calculation of the gross domestic product (GDP). These activities are not under the surveillance of the government. However, the design and adaptation of macroeconomic policies of the economic system depend on truthful and reliable economic data. So, the existence of the shadow economy affects the accuracy of the relevant data of the economic system, leading to inappropriate macroeconomic regulation, which might very well lead to the breakout of a potential financial crisis.

To manage the inflation for the purpose of maintaining the stability of the general price level, the government attempts to sustain the monetary balance between the supply and demand of the economy by regulating the money supply. However, with the existence of the underground economy, the observed GDP, the rate of unemployment, the amount of money in circulation, the actual income level, the scale of import and export, and other economic data lose their accuracy (Feige 1989). In particular, with the existence of the shadow economy, the unemployment rate tends to be estimated too high, the economic growth estimated too low so that the government's selection of economic policies is affected, and so do the behaviors of the private economic sectors, leading to the possibility of incorrectly adopting an expansionary policy based on the overestimate of unemployment and underestimate of the economic growth. For example, many economies currently face the challenge of many underground economic activities, such as smuggling foreign goods, false imports designed to cheat the foreign exchange, statistically unregulated border trades, and illegal business transactions (such as illegal gambling, drug dealings, etc.). The existence of these underground behaviors requires huge amounts of money. This demand for money represents a major unobserved factor affecting the adaptation of relevant economic policies. Because of the major leak of money under these illegal factors, the documented amount of money in circulation can no longer be reliably employed as the basis for introducing monetary policies.

In addition, because of the existence of the underground economy, the government's tax revenue is reduced, making the fiscal deficit much greater than it should be. In order to offset the losses incurred in the tax collection and consequent revenue shortfalls, while not causing inflation to go higher, the government might issue bonds to the public. When the scale of the government debts reaches such a level that starts to create the crowding-out effect and that necessitates the need to raise interest rate, the capital equilibrium level will be lowered, the demand for labor will be weakened, and the rate of unemployment will go up further. If the government increases the payment of unemployment benefits, the fiscal deficit will increase further, which in turn causes the credit market to tighten. When relying on issuing national debts and external borrowing to make up the fiscal deficit, the amount of debts will grow larger as quickly as rolling a snowball down the snow-covered hill. For example, at the end of June 1998, Russia had the domestic debt balance of US$70 billion, foreign debt US$130 billion, which totaled to 45% of the then GDP. Additionally, because of the absence of the government tax revenue, the fiscal gap of the government reached 1.9 times the actually budgeted revenue. Eventually the government lost its solvency, causing a credit crisis and market panic that led to the breakout of a major financial crisis (Peng et al. 2011). From this example, it can be seen readily that the false information, as caused by the shadow economy, could disturb the normal order of the economic management system, lead to economic chaos and consequent severe financial crisis.

The underground economy can also cause the foreign exchange rate to fluctuate, which in turn brings forward substantial impacts onto the economic system. For example, before the euro started to circulate within the Eurozone, some participants of the underground economy and people who held the currencies of the member nations of the Eurozone but lived outside the Eurozone rushed to trade their individually held member nation currencies into the US dollar. It was because effective on a pre-determined date, in order to prevent money laundry and other illegal activities, the European Union required all banks to keep a detailed identity record of all those who exchanged large amounts of money; while they were afraid that their illegal gains and identities could be revealed when exchanging their gains into the then-new euro, so these people exchanged their currency holdings into the US dollar before the euro started to circulate. The statistics indicate that at that time, the value added by the European underground economy, which mainly consisted of Russia and nations of the Eastern Europe, would be about 16% of the GDP of the entire Eurozone; the amount of currencies that were in the circulation of the underground economy amounted to about 14% of the total money supply of the Eurozone, reaching the level of around €50 billion. All the other people who also held currencies of the European nations were mainly from Eastern European nations and Turkey; and their European currency holdings reached the level of around €30 billion. These people did not know how euro would operate except they knew that individual national currencies would be eliminated and replaced with a new currency, known as euro. In order to avoid potential losses, they converted their European Union member nation currencies into a visible and tangible international currency, such as the US dollar. When these two figures were added together, the sum is more than ten times of the amount of euro that was used by the European Central Bank in its intervention in the foreign exchange market in 2014. It is also more than ten times of the amount of the US dollars used during the 1992 European currency system crisis, which eventually caused the British pound and Italian lira to leave the European Exchange Rate System and created severe consequences for the economies of the European nations (Xie 2008).

In the area of finance, because the wealth accumulated through activities of the shadow economy is considered illegal, the owners of the wealth are afraid of being followed and their wealth being seized by the government. The vested interests try to move their wealth to a foreign land either regularly or in the event of a domestic political and economic turbulence. Capital flight not only exacerbates the problem of monetary shortage within the economic system but also makes it more difficult for the economic system to balance the international payments, causing the exchange rate of the domestic currency to decline, which might very well lead to the breakout of a financial crisis. On the other hand, the shadow economy results in large amounts of capital to circulate outside the economic system, where the capital either maintains within the economic system in the form of shadow or returns back into the economic system after flight in the form of false foreign investment. All these capital behaviors not only create huge tax revenue and fiscal losses but also seriously interfere the normal financial order; they aggravate the degree of economic chaos within the economic system. In fact, in the year of 1998, when the activities in Russian shadow economy were most vigorous, the underground economy reached as high as 45% of the visible economy (Peng et al. 2011). So, from a certain angle, we could claim that the breakout of the 1998 Russian financial crisis was the disastrous consequence of "shadow economy."

As a matter of fact, almost all nations from the world more or less suffer from their respective "shadow economies." For the Western developed nations, the proportion of their shadow economies amount to about 10%. For example, the proportion for the United States is about 8%, Japan around 11%, and developing nations about 15% (Buehn and Schneider 2012). Hence, it is natural to believe that underground economy exists universally, distorts the transmission of macroeconomic information of the economic system, adversely affects the development of national macroeconomic policies, and weakens the effects of macroscopic regulations while increasing the difficulty of macroscopic control of the economic system. However, because of the hidden nature of the underground economy, it makes it difficult to observe the variables that are introduced to describe the shadow economy. For example, the size of the shadow economy is difficult to measure accurately. To improve the observation of the shadow economy for the purpose of better implementation of monetary and fiscal policies in order to materialize the expected goal of regulation, we have to make use of the tools and methods of relevant scientific disciplines. The concept of observers studied in control theory, one of such relevant disciplines, provides us a very good and practically meaningful way of observing and predicting the important variables that are difficult to perceive and to measure due to their connection to the shadow economy, shadow banking, etc.

5.3 The Problem and a Fundamental Theorem

As mentioned earlier, when not all the state variables of the economic system can be employed in feedback, we can design output feedback controllers. However, there are scenarios in real life where no output feedback can meet the requirements of design. In this case, we can design an observer to estimate the system's state. After that, we employ the estimate state as the actual state of the state in our feedback design.

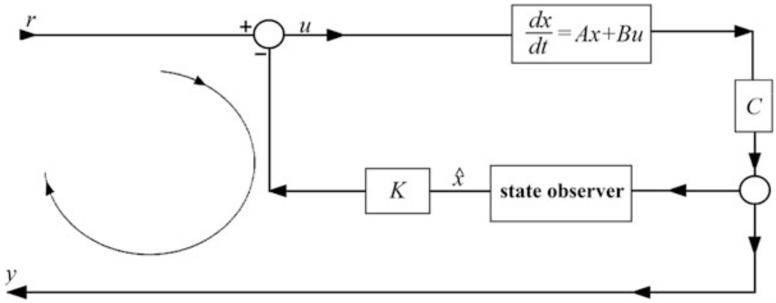

Fig. 5.1 A diagram for observers

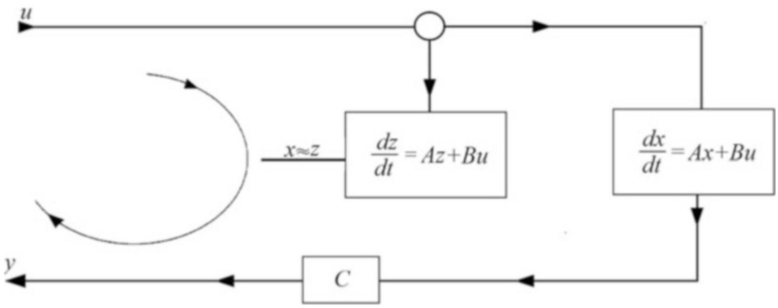

Fig. 5.2 An open-loop observer

Given a constant coefficient linear system

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \end{cases}. \tag{5.1}$$

An observer produces an estimate of the state of the system based on the input u and the output y (Fig. 5.1 shows how this concept works). Any observer is also known as a state estimator or state reconstructor.

A simplest state observer is a reconstructed system with the same state equation as the original economic system while its state can be directly measured. The idea here is to construct a model for the original economic system so that its state can be measured, see Fig. 5.2 for its schematic diagram. The observer shown in Fig. 5.2 is known as open-loop, because it cannot modify its estimate of the state based on the estimation error. To overcome this weakness, let us design a closed-loop observer so that the accuracy of estimation can be improved because the observer can modify its estimate of the state based on the estimation error. Figure 5.3 shows how a closed-loop observer looks like.

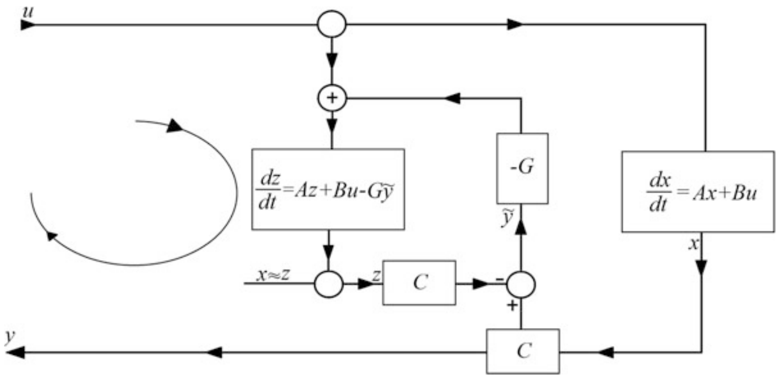

Fig. 5.3 A closed-loop observer

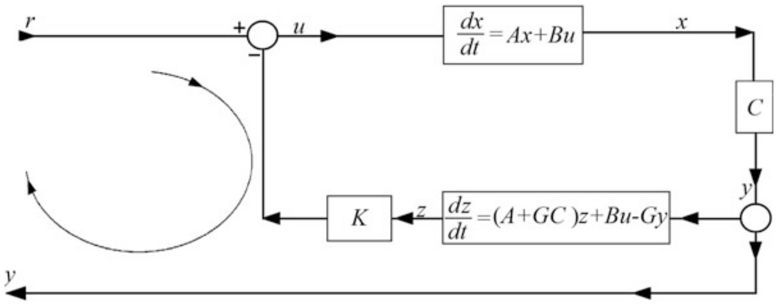

Fig. 5.4 A feedback controller with an observer

Because

$$\frac{dz}{dt} = Az + Bu - G\tilde{y} = Az + Bu - G(y - Cz) = Az + Bu + GCz - Gy,$$

the equation of our observer becomes

$$\frac{dz}{dt} = (A + GC)z + Bu - Gy. \tag{5.2}$$

So, Fig. 5.1 is specified into that shown in Fig. 5.4.

The problem of how to design the observer as given in Eq. (5.2) is about how to choose matrix G so that $z(t)$ can be used as an asymptotic estimate of $x(t)$. That is, we need to choose G such that

$$\lim_{t\to\infty} (z(t) - x(t)) = 0$$

based on Eq. (5.2) of the observer and the following state equation

$$\frac{d(z(t)-x(t))}{dt}=(A+GC)z-Ax-GCx=(A+GC)(z(t)-x(t)).$$

That implies that when $A+GC$ is a stable matrix, Eq. (5.2) provides an observer of the original economic system.

For practical purposes, when designing the observer, we require not only that the matrix $A+GC$ be stable but also that $z(t)-x(t)$ approaches zero quickly. Specifically, we need to place the poles of $A+GC$ at appropriate locations on the open left side of the complex plane.

In the following, we discuss the problem that under what conditions, there is G such that the poles of $A+GC$ can be arbitrarily placed. To this end, let us consider the following dual system of the original economic system:

$$\begin{cases}\dfrac{dx}{dt}=A^Tx+C^Tu\\ y=B^Tx\end{cases}.$$

We already know that a sufficient and necessary condition for the existence of K such that the poles of $A+BK$ can be arbitrarily placed is that (A,B) is completely controllable. Now, the ability to arbitrarily place the poles of $A+GC$ is equivalent to the capability to arbitrarily place the poles of $(A+GC)^T$, which is equivalent to the statement that there is G^T such that $A^T+G^TC^T$ has poles at pre-determined locations. So, the desired sufficient and necessary condition is that (A^T,C^T) is completely controllable. Hence, from the principle of duality, it follows that we have obtained the following result.

Theorem 5.1 The system in Eq. (5.1) has an observer of the following form:

$$\frac{dz}{dt}=(A+GC)z+Bu-Gy.$$

And, a sufficient and necessary condition for the ability to arbitrarily place the poles of the observer is that (C,A) is completely observable.

If (A^T,C^T) is stabilizable, we say that (C,A) is detectable. Now, if we do not need to arbitrarily place the poles of the observer, then a sufficient and necessary condition for the system in Eq. (5.1) to have an observer is that is detectable.

5.4 Method of Observer Design

Because the problem of designing an observer is equivalent to that of solving for G^T such that $A^T+G^TC^T$ has pre-determined poles (located on the open left plane), this is exactly the problem of how to place poles discussed earlier. Therefore, we have the following particular method of designing observers.

Step 1: Let $C^T = \left[c_1^T \ c_2^T \ \cdots \ c_r^T\right]$. Construct the following matrices:

$$R = \left[c_1^T \ A^T c_1^T \ \cdots \ A^{T\mu_1 - 1} c_1^T; \ \cdots; \ c_{r-1}^T \ A^T c_{r-1}^T \ \cdots \ A^{T\mu_r - 1} c_{r-1}^T; \ c_r^T \ A^T c_r^T \ \cdots \ A^{T\mu_r - 1} c_r^T\right]$$

$$W = \ [0\cdots0 \qquad \underset{(\mu_1 + \cdots + \mu_{r-1})\text{th column}}{e_2} \qquad ;0\cdots0 \qquad \underset{r\text{th column}}{e_r} \qquad ;0\cdots0 \qquad 0;]$$

where e_i stands for the ith column of the identity matrix of order r, and compute $\hat{G} = \left(WR^{-1}\right)^T + G^T C^T$.

Step 2: Calculate $\bar{A}^T = A^T + C^T \hat{G}^T$ and its characteristic polynomial

$\mid sI - \bar{A}^T \mid = s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0.$

Step 3: For the given n poles $\lambda_1, \cdots \lambda_n$ of the observer, calculate the polynomial

$$(s - \lambda_1)\cdots(s - \lambda_n) = s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0$$

and

$$g^T = [a_0 - \alpha_0, a_1 - \alpha_1, \cdots, a_{n-1} - \alpha_{n-1}].$$

Step 4: Calculate $\tilde{g} = g^T T^{-1}$, where

$$T^{-1} = \begin{bmatrix} q \\ q\bar{A} \\ \vdots \\ q\bar{A}^{n-1} \end{bmatrix}$$

and q is the last row of the inverse of the controllability matrix of $\left(\bar{A}^T, c_1^T\right)$.

Step 5: Calculate

$$G^T = \hat{G}^T + \begin{bmatrix} \tilde{g}^T \\ 0 \end{bmatrix}$$

which is what is desired.

Example 5.1 Assume that the control-theory model of an economy is

$$\frac{dx}{dt} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 2 \\ 0 & 0 & 0 \end{bmatrix} x + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} x.$$

Design an observer

$$\frac{dz}{dt} = (A + GC)z + Bu - Gy$$

such that its poles are -1, -1, and -2.

Solution It is straightforward to check that this given system is completely observable.

Step 1: We construct the following matrices:

$$k = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix} \text{ and } W = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

and calculate

$$\hat{G} = \left(R^T\right)^{-1} + W^T = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}.$$

Step 2: We compute

$$\bar{A}^T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 1 & 2 & 0 \end{bmatrix}$$

and its characteristic polynomial

$$\mid sI - \bar{A}^T \mid = s^3 - 2s^2 - s + 2.$$

Step 3: For $\lambda_1 = -1$, $\lambda_2 = -1$, $\lambda_3 = -2$, we compute the polynomial

$$(s+1)(s+1)(s+2) = s^3 + 4s^2 + 5s + 2$$

and $g^T = [0, -6, -6]$.

Step 4: The controllability matrix of $\left(\bar{A}^T, c_1^T\right)$ is

$$\begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}.$$

And the last row of its inverse matrix is $q = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix}$. Because

$$T^{-1} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 3 & 1 \end{bmatrix},$$

we have

$$\tilde{g}^T = g^T T^{-1} = \begin{bmatrix} -6 & -24 & -12 \end{bmatrix}.$$

Step 5: We obtain

$$G^T = \hat{G} + \begin{bmatrix} \tilde{g} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} -6 & 0 \\ -24 & 0 \\ -12 & 0 \end{bmatrix} = \begin{bmatrix} -6 & 0 \\ -24 & 0 \\ -12 & 1 \end{bmatrix}.$$

So, the desired observer is

$$\frac{dz}{dt} = \begin{bmatrix} -5 & 0 & 1 \\ -24 & 1 & 2 \\ -12 & 1 & 0 \end{bmatrix} z + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} u + \begin{bmatrix} 6 & 0 \\ 24 & 0 \\ 12 & 1 \end{bmatrix} y.$$

5.5 Observers of Lower Order

In the previous paragraphs, the order of the observer designed in Eq. (5.2) is equal to that of the original system. That is why the observer is known as full order. For most economic systems, some of the state variables can be used in the feedback operation. So, these state variables do not need to be estimated. In this case, we only need to design lower-order observers. For an economic system with r-dimensional output, there are r output variables that can be directly measured by using established methods. However, for linear economic systems, each output variable is a linear combination of the state variables. If we can use a linear transformation to make each output variable representable by a single state variable, then the r state variables are not to be estimated through any observer. In this case, we only need to estimate the remaining $(n - r)$ state variables. The observer designed for this purpose is known as an $(n - r)$ dimensional observer. It is an $(n - r)$ dimensional subsystem with much simpler structure than the original economic system; and its state equation can be derived by employing the transformation used earlier on the controlled system. Generally speaking, in the constant coefficient linear system in Eq. (5.1), assume the rank of the matrix C satisfies $r < n$. Then, there is a transformation that makes the output of the system be part of the state variables. That is, the transformation helps to rewrite the system as follows:

$$\begin{cases} \dfrac{dx'}{dt} = \begin{bmatrix} \dfrac{dx_1}{dt} \\ \dfrac{dx_2}{dt} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} u \\ y = [0 \quad I] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = x_2 \end{cases}. \tag{5.3}$$

That is, we only need to design an $(n-r)$ order observer to estimate the $(n-r)$ dimensional sub-vector x_1 of the state.

Let us take the transformation that changes the system in Eq. (5.1) into that in Eq. (5.3) as follows:

$$x' = Qx = \begin{bmatrix} D \\ C \end{bmatrix} x \tag{5.4}$$

where matrix D can be selected arbitrarily as long as matrix Q is invertible.

Because

$$[0 \quad I]Q = [0 \quad I] \begin{bmatrix} D \\ C \end{bmatrix},$$

we have

$$CQ^{-1} = [0 \quad I]$$

so that with the transformation in Eq. (5.4), the system in Eq. (5.1) is rewritten as that in Eq. (5.3).

In order to design an observer to estimate the state x_1, let us consider the subsystem:

$$\begin{cases} \dfrac{dx_1}{dt} = A_{11}x_1 + v \\ \bar{y} = A_{21}x_1 \end{cases} \tag{5.5}$$

where

$$v = A_{12}x_2 + B_1u = A_{12}y + B_1u \tag{5.6}$$

$$\bar{y} = \frac{dx_2}{dt} - A_{22}x_2 - B_2u = \frac{dy}{dt} - A_{22}y - B_2u. \tag{5.7}$$

Lemma 5.1 If the system in Eq. (5.3) is completely observable, then the system in Eq. (5.5) is also completely observable.

Proof Because the system in Eq. (5.5) is completely observable, we have

$$\operatorname{rank}\begin{bmatrix} 0 & I_r \\ A_{21} & A_{22} \\ A_{21}A_{11}+A_{22}A_{21} & A_{21}A_{11}+A_{22}^2 \\ \vdots & \vdots \end{bmatrix} = \operatorname{rank}\begin{bmatrix} 0 & I_r \\ A_{21} & 0 \\ A_{21}A_{11}+A_{22}A_{21} & 0 \\ \vdots & \vdots \end{bmatrix}$$

$$= \operatorname{rank}\begin{bmatrix} 0 & I_r \\ A_{21} & 0 \\ A_{21}A_{11} & 0 \\ \vdots & \vdots \end{bmatrix} = n.$$

So, we have

$$\operatorname{rank}\begin{bmatrix} A_{21} \\ A_{21}A_{11} \\ A_{21}A_{11}^2 \\ \vdots \\ A_{21}A_{11}^{n-2} \end{bmatrix} = n-r. \text{ That is, rank}\begin{bmatrix} A_{21} \\ A_{21}A_{11} \\ A_{21}A_{11}^2 \\ \vdots \\ A_{21}A_{11}^{n-r-1} \end{bmatrix} = n-r.$$

Therefore, A_{21}, A_{11} is completely observable. QED

Similarly, we can also prove that if the system in Eq. (5.3) is detectable, then the system in Eq. (5.5) is also detectable.

Because regular linear transformations do not alter the observability of a system, if the system in Eq. (5.1) is observable, then the system in Eq. (5.3) is also observable. Now, Lemma 5.1 implies that the system in Eq. (5.5) is observable. So, we can design an $(n-r)$ order observer as follows:

$$\frac{dz}{dt} = (A_{11}+GA_{21})z + v - G\bar{y}$$

or

$$\frac{dz}{dt} = (A_{11}+GA_{21})z + A_{12}y + B_1u - G\left(\frac{dy}{dt} - A_{22}y - B_2u\right)$$

so that $A_{11}+GA_{21}$ has the $n-r$ pre-determined poles. Hence, our estimate of the state vector is

$$\hat{x} = \begin{bmatrix} z \\ y \end{bmatrix} = \begin{bmatrix} z \\ x_2 \end{bmatrix}.$$

Because in the observer there appears $\frac{dy}{dt}$, which is not convenient in applications, we like to get rid of it. To this end, let us use the following transformation:

$$w = z + Gy.$$

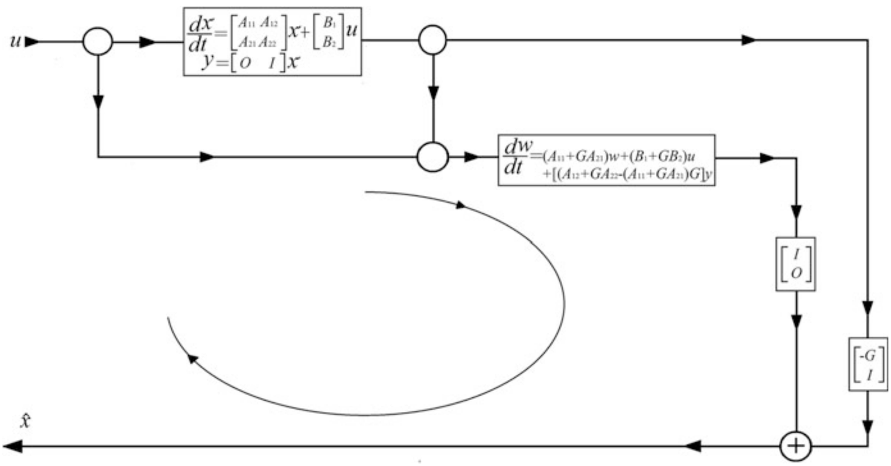

Fig. 5.5 A lower-order observer

So, the observer is simplified as follows:

$$\begin{aligned}\frac{dw}{dt}=\frac{dz}{dt}+G\frac{dy}{dt}&=(A_{11}+GA_{21})w+(B_1+GB_2)u\\&+[A_{12}+GA_{22}-(A_{11}+GA_{21})G]y.\end{aligned}\tag{5.8}$$

For now, the estimate is

$$\hat{x}=\begin{bmatrix}z\\y\end{bmatrix}=\begin{bmatrix}w-Gy\\y\end{bmatrix}=\begin{bmatrix}I\\0\end{bmatrix}w+\begin{bmatrix}-G\\I\end{bmatrix}y.\tag{5.9}$$

For the observation of the state, please see the diagram in Fig. 5.5.

Example 5.2 Assume that the control-theory model of an economy is given as follows:

$$\frac{dx}{dt}=\begin{bmatrix}0&1&0&0\\0&0&-1&0\\0&0&0&1\\0&0&11&0\end{bmatrix}x+\begin{bmatrix}0\\1\\0\\-1\end{bmatrix}u$$
$$y=[1\quad 0\quad 0\quad 0]x.$$

Design a lower-order observer so that it has the following three poles: -3, $-2\pm i$.

Solution First of all, let us rewrite the given system in the form given in Eq. (5.3):

$$\frac{d}{dt}\begin{bmatrix} x_2 \\ x_3 \\ x_4 \\ x_1 \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 11 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} x_2 \\ x_3 \\ x_4 \\ x_1 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ -1 \\ 0 \end{bmatrix}u$$

$$y = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} x_2 \\ x_3 \\ x_4 \\ x_1 \end{bmatrix}.$$

For this system, we have

$$B_1 = \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}, B_2 = 0, A_{11} = \begin{bmatrix} 0 & -1 & 0 \\ 0 & 0 & 1 \\ 0 & 11 & 0 \end{bmatrix}, A_{21} = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, A_{12} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, A_{22} = 0.$$

And the lower-order observer as given in Eq. (5.8) becomes

$$\frac{dw}{dt} = (A_{11} + GA_{21})w + B_1u - (A_{11} + GA_{21})Gy. \tag{5.10}$$

The problem of designing the desired observer is to find G such that $A_{11} + GA_{21}$ has poles -3, $-2 \pm i$. After going through all the detailed calculations, which are omitted here, we get

$$G = \begin{bmatrix} -7 \\ 28 \\ 92 \end{bmatrix}.$$

By substituting B_1, A_{11}, A_{21}, G into Eq. (5.10), we obtain

$$\frac{dw}{dt} = \begin{bmatrix} -7 & -1 & 0 \\ 28 & 0 & 1 \\ 92 & 11 & 0 \end{bmatrix}w + \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}u + \begin{bmatrix} -21 \\ 104 \\ 336 \end{bmatrix}y,$$

$$\hat{x} = \begin{bmatrix} I \\ 0 \end{bmatrix}w + \begin{bmatrix} -G \\ I \end{bmatrix}y = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}w + \begin{bmatrix} 7 \\ -28 \\ -92 \\ 1 \end{bmatrix}y.$$

That is our desired lower-order observer.

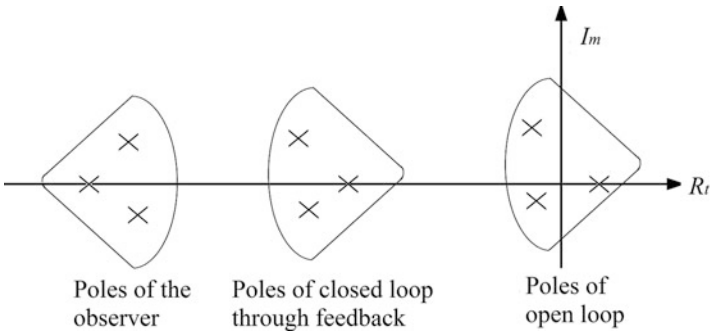

Fig. 5.6 Selection of observer's poles

5.6 Location Determination of Observer's Poles

The poles of the observer should be located slightly to the left of the poles of the corresponding closed-loop system. See Fig. 5.6 for details.

The methods of designing either full observers or lower-order observers are equally applicable to economic systems of discrete time. The only difference is that the poles of any observer of a discrete time system should be located on appropriate locations within the unit circle on the complex plane.

5.7 Some Concluding Remarks

Facing the challenge of observing and measuring the performance of an economy, this chapter looks at the problem of how to design state observers. Continuing what we have started in this chapter, the next chapter addresses (1) how observers can be attached to feedback controllers; (2) how dynamic compensators can be useful in the regulation of an economy; and (3) how what are obtained in this chapter can be generalized to the case of multiple variables.

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Chapter 6
Estimating the State of Economy Through Controllers

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Contents

In order to study an economy by using control-theory models, one has to estimate the state of the economy. To this end, this chapter studies how to construct state observers for economic systems by employing the conventional control theory and the intuition of systemic logic thinking.

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This chapter shows how to construct various state observers for linear economic systems, which are generally good estimates of the real economy. And what is presented in this chapter is the first of its kind and provides a theoretical guideline for how to estimate the state of an economy in order to introduce appropriate fiscal and monetary policies.

6.1 Introduction

This chapter continues the investigation of the same topic of the previous chapter on how to estimate the state of an economy for the purpose of introducing appropriate economic policies.

The rest of this chapter is organized as follows: In Sect. 6.2, we study how observers can be attached to feedback controllers. Section 6.3 investigates how dynamic compensators can be useful in the regulation of an economy. Section 6.4 looks at how to generalize what have been discussed in the previous sections to the case of multiple variables. The presentation of this entire work of two parts is concluded in Sect. 6.6.

6.2 State Feedback Controllers with Observers Attached

6.2.1 Separation of State Feedback Controller's Poles

Assume that the constant coefficient linear system representation of the economic system

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \end{cases} \tag{6.1}$$

is completely controllable and completely observable. Then, based on what is discussed in the previous chapter, we can design the following state feedback controller:

$$u = Kx + r$$

so that the resultant closed loop system has the pre-determined poles $\lambda_1, \lambda_2, \cdots, \lambda_n$. Because not the entire x can be used in the feedback operation, we designed the state observer in

$$\frac{dz}{dt} = (A + GC)z + Bu - Gy \tag{6.2}$$

so that $z(t)$ is an asymptotic estimate of $x(t)$ and the observer has pre-determined poles $s_1, s_2, \cdots, s_n$. The present problem we consider is that after adding an observer, can the feedback system still maintain the previously placed poles so that the system still possesses the desired properties?

The general feedback system with an observer attached is given by the following group of equations:

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ \dfrac{dz}{dt} = (A + GC)Z + Bu - Gy \\ u = Kz + v \\ y = Cx \end{cases}$$

which can be rewritten as the following combined matrix form

$$\begin{cases} \begin{bmatrix} \dfrac{dx}{dt} \\ \dfrac{dz}{dt} \end{bmatrix} = \begin{bmatrix} A & BK \\ -GC & A + GC + BK \end{bmatrix} \begin{bmatrix} x \\ z \end{bmatrix} + \begin{bmatrix} B \\ B \end{bmatrix} v \\ y = [C \;\; 0] \begin{bmatrix} x \\ z \end{bmatrix} \end{cases}. \tag{6.3}$$

Because any equivalence transformation does not alter the poles of the system, the matrix of the system in Eq. (6.3) becomes the following after the application of an equivalence transformation:

$$\begin{bmatrix} I_n & 0 \\ I_n & -I_n \end{bmatrix} \begin{bmatrix} A & BK \\ -GC & A + GC + BK \end{bmatrix} \begin{bmatrix} I_n & 0 \\ I_n & -I_n \end{bmatrix}^{-1} = \begin{bmatrix} A + BK & -BK \\ 0 & A + GC \end{bmatrix}.$$

Hence, the characteristic polynomial of the system in Eq. (6.3) is

$$\det \begin{bmatrix} sI - A & -BK \\ GC & sI - (A + GC + BK) \end{bmatrix} = \det \begin{bmatrix} sI - (A + BK) & BK \\ 0 & sI - (A + GC) \end{bmatrix}$$
$$= \det[sI - (A + BK)] \cdot \det[sI - (A + GC)].$$

That indicates that the poles of the feedback controller with an observer attached are those of the original closed loop system together with those of the observer. That is, we have the following result.

Theorem 6.1 (Separation Theorem). The set of all the poles of the closed loop of the feedback system in Eq. (6.3) with an observer attached is equal to $\sigma(A+BK)\cup\sigma(A+GC)$.

6.2.2 Transfer Function Matrix of State Feedback Controller with an Observer Attached

The equivalence transformation used in the previous subsection changes the state of the closed loop system into

$$\begin{bmatrix} I_n & 0 \\ I_n & -I_n \end{bmatrix}\begin{bmatrix} x \\ z \end{bmatrix} = \begin{bmatrix} x \\ x-z \end{bmatrix}.$$

If we let $\tilde{x} = x - z$, then we can rewrite the closed loop system as follows:

$$\begin{bmatrix} \dfrac{dx}{dt} \\ \dfrac{d\tilde{x}}{dt} \end{bmatrix} = \begin{bmatrix} A+BK & -BK \\ 0 & A+GC \end{bmatrix}\begin{bmatrix} x \\ \tilde{x} \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} v,$$

$$y = [C \quad 0]\begin{bmatrix} x \\ \tilde{x} \end{bmatrix}.$$

Its transfer function matrix is

$$\begin{aligned} &[C \quad 0]\left[sI - \begin{bmatrix} A+BK & -BK \\ 0 & A+GC \end{bmatrix}\right]^{-1}\begin{bmatrix} B \\ 0 \end{bmatrix} \\ &= [C \quad 0]\begin{bmatrix} sI-(A+BK) & BK \\ 0 & sI-(A+GC) \end{bmatrix}^{-1}\begin{bmatrix} B \\ 0 \end{bmatrix} \\ &= C[sI-(A+BK)]B. \end{aligned}$$

That means that the transfer function matrix of the state feedback controller with an observer attached is perfectly equal to that of the closed loop of the controller that directly uses state feedback.

6.2.3 Joint Design of a Feedback Controller and Observer

When the Laplace transform is applied to the observer

$$\frac{dz}{dt} = (A + GC)z + Bu - Gy,$$

we obtain

$$Z(s) = [sI - (A + GC)]^{-1}[BU(s) - GY(s)].$$

From

$$u = Kz + r$$

we obtain

$$U(s) = K[sI - (A + GC)]^{-1}BU(s) - K[sI - (A + GC)]^{-1}GY(s) + R(s).$$

By using the equality

$$[sI - (A + GC)]^{-1} = \frac{Adj[sI - (A + GC)]}{\det[sI - (A + GC)]},$$

the previous equation can be rewritten as follows:

$$U(s) = \left[\frac{L(s)}{D(s)}U(s) + \frac{M(s)}{D(s)}Y(s)\right] + R(s) \tag{6.4}$$

where

$$D(s) = \det[sI - (A + GC)],$$
$$L(s) = K \cdot Adj[sI - (A + GC)] \cdot B,$$
$$M(s) = -K \cdot Adj[sI - (A + GC)]^{-1} \cdot G.$$

For how all the parts connect to each other in Eq. (6.4), please consult with the diagram in Fig. 6.1.

This reasoning reduces the problem of designing a control system into the following: given the transfer function of an open loop, find polynomials $D(s)$, $L(s)$, and $M(s)$ so that the poles of the resultant closed loop are placed at the pre-determined locations or the system possesses the pre-determined transfer function of the closed loop. Shanhian and Hassul (1992) provided a procedure for calculating $D(s)$, $L(s)$, and $M(s)$ based on the transfer function $G(s)$ of the open loop and the desired transfer function $T_d(s)$ of the closed loop.

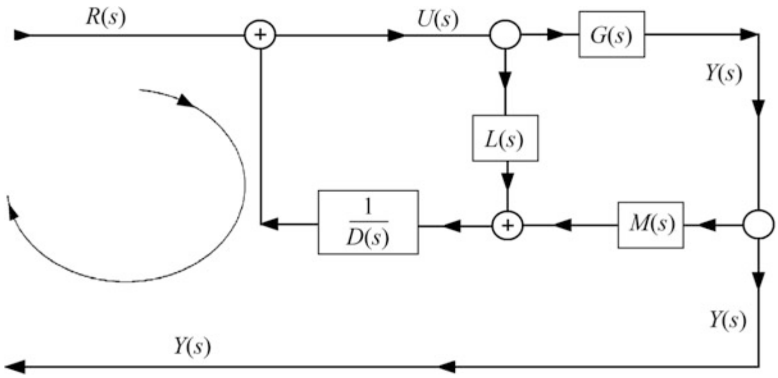

Fig. 6.1 The controller-observer system

6.3 Design of Dynamic Compensators

Most often, the monetary authority of the economic system determines to implement either a stabilizing policy or an aggressive policy by studying and analyzing the current economic situations in order to affect the supply of credit from the commercial banks, the total output through regulating investment and consumption, so that the observed macroeconomic variable of the economic system reaches a certain stable state. However, because the existence of the shadow economy creates an important impact on how effectively the monetary policies could have on the economy, the shadow banking also provides the same or similar financial intermediation for the entire market as the visible banking system does; there is also a credit creation process that is parallel to that of the visible banking system (Gorton and Metrick 2009). Because of their drift outside the government supervision, these quasi-banking activities of the shadow banks are not included in the detection range of the monetary authority. That creates a leakage for a large portion of the money supply of the entire economy and lowers the prediction accuracy of the money multiplier of the monetary authority. Hence, the monetary policy instruments available to the monetary authority could not effectively work on the shadow banks. That affects the efficiency of the credit transmission channel, which in turn hinders monetary policy instruments to play their roles, delays the response of the intermediate targets of the instruments, and weakens the connection between the intermediate targets and the ultimate goal. So, the mechanism of monetary policies cannot be properly transmitted to the real economy, while the adopted monetary policies can only play their roles within limited ranges.

Because shadow banks are extremely sensitive to asset prices and drifting outside the established supervision system, mismatches between short-term borrowings and long-term loans commonly exist within the shadow banking system, and the financial innovations that are traded excessively and highly leveraged operations can all easily generate liquidity risks. Such risks can easily spread over into the visible banking system, leading to major risks for the entire financial system. Therefore, many scholars trace the essential reason for the breakout of the 2008 global financial crisis to shadow banks, proposing that the shadow banking system played the role of triggering the financial crisis (Nersisyan and Wray 2010; Pacces 2010; Rosen 2009; Hsu and Moroz 2010). Additionally, the calculation of the total amount of financing of the economy consists mainly of the methods of conventional financing without including private lending and other kinds of credit amounts acquired through nonconventional means. According to a survey conducted in China in July 2013 (CHFS), around 33.5% of Chinese households participated in private lending activities, involving the total amount of lending of around ¥8600 billion. However, this set of data of the shadow banking was not included in any sources of data that were publically available. That makes it difficult for the monetary authority to estimate the scale of the invisible credit.

The diversified form and the expanding product scale of the shadow banking compromise the effect of monetary policies through delaying the regulation effect of the policies, lowering the controllability and observability of the liquidity, making use of the credit channel of the commercial banks, etc. Therefore, it is impossible for the monetary authority to materialize its ultimate goals by directly applying monetary instruments. Instead, it has to observe the economic indicators that it can control and constantly adjust the adopted monetary instruments by using the feedback information of these economic indicators in order to offset and to reduce the effect of the shadow economy on the macroeconomic activities so that the performance of the economic system is in a relatively stable state.

The aforementioned feedback and adjustment of the monetary instruments are in fact some kinds of compensated controls applied on the state variables of the economic system after having first employed relevant monetary policies in order to materialize the goal of macroeconomic control. Therefore, in terms of economic systems, if the main concern is the stability of the system, then we can make the performance of the economy stable by applying dynamic compensation on the state variables of the system. In this section, we will look at the details on how to design dynamic compensators for economic systems.

If we only consider the stability of the economic system, we can assume the input from the outside is 0. In this case, the closed loop system in Eq. (6.3) becomes

$$\begin{cases} \begin{bmatrix} \dfrac{dx}{dt} \\ \dfrac{dz}{dt} \end{bmatrix} = \begin{bmatrix} A & BK \\ -GC & A+GC+BK \end{bmatrix} \begin{bmatrix} x \\ z \end{bmatrix} \\ y = \begin{bmatrix} C & 0 \end{bmatrix} \begin{bmatrix} x \\ z \end{bmatrix} \end{cases}$$

whose block diagram is given in Fig. 6.2, where the part boxed in by the dotted line is referred to as dynamic compensator of the original system's output.

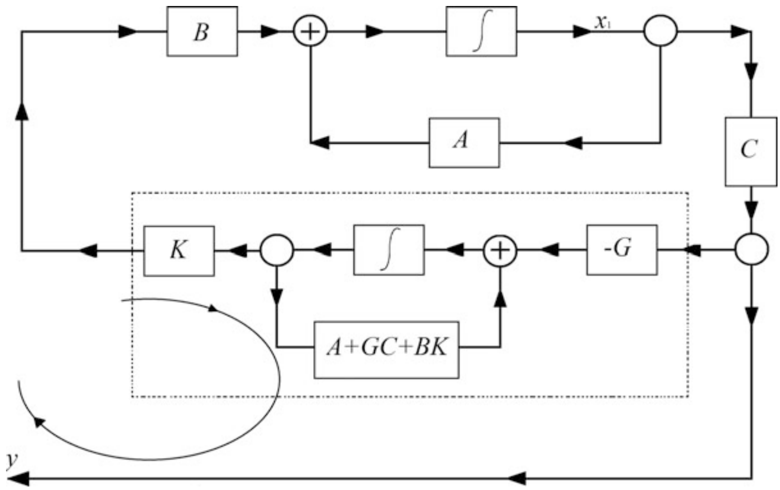

Fig. 6.2 Dynamic compensator of output

The equation of the dynamic compensator of the original system's output is given as follows:

$$\begin{cases} \dfrac{dz}{dt} = (A + GC + BK)z - Gy \\ u = Kz \end{cases}. \tag{6.5}$$

The general form of a dynamic compensator is

$$\begin{cases} \dfrac{dz}{dt} = Ez + Fy \\ u = Kz + Ly \end{cases}. \tag{6.6}$$

Under its effect, the closed loop system is

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \\ \dfrac{dz}{dt} = Ez + Fy \\ u = Kz + Ly \end{cases}$$

that is,

$$\begin{cases} \dfrac{dx}{dt} = (A + BLC)x + BKz \\ \dfrac{dz}{dt} = FCx + Ez \end{cases}. \tag{6.7}$$

If we can design a dynamic compensator as in Eq. (6.6) for the system in Eq. (6.1) such that the poles of the closed loop system in Eq. (6.7) can be arbitrarily placed, then we say that the system can arbitrarily place its poles by employing dynamic compensators. If we can design a dynamic compensator to make the resultant closed loop system stable, then we say that the system can be stabilized by using dynamic compensators.

As a matter of fact, in terms of a completely closed economic system, at the initial stage, the designer of the system can employ certain policy instruments to guarantee the stability of the closed system. That is, initially, the economic system is completely observable and controllable. However, with the development of the economic system, the internal structure tends to become more complicated with multidimensional complexities emerging, making the initial structure and characteristics of the economy evolve. In other words, in the operation of the economic system, there might be some subsystems that are still observable or controllable, while there might have appeared some subsystems that are no longer observable or controllable, and the natural evolution of some of these subsystems could be unstable. Besides, as the system gradually becomes more open, factors that affect the operation of the economic system start to interact with various unprecedented factors nonlinearly; different kinds of economic problems become increasingly multifaceted while evolving from lower dimensional complexities to higher dimensional complexities, making the internal structure of the economic system possess more diverse sophistications. As a matter of fact, the discovery of chaotic phenomena in economics had created a shock on the mainstream economic theories, which means that there is endogenous instability within the macroeconomic operation of any open economic system (Cheng 1999). This characteristic of endogenous instability of any open economic system is referred to as the fixed modes of the system. In short, if we can decompose an economic system into a completely observable and controllable subsystem and a not completely observable and controllable subsystem, then the poles of the latter subsystem are known as the fixed modes of the original system.

Based on what is discussed above, it follows that any observer is a dynamic compensator. Additionally, other types of dynamic compensators can also be designed. As for dynamic compensators, we have the following result.

Theorem 6.2 The fixed modes of the system in Eq. (6.1) stay the same no matter which dynamic feedback is applied.

Proof Without loss of generality, assume that the system has been written in the standard structural form. That is, in Eq. (6.1), we have

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ 0 & A_{22} & A_{23} & A_{24} \\ 0 & 0 & A_{33} & A_{34} \\ 0 & 0 & 0 & A_{44} \end{bmatrix}, B = \begin{bmatrix} B_1 \\ B_2 \\ 0 \\ 0 \end{bmatrix}, C = [0 \quad C_2 \quad 0 \quad C_4].$$

So, the characteristic polynomial of the closed loop system in Eq. (6.7) is

$$\begin{vmatrix} sI-(A+BLC) & -BK \\ FC & sI-E \end{vmatrix} =$$

$$\begin{vmatrix} sI-A_{11} & -(A_{12}+B_1LC_2) & -A_{13} & -(A_{14}+B_1LC_4) & -B_1K \\ 0 & sI-(A_{22}+B_2LC_2) & 0 & -(A_{24}+B_2LC_4) & -B_2K \\ 0 & 0 & sI-A_{33} & -A_{34} & 0 \\ 0 & 0 & 0 & sI-A_{44} & 0 \\ 0 & -FC_2 & 0 & -FC_4 & sI-E \end{vmatrix}.$$

By adjusting the last column of the previous expression to the third column and then adjusting the last row of the resultant determinant to the third row, we have

$$\begin{vmatrix} sI-(A+BLC) & -BK \\ FC & sI-E \end{vmatrix} =$$

$$\begin{vmatrix} sI-A_{11} & -(A_{12}+B_1LC_2) & -B_1K & -A_{13} & -(A_{14}+B_1LC_4) \\ 0 & sI-(A_{22}+B_2LC_2) & -B_2K & 0 & -(A_{24}+B_2LC_4) \\ 0 & -FC_2 & sI-E & 0 & -FC_4 \\ 0 & 0 & 0 & sI-A_{33} & -A_{34} \\ 0 & 0 & 0 & 0 & sI-A_{44} \end{vmatrix}$$

$$= |sI-A_{11}||sI-A_{33}||sI-A_{44}|\begin{vmatrix} sI-(A_{22}+B_2LC_2) & -B_2K \\ -FC_2 & sI-E \end{vmatrix}.$$

That is, for any dynamic feedback of the output, the set of the poles of the resultant closed loop system contains $\Lambda(A)=\sigma(A_{11})\cup\sigma(A_{33})\cup\sigma(A_{44})$. QED

Theorem 6.3 A sufficient and necessary condition for the system in Eq. (6.1) to be able to arbitrarily place its poles through using a dynamic compensator is that the system is completely controllable and completely observable.

Proof Let us first show the sufficiency. Assume that the system in Eq. (6.1) is controllable and observable. Because (A,B) is controllable, there is K such that $\sigma(A+BK)$ has pre-determined poles. Because (C,A) is observable, there is G such that $\sigma(A+GC)$ has pre-determined poles. From Theorem 6.1, it follows that the dynamic compensator in Eq. (6.5) constructed by using the matrices K and G is a desired dynamic compensator that has the pre-determined poles as its poles.

The proof of the necessary condition depends on Theorem 6.2. Assume that the system in Eq. (6.1) is not completely controllable and completely observable. Then, the set of the fixed modes of A is not empty. These poles stay the same when a dynamic feedback is applied. That is, this system cannot arbitrarily place its poles by applying dynamic feedback of the output (a contradiction). QED

Example 6.1 Assume that the control-theory model of an economic system is given as follows:

$$\begin{cases} \dfrac{dx}{dt} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} x + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \\ y = [\,0 \quad 1\,]x \end{cases}.$$

Design a dynamic compensator of the output such that the resultant closed loop system has poles -1, -2, -3, and -3.

Solution

Step 1: Find K such that $\sigma(A+BK)=\{-1,-2\}$. To this end, we find $K=[-3 \quad 1]$ by using the method of placing poles for a single input system.
Step 2: Construct an observer such that $\sigma(A+GC)=\{-3,-3\}$ and let $G=[8 \quad -6]^T$.
Step 3: From Eq. (6.5), we obtain our desired dynamic compensator as follows:

$$\begin{cases} \dfrac{dz}{dt} = \begin{bmatrix} -3 & 10 \\ -1 & -6 \end{bmatrix} z - \begin{bmatrix} 8 \\ -6 \end{bmatrix} y \\ u = [\,-3 \quad 1\,]z \end{cases}.$$

The result in Theorem 6.1 also holds true for lower-order observers. So, we can design dynamic compensators of the output by using lower-order observers, too.

6.4 Design of Multiple Variable PD Controllers

In this section, we see how to generalize various controllers we studied so far to the case of economic systems of multiple variables, which is more real-life like in terms of potential applications of this chapter.

For the following constant coefficient linear system

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \end{cases}$$

let us use the following PD output feedback, where P stands for proportion and D differentiation (for an intuitive illustration of this PD output feedback mechanism, please see Fig. 6.3),

$$u = -Py - Q\frac{dy}{dt} + v.$$

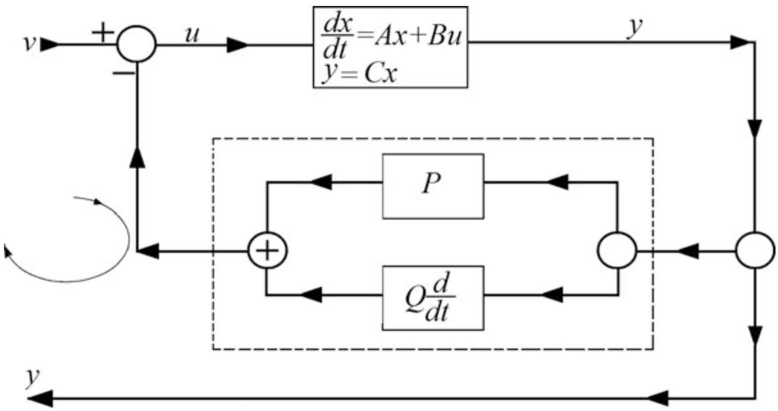

Fig. 6.3 A PD output feedback controller

So, we obtain the following closed loop system

$$\frac{dx}{dt} = (I + BQC)^{-1}(A - BPC)x + (I + BQC)^{-1}Bv.$$

Its characteristic polynomial is

$$\begin{aligned}\hat{p}(s) &= \det\left[sI - (I + BQC)^{-1}(A - BPC)\right]\\ &= \det(I + BQC)^{-1} \cdot \det[(I + BQC)sI - (A - BPC)]\\ &= \frac{\det[sI - A + B(P + sQ)C]}{\det(I + BQC)}.\end{aligned}$$

By letting

$$P = kp, Q = kq \tag{6.8}$$

we have

$$\hat{p}(s) = \frac{\det[sI - A]}{\det(I + BkqC)}\det\left[I + (sI - A)^{-1}Bk(p + sq)C\right].$$

From the identity $\det[I + ab] = I + ba$, the previous expression is simplified into

$$\hat{p}(s) = \frac{1}{1 + qCBk}[p(s) + (p + sq)W(s)k],$$

where

$$W(s) = C\mathrm{Adj}(sI - A)B = M_1 s^{n-1} + \cdots + M_{n-1}s + M_n,$$
$$p(s) = \det(sI - A) = s^n + a_{n-1}s^{n-1} \cdots + a_1 s + a_0.$$

This further simplifies $\hat{p}(s)$ into

$$\hat{p}(s) = s^n + \frac{a_{n-1} + pM_1k + qM_2k}{1 + qM_1k}s^{n-1} + \cdots + \frac{a_1 + pM_{n-1}k + qM_nk}{1 + qM_1k}s + \frac{a_0 + pM_nk}{1 + qM_1k}. \tag{6.9}$$

Assume that the poles of the system that need to be placed are $\lambda_1, \lambda_2 \cdots, \lambda_n$. Then we require the characteristic polynomial to be

$$p_d(s) = (s - \lambda_1)\cdots(s - \lambda_n)s^n = s^n + \alpha_{n-1}s^{n-1} + \cdots + \alpha_1 s + \alpha_0. \tag{6.10}$$

If $n \leq 2r$, by letting the terms of same powers of $\hat{p}(s)$ and $p_d(s)$ be the same, we obtain

$$\begin{cases} [p \quad q]\begin{bmatrix} M_1 \\ M_2 - \alpha_{n-1}M_1 \end{bmatrix}k = \alpha_{n-1} - a_{n-1} \\ \vdots \\ [p \quad q]\begin{bmatrix} M_{n-1} \\ M_n - \alpha_1 M_1 \end{bmatrix}k = \alpha_1 - a_1 \\ [p \quad q]\begin{bmatrix} M_n \\ -\alpha_0 M_1 \end{bmatrix}k = \alpha_0 - a_0 \end{cases}. \tag{6.11}$$

We first determine the vector k and then solve the previous n linear equations for the $2r$ unknown variables, including p and q. Therefore, we have $P = kp$ and $Q = kq$. When $n = 2r$, we have a unique solution. When $n < 2r$, we first select values for $(2r - n)$ unknowns and then solve for the rest n unknowns.

In order for the previous system of equations to have a solution, we need the n equations to be consistent. That means the following $2r \times m$ matrices

$$\begin{bmatrix} M_i \\ M_{i+1} - \alpha_{n-i}M_1 \end{bmatrix}, \quad i = 1, 2, \cdots, n$$

are linearly independent. That is, there are not all zero constants $\beta_1, \beta_2 \cdots, \beta_n$ such that

$$\beta_1 \begin{bmatrix} M_1 \\ M_2 - \alpha_{n-1} M_1 \end{bmatrix} + \cdots + \beta_n \begin{bmatrix} M_{n-1} \\ M_n - \alpha_0 M_1 \end{bmatrix} = 0. \tag{6.12}$$

By left multiplying the previous equation by $[p \quad q]$ and right multiplying by k, we obtain

$$\beta_1(\alpha_{n-1} - a_{n-1}) + \cdots + \beta_n(\alpha_0 - a_0) = 0. \tag{6.13}$$

When this condition is satisfied, we can solve for P and Q so that through using the PD output we can arbitrarily place the n poles. If the previous condition is not satisfied, we first select matrices $\hat{P}$ and $\hat{Q}$ and produces a new system $\left(\hat{A}, \hat{B}, \hat{C}\right)$. Then we place the poles by using the PD output feedback of this new system as outlined in the previous steps, compute the matrices P and Q, and obtain $P + \hat{P}$ and $Q + \hat{Q}$, which are what we wanted. If no matter how we select matrices $\hat{P}$ and $\hat{Q}$, the resultant new system still does not satisfy the needed condition, we have a singular scenario on hands, which demand further investigation.

Example 6.2 Assume that the control-theory model of an open loop and unstable economic system is given as follows:

$$\begin{cases} \dfrac{dx}{dt} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{bmatrix} x + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} u \\ y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} x \end{cases}.$$

Find a PD output feedback so that the resultant closed loop system has poles -1, -2, -3, and, -4.

Solution We compute

$$\begin{aligned} W(s) = C\mathrm{Adj}(sI - A)B &= \begin{bmatrix} s^2 + 1 & 0 \\ 0 & s^2 - 1 \end{bmatrix} \\ &= \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} s^3 + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} s^2 + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} s + \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \end{aligned}$$

$$p(s) = \det(sI - A) = s^4 - 1$$

$$p_d(s) = (s+1)(s+2)(s+3)(s+4) = s^4 + 10s^3 + 35s^2 + 50s + 24.$$

The algebraic equations corresponding to Eq. (6.11) are

$$[p \quad q]\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \cdots & \cdots \\ 1 & 0 \\ 0 & 1 \end{bmatrix} k = 10$$

$$[p \quad q]\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ \cdots & \cdots \\ 0 & 0 \\ 0 & 0 \end{bmatrix} k = 35$$

$$[p \quad q]\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \cdots & \cdots \\ 1 & 0 \\ 0 & -1 \end{bmatrix} k = 50$$

$$[p \quad q]\begin{bmatrix} 1 & 0 \\ 0 & -1 \\ \cdots & \cdots \\ 0 & 0 \\ 0 & 0 \end{bmatrix} k = 25.$$

If we let $k = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$, then we obtain the following system of four equations

$$\begin{bmatrix} 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & -1 & 0 & 0 \end{bmatrix}\begin{bmatrix} p_1 \\ p_2 \\ q_1 \\ q_2 \end{bmatrix} = \begin{bmatrix} 10 \\ 35 \\ 50 \\ 25 \end{bmatrix}$$

from which we have $p_1 = 30, p_2 = 5, q_1 = 30, q_2 = -20$ so that

$$P = \begin{bmatrix} 1 \\ 1 \end{bmatrix}[30 \quad 5] = \begin{bmatrix} 30 & 5 \\ 30 & 5 \end{bmatrix} \text{ and } Q = \begin{bmatrix} 1 \\ 1 \end{bmatrix}[30 \quad -20] = \begin{bmatrix} 30 & -20 \\ 30 & -20 \end{bmatrix}.$$

If $n \le 2m$, assume $P = pk, Q = qk$. Then we can place the n poles by using a similar method. In this case, Eq. (6.11) needs to be modified as follows:

$$\begin{cases} k[M_1 \quad M_2 - \alpha_{n-1}M_1]\begin{bmatrix} p \\ q \end{bmatrix} = \alpha_{n-1} - a_{n-1} \\ \vdots \\ k[M_n \quad -\alpha_0 M_1]\begin{bmatrix} p \\ q \end{bmatrix} = \alpha_0 - a_0 \end{cases} \tag{6.14}$$

with all others kept the same.

When $n > \max(2r, 2m)$, we can only place $l = \max(2r, 2m)$ poles with the rest $(n - l)$ poles floating at unknown locations.

After the 2008 global financial crisis, the regulatory management of the shadow banking system is exactly an example of how to apply the concept of observability in the control of macroeconomic financial systems. During the past years since the breakout of the 2008 global financial crisis, financial intermediaries continue to collapse with new sources of risk exposed. Right after the debt crises of the banking systems in Iceland and Middle East were over, sovereign debt crises of Dubai, Greece, Portugal, Ireland, Italy, Spain, and others appeared. The crises led to weakness in the global economic recovery and caused the volatility of financial markets to rise sharply. When the pattern of international capital flow changes frequently, and when the number of unstabilizing, uncertain factors continues to increase, the shadow banking system gradually emerges.

It was Paul McCulley (2009) who first introduced the concept of shadow banking. As the study of the concept deepened, some economists believe that the shadow banking was the culprit of this major crisis. This conclusion has been supported by international organizations and various national governments. For example, International Monetary Fund (2008) points out that the culprit of the crisis is the high leverage used by the shadow banks. Other than agreeing with the proposition that it is the shadow banking that caused the financial crisis, Rosen (2009) also tests the hypothesis that the securitization of assets is the source of the inducing effect. Hsu and Moroz (2010) believe that the instability of the shadow banking and the run caused by the lack of lender of last resort accelerated the spread of the initial subprime mortgage crisis over to the entire financial system. Brunnermeier (2008) proposes that the highly leveraged operation of the shadow banking requires higher amount of security deposits as the backup; and when assets depreciate, the operation of deleveraging will be needed, which in turn accelerate the losses. FCIC (2010) on the other hand believes that during financial difficulties, shadow banking becomes extremely vulnerable due to its reliance on the highly leveraged short-term capital market without clear government support; such extreme vulnerability could easily cause the entire financial system to become unstable; and when the instability is transmitted to the traditional commercial banking system, it might very well trigger the breakout of a financial crisis.

The main forms of the shadow banking include investment banks, finance companies, ABCP (asset-backed commercial papers) conduits, credit hedge funds, money market funds, bond insurers, structural investment vehicles, government-sponsored enterprises, etc. The most representative shadow banks are the five major investment banks of the United States. Although these financial firms are not banking institutions, they in fact do play de facto banking functions. They do not accept deposits and are not subject to any supervision; they design structurally complicated financial derivatives and participate in opaque over-the-counter transactions. Because they do not have the abundant capital as commercial banks do, investment banks, funds, and other financial organizations conduct their business by extensively using financial leverages. The shadow banks provided the bridges between subprime lenders and market surplus funds and were the main intermediary of financing for the subprime lenders. At the same time when they brought prosperity to the financial market, these shadow banks also created a huge vulnerability for the entire financial system through their rapid development and application of highly leveraged operations. That directly triggered the breakout of the most severe global financial crisis since the Great Depression (He and Zheng 2009).

The June 2010 work report of New York Federal Reserve Bank (Pozsar et al. 2010) points out that in the past 10 some years, the shadow banking system provided credit with cheap sources of funds by converting opaque, high-risk long-term assets into seemingly risk-free short-term debts; the duration and credit conversions, done by the shadow banking system before the financial crisis, greatly contributed to the housing and real estate market bubble.

As a matter of fact, since until the breakout of the 2008 global financial crisis as caused by the US subprime mortgage crisis, such needs as evaluating the latent potential risks of the new structural investment vehicles and financial derivatives, sheet activities, and credit rating methodology of financial institutions and other relevant issues had not caught enough attention of the major market players and the regulatory authority. The regulatory authority underestimated the risk effect and systemic importance of the endogenous characteristics of shadow banks and neglected the economic effect of the shadow system. Because its high profitability concealed its relevance with the traditional banking system and its risk's contagion, the investigations on shadow banking institutions, products, and markets were not accompanied with corresponding tracking and because a scientific and dynamic risk monitoring framework was not established in a timely fashion. Therefore, it made it difficult to comprehensively, accurately collect and statistically analyze the relevant information and data. That made it impossible for market players to comprehensively evaluate and analyze the risk and effect of the shadow banking system and to employ in a timely fashion effective regulatory measures and actions.

Because it drifts outside the effective supervision of the government, the shadow banking expanded and eventually caused the financial crisis. Paul Krugman stated in his book, entitled *The Return of Depression Economics and the Crisis of 2008* (published by W. W. Norton & Company 2009), that any organization that operates like a bank and needs to be rescued during crises like a bank has to be supervised like a bank. Hence, since after the financial crisis, various economic systems have strengthened their monitoring and supervision of their shadow banks. For example, the US financial regulatory reform bill in 2010 expanded the scope of regulation and strengthened the supervision of the asset securitization market, over-the-counter derivative market, private equity funds, hedge funds, and credit rating agencies. The US financial regulatory reform bill stipulates that all of the private funds and hedge funds with total assets over US$100 million need to register with the Securities and Exchange Commission (SEC), and those with total assets less than US$100 million need to register with their individual states in order to help the regulatory authorities monitor and detect the system's risk. Additionally, the over-the-counter (OTC) derivative market, which was not well supervised before, is also included in the regulatory field; and most of the derivatives must be traded on exchanges through a third-party clearance house. It is the first time in history that the reform bill introduces a comprehensive set of supervision criteria on the OTC derivatives, covering trading behaviors and companies that sell the products. Also, large hedge funds and private equity funds are required to reveal to the supervision organizations the information about their assets and how they employ leverages. The new regulatory scheme of the European Commission requires that private equity funds, hedge funds, etc. have to register, regularly publish information, and increase their trading transparency (Li and Zhao 2012). The financial service agency of Japan demands all registered hedge funds to report how they manage the risk within their applications of capital (Li and Zhao 2012).

As a matter of fact, after the 2008 global financial crisis, the regulatory management of the shadow banking system is exactly a practical application of the concept of observers in the control of the macroeconomic financial systems. Before the financial crisis, the major economic powers from around the world did not monitor and supervise the scale of and the leverages applied by the shadow banks. That made it extremely difficult for the monetary authorities to grasp the magnitude of the credit creation of the shadow banks and their leverage ratios. For example, prior to its bankruptcy, Lehman Brothers had an amount of assets of approximately US$20 billion. However, the asset size under its management reached US$600 billion, where the leverage ratio extended as high as 30. That made it extremely difficult for the monetary author to estimate the magnitude of risk created by the shadow banks on the real banking system and the actual economy. By strengthening the supervision of the shadow banks, it makes the operation of the shadow banks more transparent and the supervision of the transactions of the shadow banks more convenient. In other words, under practically possible scenarios, all transactions of the shadow banks must be cleared through the central clearance house and reported promptly to regulatory organizations, investors, and the public. Through the observations of these observers, the regulatory organizations can grasp with more details the state of operation of the shadow banking system so that when the market pressure and bankruptcy situation are known, the regulatory organizations can take appropriate actions to limit the behaviors of the shadow banks in order to avoid the potential financial instability as it might be caused by the market pressure and bankruptcies.

6.5 Conclusion

For most economic systems, it is generally difficult to directly observe and measure the state variables of their control-theory models. That makes it a real challenge to practically apply the control methods developed on state feedback and output feedback mechanisms. Therefore, for most of the situations of practical concern, we have to estimate the state of the economy. That warrants that we need to know how to construct state observers for economic systems.

Each state observer of the economic system is a new system, which, as output, produces estimates for the true state of the original economic system under certain conditions of convergence by using the input and output of the original economic system as its input. So, by employing a state observer, we can use the estimated state in the place of the true state, which cannot be directly observed and measured, for our purpose of regulating the economy based on feedback of the economic performance.

This chapter shows how to construct state observers for linear economic systems. Considering the complexity of economies, we also provide ways to construct lower-order observers for linear economic systems. Because a lower-order observer only estimates those state variables that cannot be directly measured from the output of the economic system, the dimension of its dynamic system is smaller than that of the original economic system and smaller than that of any full-order observer. That makes the structure of feedback control of the entire economy much simpler and more convenient to apply in practical works.

Because nonlinear models of the economic system capture more aspects of the economy, it will be very important to address the following question, which is still open, of how to design observers for nonlinear models of the economy. Additionally, because the feedback control of the economic system by using lower-order observers is of a simpler structure, it becomes important to look at the existence and the actual construction of lower-order observers for nonlinear models of the economic system.

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Part II
Instability: The Brewing of Currency Wars

Chapter 7
Some Major Financial Crises in History: 1929–2008

Contents

The focus of this chapter, as suggested by the title, is to review some of the very severe financial crises that occurred during 1929–2008 in the United States and throughout the world. For each case, we will try to address the following questions:

- What caused financial difficulties?
- How funds flowed to meet financial needs?
- What was the response of the commercial banks and central banks?
- How was the financial condition of the economic system affected?
- What was the cause of the disruption to the normal functioning of the financial system?
- What form did the financial crisis take?
- How was it resolved?

The cases presented in this chapter and other cases discussed throughout this book provide a very good reason for why one needs to investigate the mechanism for how financial disasters occur, how such crises could be potentially avoided, or, if not possible to avoid, how the disastrous consequences could be potentially lessened.

J. Yi-Lin Forrest et al., *Currency Wars*, Contemporary Systems Thinking,
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7.1 The Credit Crunch of 1966

The credit crunch of 1966 was the first severe financial crisis after World War II. It occurred when commercial banks were suddenly prevented from meeting the strong demand of borrowing from the corporate sector (Burger 1969). In particular, as the year 1966 began, the US economy experienced a strong surge of spending in investment in plant and equipment, which was low in the late 1950s and early 1960s and grew sharply in 1964 and 1965, while inventory investments also jumped sharply in 1966. Nonfinancial corporations financed their investment growth through 1965 mainly through internal funds, which consequently exerted little upward pressure on interest rates. During this unprecedented economic growth in the United States, the bank prime rate remained constant at 4.5 percent from 1960 to December 1965, while Moody's AAA corporate bond rate was also stable at nearly 4.5 percent. Although the liquidity ratio of nonfinancial corporations declined steadily from 1963 through 1965, it was still high for the period since 1961. So, corporate balance sheets did not suffer much damage from the surging spending in investment through 1965. At the same time, government defense spending expanded sharply in 1965.

Facing the rapid spending increase, the capacity utilization rate for manufacturing reached 91.6% in March 1966, the highest level in the entire postwar period, the unemployment rate fell to 3.8%, and prices started to escalate. The favorable financial environment deteriorated rapidly in 1966 within the overheated economy; interest rates rose sharply; profits peaked in the first quarter of 1966. These developments had important implications for the financing gap between capital expenditures and internal funds. The internal funds of nonfinancial corporations stopped increasing.

The declining profits and rising interest rates put additional pressure on nonfinancial corporations that needed to meet their debt payment commitments. Some corporations tried to sell assets or borrow additional money to pay their existing debts. Corporations unable to raise these funds would be forced into bankruptcy. The stock market peaked at the start of 1966; the growth rate of investment dropped sharply from that in 1965; and investment by nonfinancial corporations grew only slightly in 1966.

In short, nonfinancial corporations in 1966 experienced two kinds of financial difficulties: difficulty in meeting their debt payment commitments and that of meeting their high level of capital expenditures with internal funds. To this end, the flow of funds data indicates that corporations met these difficulties in the first quarter of 1966 primarily from long-term debt and loans from banks and in the second quarter by increasing their loans from the banks. However, in the third quarter when the crisis occurred, the net credit market borrowing of nonfinancial corporations fell by 25% from the second quarter pace, and in the fourth quarter, it was off by 44%. That is, in the second half of 1966, the nonfinancial corporate sector was shut out from external sources of funds, particularly from commercial banks, where bank loans dropped drastically from their peak in the second quarter, while capital expenditures remained high throughout 1966.

What happened here that brought about the financial crisis in August 1966 was that in late 1965, responding to the rapidly expanding economy, the Federal Reserve decided to tighten its monetary policy by raising the discount rate from 4% in December 1965. At its April and May meetings of 1966, the Federal Open Market Committee (FOMC) concluded that additional stabilization policy measures were needed. So, reserve and money supply growth slowed during the April–June period. However, with 0.9% increase in bank reserves and 0.7% in the money supply, bank credit expanded rapidly at a 9.1%, while business loans increased at 20.5%. Because investments in securities and nonbusiness loans did not increase nearly as rapidly as business loans did at commercial banks, the banks increased their lending to business by lowering investments and loans to other sectors.

With demand deposits decreasing, banks used large negotiable certificates of deposit (CDs) to increase their time deposits. These CDs helped lower reserve requirements and support a larger volume of bank lending. Additionally, banks aggressively sold small (under $100,000) CDs to individuals, which too enabled the banks to use their reserves more efficiently.

However, the ability for banks to small time deposits placed pressures on other financial intermediaries, such as the savings and loan associations (S&Ls). Business losses in deposits to the banks put additional squeeze on the S&Ls, which had been suffering losses of deposits to the rising interest rates since January. Different from the banks, the S&Ls were not able to remedy the situation by issuing CDs. Advances to the S&Ls by the Federal Home Loan Bank Board increased sharply in the second quarter.

The Fed became concerned with the intensifying squeeze on the S&Ls and the potential of inflation from the continuing expansion of business loans by commercial banks. Toward the end of the second quarter, the Fed began to take steps to bring both problems under control. Specifically, in June the Fed raised from 4% to 5% the reserve requirements against time deposits in excess of $5 million at member banks. In July, the Fed lowered the maximum rates payable on small time deposits. The purpose of doing so was to make it difficult for big banks to bid for deposits, hence reducing the pressure on the S&Ls and slowing down the expansion of bank loans.

Additionally, in May, the federal funds rate increased rapidly, while the discount rate was left constant at 4.5% throughout 1966. That made it less costly for banks to borrow at the discount window than in the market for Fed funds. The Fed also kept the maximum Regulation Q ceiling rate the same on large negotiable certificates of deposit. In June, the rate on the secondary market for CDs of 6 months or longer maturity rose upward through the Regulation Q ceiling. In July, the rate on shorter maturity CDs behaved similarly. Consequently, banks' holdings of negotiable time CDs began to decline.

Lastly, monetary policy continued to tighten sharply. Bank reserves declined by 2.7% from June to August, and the money supply dropped by 2.4%. The National

Bureau of Economic Research designated June 1966 as the peak of the expansion and the beginning of a growth recession.

With reserves declining, access to the discount window cut off, and ability to raise funds from time deposits diminished, the commercial banks started to feel the squeeze and had to cut back on the growth of bank credit. However, business loans continued to increase because the banks decreased their investments during this same period while started liquidating their investments in municipal securities in order to come up with the needed funds. However, the market for municipal securities was relatively thin; the sell-off by the banks made the market become "disorganized" during the latter part of August. The unsettlement in the municipal securities market also affected other financial markets adversely. That caused market participants to become apprehensive about the ability of the markets to meet the heavy demands for credit, given the still-weakened condition of the thrifts, the squeeze on the banks, and the continuing tight monetary policy of the Fed.

To prevent the financial crisis from further developing, the Fed took two important actions. First, at its meeting on August 23, 1966, the FOMC concluded that its tight monetary policy would have to be abandoned as long as intense demands for liquidity existed in the financial markets. Second, the Fed sent to each member bank a letter, essentially stating that the banks should stop liquidating municipal securities and reduce their business loans and that the discount window would be open to those banks that did so.

While this letter was working to relieve the mounting feeling of crisis in the financial markets, market participants were also reassured by an announcement on September 8 that the government would cut back on low-priority federal expenditures, temporarily suspend certain tax incentives for business investment, and curtail federal agency borrowing in the capital markets.

While monetary policy eased during the rest of the year, pressures in the financial markets were also alleviated. That eventually stabilized the financial markets; fears of a serious financial panic subsided, and continued high military spending kept the subsequent economic downturn relatively mild.

That was how the first financial crisis of the postwar period, the credit crunch of 1966, finally passed.

7.2 The Year 1970: Penn Central

The June (1970) announcement of the bankruptcy of Penn Central Railroad shocked the commercial paper market; for more details, see Geisst (2006).

To understand this crisis, let us first look at the relevant history. In particular, in 1968, the economy resumed its expansion, which was strongly supported by investment in plant and equipment since mid-1968 and government defense spending. A 10% income tax surcharge, passed in June 1968, did not slow the development of the economy, as many had expected. The unemployment rate dropped to 3.6% in 1968, and the capacity utilization rate was at a high of 87.1%.

Compensation of employees in the nonfinancial corporate world increased by 12.7% in 1968, and prices continued to rise. However, profits, as a percentage of the domestic income of nonfinancial corporations, continued to decline in 1968, as ever since 1966. The level of internal funds declined in 1969 with profits. That decline, combined with an increase in capital expenditures, led to a widening financing gap of nonfinancial corporations during 1969, while inventory investment remained high. The financing gap grew steadily throughout the year and peaked at 18.6% of capital expenditures in the fourth quarter.

Similar to the 1966 situation, in 1969, internal funds fell, while nonfinancial corporations funded a growing financing gap when monetary policy was tightening significantly. However, credit market borrowing dropped off sharply in 1966, whereas in 1969 the decline was very gradual. While funds raised in the bond market dropped sharply since the start of the year, bank loans fell gradually. As a matter of fact, the important sources of debt in the last three quarters were loans from finance companies and borrowing in the rapidly expanding commercial paper market.

In terms of monetary and financial policies and the flow of funds for the commercial banking sector, the Fed in 1969 adopted a restrictive monetary policy to slow the expansion of aggregate money demands in the economy and to dissipate deeply rooted expectations of continuing inflation. The Fed raised the discount rate in December 1968 and in April 1969. By increasing its open market sales, the Fed was able to sharply grow net borrowed reserves in the first half of 1969, while offsetting member banks' borrowing by reducing non-borrowed reserves. Total member bank reserves dropped a little in the first half of 1969, after having increased sharply in the second half of 1968. And the monetary aggregates and bank credit slowed their rates of growth, too. And additionally, the Fed increased reserve requirements for demand deposits at all member banks by 112% in April, aiming at directly influencing inflationary expectations. Although the Fed did not raise the Regulation Q ceiling rate on large negotiable certificates of deposit at the end of 1968, the rates on the secondary market rose above the ceiling rate and remained above it throughout 1969. That once more made the commercial banks unable to market new issues and faced a runoff of outstanding CDs.

To offset the continuing drain during 1969 in large time deposits, the banks borrowed dramatically from their overseas branches, which were able to acquire funds through the Eurodollar market. Additionally, because many large banks of the time adopted the one-bank holding company form, the bank holding companies were able in 1969 to sell commercial papers and transfer the funds to their banks by purchasing loans originated by the banks. Therefore, the banks had sufficient funds for their further lending. At the same time, the banks, too, raised funds by borrowing federal funds and utilizing security repurchase agreements. As in 1966, commercial banks also cut back on other components of bank credit in order to use their available funds for business loans. By manipulating their funds in all these ways, commercial banks were able to increase their business loans in the first half of 1969 by 16.2%.

To counter the growth in credit and because inflation seemed decreasing, the FOMC maintained its existing monetary restraint on the economy from June to December 1969. The federal funds rate remained near 9%; net borrowed reserves decreased slightly. However, as judged by the monetary aggregates, the monetary policy was tightening in the second half of 1969; and the narrow and broad measures of the money supply and total bank credit slowed dramatically. The real GNP growth became negative in the fourth quarter of 1969, and the recession of 1969–1970 started.

Profits fell sharply in 1968 and 1969, and interest rates for corporate borrowing were at record highs by June 1969. Although the nonfinancial corporate use of debts declined in 1969 after reaching the peak of 3.7% of GNP in the fourth quarter of 1968, the debt-equity ratio increased in 1969, particularly the ratio measured by total debt outstanding divided by the market value of equity. And, other aspects of corporate financial conditions deteriorated, too. Thus corporations became progressively vulnerable to adverse conditions in the financial markets, as their debt had to be renegotiated more frequently. Additionally, the growth of short-term liabilities outpaced the ability of these corporations to add to their liquid assets, and the liquidity ratio continued to fall.

The sharply and continuously falling interest coverage ratio during 1968–1970 suggested that nonfinancial corporations had more difficulty in servicing their debts, which adversely affected the quality of bank loans to business and made banks restrict credit to the business sector during the second half of 1969. As 1970 began, the FOMC moved to make credit conditions easier while still maintaining pressure on bank lending although nonfinancial corporations were still in need of funds. Falling internal funds made nonfinancial corporations experience a $19.9 billion financing gap and a large demand for funds to pay off maturing debts. To this end, the corporations sold liquid assets and issued new equity and corporate bonds in the first quarter of 1970, as bank loans (and also finance company loans) declined. They borrowed majorly in the rapidly growing commercial paper market, which became an important source of financing for large, well-known firms in the latter part of the 1960s.

In particular, the Penn Central Co. had about $200 million worth of commercial paper outstanding at the end of the first quarter of 1970, as one such company that relied heavily on commercial paper for its financing. Like many other nonfinancial corporations, Penn Central suffered from earning difficulties except that its situation was more severe. That made Penn Central experience increasing difficulty in marketing its commercial paper. When the corporation filed for reorganization (bankruptcy) on June 21, 1970, fear spread to the holders of other companies' commercial papers. The risk premium incorporated into commercial paper interest rates increased sharply.

Because in the commercial paper market borrowers maintain backup lines of credit from their banks in order to deal with the situation when holders of commercial papers do not roll them over, corporations can potentially place enormous demands for funds upon the commercial banking system. The Fed was aware of the demand for liquidity and the possibility that banks would be unable to meet the financing demands of corporations with commercial papers coming due. In that case, additional bankruptcies and a generalized financial crisis could very well develop. To prevent such a scenario from happening, the Fed acted to forestall such a possibility. At the meeting on June 23, 1970, the FOMC determined that open market operations should be conducted with a view to moderating pressures on financial markets because of market uncertainties and liquidity strains.

The potential of a financial crisis following the Penn Central bankruptcy forced the Fed to open its discount window on June 22 to help banks meet the needs of businesses unable to roll over their maturing commercial paper. On June 23, the very next day, the Fed suspended Regulation Q interest rate ceilings on short-term large-denomination CDs.

When Penn Central eventually failed, outstanding nonbank commercial paper declined by as much as approximately $3 billion. As companies, which were shut out of the commercial paper market, turned to banks, borrowing from the discount window by the banks increased rapidly. These banks were thus capable of meeting the demands for funds from corporations that were shut out of the commercial paper market. Because money was readily available, the crisis was soon over.

7.3 The Year 1974: Franklin National

The failure of Franklin National Bank, once the twentieth largest bank in the United States, precipitated a financial crisis in 1974 (Spero 1980) that had international ramifications.

Historically, the 1970 recession ended in November with growth in real GNP for the rest of the year averaged 2.9%. That is low and atypical for the first year of recovery from a recession. And the capacity utilization rate increased only slightly from its low of 75.9% in November 1970. Additionally, the unemployment rate averaged close to 6 percent. The economic growth in 1971 was also disappointing. To maintain the system of fixed exchange rates, foreign central banks were forced to take in increasing amounts of dollars. With the pressure becoming too much to bear in late summer, President Nixon announced a New Economic Policy (NEP) on August 15 in order to address the domestic and international difficulties by suspending the convertibility of the dollar into gold, instituting a 10% surcharge on imports, freezing wages and prices for 90 days, and proposing tax legislation designed to spur economic recovery. The fiscal and monetary policy became highly expansionary in 1972. The high employment budget was in deficit throughout the year, and the monetary aggregates increased quickly.

A combination of stimulative monetary and fiscal policies, devaluation of the dollar, and wage and price controls was introduced in 1972 in the hope of producing rapid economic growth at stable prices. The capacity utilization rate climbed steadily throughout the year, and the unemployment rate declined slowly to 4.9%. Investment in plant and equipment began to increase sharply in the fourth quarter. Profits of nonfinancial corporations peaked in the first quarter of 1973. However, the investment demand remained strong, while decline in profits reduced internal funds, which forced the financing gap for capital expenditures to reach high levels in 1973. By that time, selling liquid assets could no longer be used as a source of funds, because such assets had been sold off earlier every time when the financing gap widened. For them to meet their growing need for funds in 1973, nonfinancial corporations for the most part relied heavily on bank loans, because the controls on wage and price had pushed the commercial paper rate above the prime rate so that bank financing became much more attractive to large corporations. That in turn increased bank lending to the corporate sector dramatically.

As economic activity, loan demand, and prices began to accelerate toward the end of 1972, the FOMC voted from December 1972 to August 1973 to restrain the economic growth by slowing down the growth of the monetary aggregates. However, prices continued to increase rapidly, inflationary pressure continued to escalate, and the demand for funds from the corporate sector continued at a high level. The strong demand for funds, combined with the tight monetary policy and inflation, drove interest rates to new highs, while the growth rate of real GNP slowed sharply in the second quarter of 1973. Short-term market rates fell throughout the rest of the year and into the first part of 1974, as the economy slowed further. And the start of a recession was declared by the National Bureau of Economic Research in November 1973.

Because a significant fraction of bank loans to business were of floating interest rates, the sharp increase in interest rates resulted in rapidly higher interest costs for nonfinancial corporations. Combined with falling profits, the interest coverage ratio of these corporations sunk to new lows in the first part of 1974. And due to the accounting treatment of inventories at historical cost, reported profits were overstated in 1974, when inventory prices were increasing rapidly, so that corporations paid additional income taxes on these artificially high reported profits. Also, the liquidity ratio of these corporations declined to new lows in 1974, because they were not able to finance spending needs in 1974 by drawing down their stock of liquid assets. As a result, the rate of business bankruptcies increased sharply in 1974.

Other than the corporations, the Real Estate Investment Trusts (REITs) were also borrowers who had large needs for short-term loans in this period. With the expansion of the real estate market, the REITs experienced rapid growth in the early 1970s. However, as difficulties developed in the real estate market, the fortunes of the REITs took a turn for the worse. The difficult economic conditions made many housing projects unprofitable in 1973. The rising prices and interest rates of this period rapidly escalated costs for developers. And, the shortages of materials of the time led to costly delays for many projects; the unavailability of mortgage money made many developers unable to obtain financing for their projects so that an increasing number of developers had difficulty paying their loans to the REITs, which in turn began losing money.

The failure of the Kassuba Development Corporation in December 1973 forced auditors of the REITs to require the REITs to increase their provisions for loan losses and to stop counting as income interest payments that had accrued but that had not been received. Both of these actions had a negative impact on earnings. Because it became more difficult for the REITs to borrow in the commercial paper market, they turned to commercial banks in early 1974; and the consequent increased bank loans added to the difficulties of the banks experienced from their large loan exposure to the corporate sector.

Because the monetary policy had remained tight throughout this period, except for the brief moment during the oil embargo, the banks' liquidity came under increasing strain. The low levels of liquidity and the slow growth of deposits of the time led the banks to rely on expensive purchased funds to meet the large loan demand. And because the banks increased their lending to the REITs and to nonfinancial corporations at a time when both experienced financial difficulties, many of the bank loans in 1974 were not performing. Such reliance on expensive purchased funds and loan losses affected commercial banks' income adversely, making the net income as a percentage of average total assets for all commercial banks decline in 1974. Then came the biggest shock by far to the financial system from the difficulties and eventual failure of the Franklin National Bank in 1974, where Franklin was still the twentieth largest bank in the United States at the end of 1973 with deposits of $3.7 billion. The US market for large negotiable CDs was disrupted; internationally, the crisis affected the foreign exchange and Eurodollar markets.

Consequent to the public knowledge of its difficulties, Franklin no longer had access to new borrowing in the money markets; holders of Franklin's liabilities in the domestic CD market, the Eurodollar interbank market, and foreign exchange contracts became apprehensive about the safety of their funds and tried to withdraw what they could. Finally, the markets, as a whole, became nervous, and a flight to safety and liquidity developed. Due to its previous heavy reliance on borrowed funds, Franklin's inability to borrow after May terminally damaged its continued viability, although it only declared insolvent on October 8, 1974.

What happened in 1974 posed more of a threat to the financial system than any previous crisis in the postwar period had. Additionally, the 1974 crisis threatened for the first time since the 1930s international financial system, although prompt actions by the Fed prevented the full consequences of the crisis from developing. And, this crisis was also significant in that it involved an important expansion in the concept of a lender of last resort (the Fed). Both the protection of Franklin's Eurodollar liabilities and the assumption by the Federal Reserve Bank of New York of Franklin's foreign exchange commitments were unprecedented. This experience of Franklin National was unique at the time in that it involved an expansion of the traditional responsibilities of the central bank in the United States of America. That expansion consisted of the clear and explicit acceptance of the use of the resources of the Fed to help stabilize overseas financial markets.

7.4 The Silver Crisis of 1980

The financial crisis of 1974 was the most far-reaching and the severest among those that had previously occurred in the postwar period, while the recession, which ended in March 1975, was the deepest of any since the Great Depression. Consequently in 1975 and 1976, corporations and banks turned their attention toward rebuilding their liquidity and balance sheets. However, favorable financial developments in the corporate and banking sectors started to change in 1977 and turned negative in 1978 as the economy expanded.

Investment in plant and equipment by nonfinancial corporations posted strong gains in both 1977 and 1978 with borrowing in the credit market beyond internal funds. An increasing proportion of the debt used to finance the investment was short term. So, the maturity ratio of total debt outstanding, after improving in 1975 and 1976, once again started to deteriorate in 1977 and 1978. And, the liquidity ratio for nonfinancial corporations peaked in the last quarter of 1976 and the debt-equity ratio increased in both 1977 and 1978. By the second quarter of 1978, economic activity was expanding powerfully with the unemployment rate falling to under 6% in 1978 and the capacity utilization rate climbing to 87.1% by December. The GNP price deflator increased by 14.7% during the year, and the compensation of employees in nonfinancial corporate business jumped by 15%, while the productivity growth slowed sharply. After increasing at an average of 2.6% a year during 1975–1977, the output per hour of all employees, in 1972 dollar, in the nonfinancial corporate business sector slowed to merely a 0.9% increase in 1978. The profits of nonfinancial corporations peaked in the third quarter of 1977 at 8.7% of total domestic income of the sector. Then the profits continued to fall steadily through the first quarter of 1980 since the second quarter of 1978.

Because inventory investment of nonfinancial corporations increased at a relatively high rate, and investment in plant and equipment continued its upward growth, the financing gap began to widen. Additionally, these corporations also used funds in 1978 to acquire liquid assets and to increase their net trade credit outstanding. All the expenditures were financed in 1978 almost entirely by debt. At the same time, the debt of the household sector reached record levels in 1978 with the sharpest jump recorded in consumer credit, while the rapidly increasing price level adversely affected the foreign exchange value of the US dollar. So, to slow the sharp rise in prices and the expanding credit demands, and to protect the value of the dollar abroad, the Fed began to tighten the monetary policy in April 1978. As a consequence, small time and savings deposits at all savings institutions, such as the savings and loans, jumped by more than $10 billion in the third quarter of 1978.

Although the certificates were less successful for the commercial banks, they were able to raise $86.5 billion in the fourth quarter from large time deposits, fed funds and repurchase agreements, and commercial paper. The banks used this purchased money to fund the strong loan demand, making the expansion of credit continue. Responding to the banks' activities, the Fed on November 1st announced a series of measures designed to slow the expansion of bank credit and to improve the foreign exchange value of the dollar. Although these measures moderated the steep slide in the dollar's value, they did not have as much success in restraining the growth of bank credit, which increased at an annual rate of 13.9% from December 1978 to June 1979.

Due to the second oil shock in early 1979, the oil price increased, and shortages at the same time depressed economic activity and increased inflationary pressures so that the growth of real GNP slowed in the first quarter and turned negative in the second. Productivity slowed further from its 1978 pace, unit labor costs increased, while profits dropped sharply, as did the interest coverage ratio. The slowdown in economic activity and the decline in profit share for nonfinancial corporate business were accompanied by a deceleration in investment.

Although investment in plant and equipment slowed down in the first half of 1979 at merely 1.8% annual rate, involuntary inventory investment increased, making the financing gap widen. So, the nonfinancial corporate sector increased its borrowing in the first half of 1979. During this period, consumer and other loans also increased rapidly, while borrowing by the household sector as a percent of GNP began to decline, and the net funds borrowed by the federal government in the credit markets fell to low levels in 1979. Under all these pressures, the Fed did not ease its monetary policy, and the federal funds and discount rates were held steady.

Surprising to those who predicted recession in 1979 was that as the impact of the oil shock receded, the economy rebounded strongly, and real GNP increased by 4.7% in the third quarter. Both investment and consumer spending increased rapidly, and the rate of growth of the monetary aggregates began to accelerate. To counter inflation and the growth of the monetary aggregates under control, and to stop the growing speculation and the decline of the dollar, the Fed announced three actions on October 6, 1979:

- The Board raised the discount rate from 11% to 12%.
- New procedures for monetary policy would be adopted so that it would become possible for much greater variability in interest rates.
- Reserve requirements on the managed liabilities, or "purchased" funds, of large banks would be imposed.

For all member banks with over $100 million in total of the following four nondeposit sources of funds, large (over $100,000) CDs with maturities of less than 1 year, Eurodollar borrowings, security repurchase agreements, and federal funds borrowing from nonmember institutions, the Fed also put into effect a marginal reserve requirement of 8% on net increases above a base-period level (September 13–26, 1979). Additionally, the requirement was also applied to Edge corporations and to the US branches and agencies of foreign banks whose foreign parents had worldwide banking assets over $1 billion.

This marginal reserve requirement was introduced to stop large banks from managing their liabilities so as to avoid the impact of tight monetary policy. This policy apparently succeeded in the fourth quarter when bank credit increased at only a 3.9% annual rate, while all the managed liabilities of the banks showed low or negative growth.

In terms of inflationary, although the growth rate of the GNP price deflator slowed in the fourth quarter, the growth rate of the consumer price index increased. Additionally, the inflationary expectation was kindled by rising energy prices, Soviet invasion of Afghanistan, and the Iranian hostage situation. With the arrival of 1980, beginning to accelerate was a broadly based inflation, which led to a marked increase in borrowing in anticipation of price increases.

As profits continued sharp decline and as expenditures for plant and equipment increased, the financing gap increased, reaching its highest level since the second quarter of 1974. Bank credit, which grew only at 3.9% annually in fourth quarter of 1979, jumped to 10.6% annually rate in the first quarter of 1980, while total loans grew at an 11.6% rate and business loans at 15.7%. The monetary aggregates began to increase drastically in February and grew at 6.2% annually rate. So, banks borrowed heavily at the discount window. Borrowings rose sharply in the first quarter of 1980. On February 15, the Fed again increased the discount rate a full percentage point from 12% to 13%.

With expectations of inflation and heavy demands for credit, interest rates rose to unprecedented levels, making investors in the bond markets face enormous potential losses and become reluctant to commit additional funds for long term. And, institutions and individuals who had speculated on lower interest rates were badly burned by dramatically increased rates in early 1980 with the First Pennsylvania Bank being one of the biggest losers. The savings and loan associations (S&Ls) also ran into trouble because of their commitment to financing home ownership that was not designed to cope with high and volatile interest rates.

High interest rates and declining profitability made asset quality decline for both consumer and business sectors. Consumers were trouble when real disposable personal income failed to keep up with the increasing level of debt. And, in the nonfinancial corporate sector, high interest rates and declining profitability sent the number of business bankruptcies up and interest coverage ratios down. In the extremely volatile environment of the time, many firms sharply increased their bank loan commitments, making the total bank commitments for commercial and industrial loans increased by 45.9% from January to March 1980. Hence, the financial environment was deteriorating rapidly in March. On March 14, the administration announced a program to arrest the unfavorable developments, where the president authorized the Fed to restrict and control the extension of credit.

Accordingly, the Fed increased the marginal reserve requirements on managed liabilities to 10% from 8% established in October 1979, extended these requirements to nonmember banks, and established a 3% surcharge to the discount rate on frequent borrowings of large member banks at the discount window. It also required lenders to meet a special deposit requirement of 15% on all consumer credit extended through credit cards, check-credit overdraft plans, unsecured personal loans, and secured credit when the proceeds are not used to finance the collateral. And very important was the Fed's voluntary credit restraint program, under which banking institutions and finance companies had to limit lending to US borrowers in 1980 to an increase of between 6% and 9%.

In response, banks decreased their lending sharply so that new loan growth quickly dried up. The abrupt cutoff of consumer credit threw the economy into a tailspin: The real GNP declined at an annual rate of 9.4% in the second quarter after increasing at a 1.9% in the first quarter. And production and employment started to decline rapidly in March.

The Fed's limitation on lending to financial speculation played an important role in a series of events that led to a financial crisis centered at the silver future market in late March 1980. In the late summer and early fall of 1979, a number of wealthy Arab investors drove the price of silver up in the futures markets from $9 an ounce to over $17 an ounce. On October 25, 1979 the Chicago Board of Trade established position limits of 600 contracts for each trader. That forced individuals with positions of more than that number of contracts to liquidate by April 1, 1980. However, the price of silver continued to rise and reached over $50.00 an ounce by January 18, 1980. On January 21 (Monday), 1980 the Comex delayed its opening until 1:30 p.m. and allowed liquidation only, and the CBOT took similar action starting on the next day. Immediately, the price of silver began to fall due to the rule change, the strengthened dollar as caused by the high price of silver, and because industrial users of silver looked for alternatives, refineries increased production of silver, and individuals began to sell silver possessions for their cash value. It reached approximately $35 an ounce in early February and then fell again in mid-March.

During this silver episode, the total bank credit peaked at $1.0–1.1 billion level in late March and early April. The use of domestic bank credit in connection with this situation increased by $800 million for February and March, while total business loans and total bank loans rose, respectively, by $6.2 billion and $9.3 billion on a nonseasonally adjusted basis. That is, when the Fed Board was trying to control the growth in bank credit and the use of bank credit for speculative purposes, about 13% of all business loans had gone to fuel the speculation in the silver market. Then the Fed's tough new credit controls announced on March 14, 1980 made the continuation of this enormous borrowing difficult and brought the silver crisis of 1980 to its end (Fay 1982).

7.5 The 1982 Crisis

This time the crisis centered on a crisis of confidence in the US commercial banks. Making the bad situation worse were the problems of the thrift institutions and the financial manipulations of a small Wall Street government securities firm (Kane 1989; Wilson 1986; Hightower 2013; Weintraub 1984).

Going back in time, the 1980 recession was steep, where the real GNP declined over 9% annually in the second quarter and demands for credit accordingly reduced. That led to an abrupt fall in interest rates from the lofty peaks attained in March. Surprisingly, the trough of the recession was reached in July. In the fourth quarter of 1980, the nonfinancial corporate sector increased its use of external funds, as the financing gap began to widen, making business loans at commercial banks rise at 18.2% annually in the second half of 1980. Inflationary expectations prompted the FOMC to tighten monetary policy sharply so that non-borrowed reserves increased only 2% annually rate in the last half of 1980, while the reserves had increased 35.2% annually in the second quarter. On September 25, November 14, and December 4 of 1980, the Fed raised the discount rate 1% point each time to 13%, while the federal funds rate reached the unprecedented level of 19% by December, and the prime rate passed the 20% mark in December. On November 14, the Fed also imposed on frequent borrowings at the discount window by depository institutions with ≥$500 million in deposits a 2% surcharge, which was increased to 3% in December.

In the first quarter of 1981, responding to strong economic growth, the profits of nonfinancial corporations rose; and the increasing internal funds reduced the financing gap. The tight monetary policy slowed the growth of the economy in the second quarter and made the real GNP stagnate. In the first half of 1981, the monetary aggregates, total bank reserves, and bank credit all slowed their growth; and in July 1981, the economy entered its second recession in 2 years. The financing gap continued to widen in the third quarter. Beginning in the fourth quarter of 1981, nonfinancial corporations reduced their capital expenditures and began to liquidate excess inventory stacks. So, by the first quarter of 1982, the financing gap had fallen to 6% of capital expenditures and reached a low of 17% in the fourth quarter of 1982.

Business loans by commercial banks to nonfinancial corporations increased 14.2% annually in the first half of 1982 and only 7.5% for the rest of the year. Because of the back-to-back recessions, profit levels had been generally subpar since 1979, which, together with the high interest rates and sustained short-term borrowing, brought corporate financial condition to a postwar low.

The ratio of nonfinancial corporate total debt outstanding to the market value of equity decreased in 1982 as a whole, although this ratio was influenced by the strong stock market rally in the second half of 1982. The record number of bankruptcies in 1982 depicted the worsening financial condition of the business sector. Many banks responded to the inability of some business customers to make timely interest and principal payments on their commercial and industrial loans. Even so, losses on commercial and industrial loans at commercial banks sill rose sharply in 1982, leading to 34 commercial bank failures for the year, the largest since World War II.

7.5.1 Thrift Institutions

Other than the commercial banks, the thrift institutions, such as S&Ls and mutual savings banks, also experienced difficulties of different kinds. For more details, see Kane (1989).

The difficulties of the thrifts, particularly the S&Ls, came from their financing long-term mortgages in a time of high and rising interest rates. Depositors found that money market instruments gave them higher returns than deposits with S&Ls. To partly help the S&Ls and other thrift institutions, a substantial deregulation of interest rates was put into effect in the late 1970s and early 1980s. However, in the high interest period of 1980–1982, these actions substituted one problem for another. The unprecedented levels of short-term interest rates in this period meant that the sources of funds became enormously expensive, while the interest income from the long-term mortgages, issued in a period of much lower interest rates, was grossly inadequate to cover the cost of liabilities. That is, the income of thrift institutions was adversely affected. As the operating losses of the thrifts climbed, their net worth began to deteriorate. To save the financially inviable savings and loans, the Federal Home Loan Bank Board (FHLBB) encouraged mergers of those troubled associations into stronger institutions, resulting in 296 mergers in 1981 and 425 mergers in 1982 with 483 associations ceased to exist in 1982.

To allay market fears, and to prevent any runs on S&Ls from developing, the Congress passed a joint resolution in March 1982 and boosted public confidence in the safety of deposits in S&Ls by stating that the full faith and credit of the US government stood behind the resources of the FSLIC and FDIC. However, the most significant development that improved the situation of the S&Ls was the drop in interest rates in the second half of 1982. That helped to release the intense pressure on earnings of the thrifts. And later, the Garn-St. Germain Depository Institutions Act of 1982 was passed to deal with the long-term problems of the thrifts. It authorizes the thrifts (and commercial banks) to issue money market deposit accounts to compete with the successful money market mutual funds, allows the thrifts to increase their proportion of loans, and removes some constraints on the kinds of investments the thrifts can make.

However, before the year concluded, three acute crises appeared; they threatened the stability of the US financial system and created a serious crisis of confidence in the nation's commercial banks. These three crises involved Drysdale Government Securities, Inc., Penn Square National Bank, and international lending by multinational banks.

7.5.2 *Drysdale Government Securities, Inc.*

On May 17, 1982, the headline news revealed that the Drysdale, a small government securities trading firm, owed the Chase Manhattan Bank $160 million in interest payments on borrowed government securities and could not meet its obligation.

The Drysdale was incorporated on January 29, 1982, with $20 million capital. Generally, as a dealer trading its own account, it borrowed to finance its holdings of securities by using repurchase agreements (RPs). When it sold securities to a lender, it agreed to repurchase the securities in the future. When the dealer repurchased the securities, it would pay the lender an additional sum as interest on the amount of money the lender advanced earlier. As a protection to the lender, the money advanced was usually less than the value of the securities sold measured without considering the coupon interest accrued but not yet paid. However, when Drysdale was concerned, its trouble began with reverse RPs, where Drysdale initiated transactions like regular RPs with Chase and instead of money Drysdale wanted to borrow securities; then it turned around and sold the securities outright for profits. Drysdale considered the profits as addition to its working capital and used it to acquire additional risk positions, speculating that by the time it needed to buy the securities in the market to return to Chase, the price of the securities would have dropped (the interest rate would have risen) so that it could make another round of profit. By May 17, 1982, Drysdale was doing $160 million of reverse RPs with Chase.

However, interest rates went against Drysdale; when a coupon payment to Chase was due on Monday, May 17, 1982, its losses reached $160 million and could not afford to make the payment. Chase informed the president of the Federal Reserve Bank of New York about the problem and the potential shock to the market. As the problem became known to the public and the market reaction appeared to worsen on Tuesday, the Fed indicated that it was ready to intervene in its capacity as lender of last resort and temporarily liberalized its rules regarding the lending of securities from the Federal Reserve's portfolio in order to prevent a potential disruption to the orderly functioning of the market.

By Wednesday afternoon, fears had died down, and the market continued to function without further disruption although Chase's stock fell by $4.75 a share at the close of trading on Wednesday. For more details, see Wilson (1986).

7.5.3 Penn Square Bank

Like most banks in 1982, Penn Square suffered from unusually large losses from its undiversified loan portfolio allocated mostly in the energy industry in Oklahoma. When the oil and gas industry deepened its decline, many of the loans became nonperforming, and nearly 13% of the loans were delinquent in payment. With also more than 3000 credit and collateral exceptions, Penn Square experienced book insolvency. When the market confidence in the bank dwindled, a runoff of deposits and other funding sources happened, leading to liquidity insolvency. Finally, the severe downturn in economic conditions pushed the bank over the edge.

Penn Square's failure created difficulties far beyond itself, because 43 other banks, including Continental Illinois, a very large bank, had bought large loan participations from Penn Square in the amount of over $2 billion. The losses from these loans were significant at all of the banks involved. For example, they forced Seattle First National Bank to merge with the Bank of America to avoid failure and resulted in an unprecedented government bailout for Continental Illinoisin 1984.

However, Penn Square's failure also made all banks have difficulty selling their CDs, as a flight to better quality investments developed. With depositors and major banks suffering large losses, the crisis of confidence in the banking system grew.

Concerned about the implication of Penn Square's failure for the health of the financial and banking systems, the Fed took actions: receiver's certificates would be acceptable as collateral for borrowing at the discount window for credit unions and others to meet their potential liquidity needs. For more details, see Hightower (2013).

The banking system eventually survived the Penn Square failure. However, it was soon hit by the debt repayment problems of the less developed countries (LDCs), signaled by Mexico's announcement in August, 1982 that it could not afford to make its payments on loans outstanding to over 100 commercial banks.

7.5.4 Mexico

This announcement posed a serious problem for banks in the United States, because $24.9 billion of the approximately $80 billion in loans that Mexico had outstanding was owed to US banks and the combined loan value of the nine largest US banks totaled $13.4 billion, nearly 50 percent of the nine banks' total capital.

The deep recession in the United States and other industrial countries in 1982 deeply affected Mexico and its exports; and high interest rates in the United States increased Mexico's repayment burden on its short-term, floating interest rates debts. A substantial and sustained capital flight developed as the situation worsened. In desperation, Mexico imposed exchange controls and appealed to the United States for aid.

Over the weekend of August 14–15, the United States granted Mexico $2 billion in emergency credits with advance payments made by the Department of Energy for $1 billion worth of Mexican oil and the US Commercial Commodity Corporation another $1 billion for grain imports from the United States. Also, a $1.5 billion bridge loan was arranged by the Bank for International Settlements, which is made up of central banks from the major industrial countries.

On Friday, August 20, 1982, Mexican officials met with representatives of over 100 banks from around the world to consider a restructuring of Mexico's foreign debt in New York. The final agreement included a 90-day postponement of $10 billion in debt principal that was coming due and $1 billion in new credits from American banks guaranteed by the US government. In addition, an announcement was made that $4.5 billion of new credits from the International Monetary Fund were expected by mid-October.

Other than the emergency aid, the ending of the recession in the United States in 1982 and lower interest rates in the second half of the year also helped relieve the pressure on the banking system. For more details, see Weintraub (1984).

7.6 The 1980s: Emerging Markets Debt Default Crises

Economic shocks of the 1970s led to economic crises in the 1980s and made developed nations to feel obligated to assist developing nations to finance their needs. Then the mounting debts acquired by developing nations became a tremendous liability when interest rates ratcheted up in response to escalating inflation. That led to the so-called debt crisis, the subsequent financial problems in liquidity squeeze the debtor nations experienced throughout the world, especially Latin America. At the same time, Asia recovered quickly because of high rates of growth, state intervention, and capital controls.

Developing nations suffered from both the oils shocks of the 1970s and declining aids. The decreased assistance to developing nations in the early 1970s created a gap for financing oil imports and economic development; commercial banks captured the opportunity and filled the gap with petrodollars by providing structured loans using floating interest rates (Giddy 1994).

Latin American nations turned from import substitution industrialization policies to export-oriented production. When developed nations' demand for goods from Latin America weakened, the export sector of Latin America stagnated with tax revenue diminished, creating growing deficit (Griffith-Jones and Sunkel 1986). The cyclical nature of the economic base, the export industry, and international credit flows jointly exposed Latin American nations to external shocks.

When Paul Volcker, chair of the Fed, raised the federal funds rate to fight inflation in the United States in late 1979, 1980, and 1981 (Goodfriend 2005), the United States experienced recessions with strengthened dollar and increased LIBOR rate, to which most of the floating rate debt was tied. That caused difficulties for developing countries to repay and service their debts (Kahler 1985), while the exports of Latin America were weakened, leaving these countries with reduced income to cover their increasing debt service. With the deteriorating situation, starting in 1980, banks stopped lending to developing countries. These made developing countries face a sudden stop in economic growth and in access to foreign credit (Meissner 1984), and international banks, particularly US banks, face enormous potential losses from their outstanding loans.

The debt crisis came to light on August 12, 1982, when Mexican finance minister Silva Herzog announced that Mexico could not meet its upcoming payments to foreign debt, because Mexican earnings from oil export had dropped unexpectedly, while interest rates suddenly increased. Other countries experienced similar situation: increasing interest rates. And with declining prices of commodities, the shocks of sharp reduction in foreign lending rippled across the developing world (Sachs 1989). Local currencies were overvalued, and devaluations were expected, which made capital flight viewed as speculative attacks against the local currencies (Edwards 1989b).

The debt crisis could cause many international banks, especially US banks, into insolvency and therefore threatened to stop trade and finance between developed and developing nations. That would wreak havoc on the international financial system through interrupted trade and finance between developed and developing nations. So, developed nations had a stake in maintaining liquidity in the system and enforcing debt payment (Kapstein 1994).

The four most indebted countries were Mexico, Venezuela, Argentina, and Brazil. Jointly they held 75% of commercial bank debt. And the larger debtors were located in Latin America, including Bolivia, Chile, Colombia, Costa Rica, Ecuador, Peru, and Uruguay, in the Caribbean (Jamaica), in Asia (the Philippines), in North Africa (Morocco), in the South Sahara (Nigeria and Ivory Coast), and in Eastern Europe (Yugoslavia) (da Costa 1991). Countries in sub-Saharan Africa also faced debt-servicing problems although they had relatively smaller levels of debt.

What brought these nations in debt was their rapid growth due to increasing international trade during 1965–1973, and then they were forced to borrow during the oil crises in order to maintain growth and hence suffered from the subsequent interest rate rise. During 1980–1982, the recession in developed countries collapsed the prices of commodities, which in turn worsened the matter for developing nations (Griffith-Jones and Sunkel 1986).

To counter the debt crisis, central banks made emergency loans to Mexico, Argentina, and Brazil; and some countries, such as South Korea, cut budget deficits and devalued exchange rates (Sachs 1989). Although fiscal spending during crisis could alleviate the impact of the downturn, fiscal spending in Latin America continued to favor social groups that were better politically represented. With reducing tax revenue, deficits increased (Edwards 1989b). When the deficits were financed by printing money, the subsequent devaluations pushed the already weakened economies into hyperinflation during 1980–1987 (in Brazil and Mexico) (da Costa 1991). To stabilize the exchange rates and prices of goods, central banks drastically exhausted their foreign exchange reserves. Following the Mexico bail out (see the end of the previous section), Argentina and Brazil soon spiraled into crisis, too, received aids from the largest central banks, and rescheduled their payments with the IMF and the banks. As expected, the debt reliefs were linked to structural reforms (Rotberg 1989) and transfer from short-lived consumption-based policies to job-creating investment-oriented policies (Rhodes 1989), most of which were punitive toward the country undergoing them.

Accompanying the debt crisis, income and employment in developing nations dropped, and poverty soared, because loan repayment took precedence over economic well-being. That was translated into a real shock for the citizens of these countries, many of whom were unable to pay for housing and utilities, such as water, sewage, and electricity (Griffith-Jones and Sunkel 1986).

Devaluation occurred with most major debtors adopting a crawling peg regime as of July 1986 and multiple exchange rate regimes, where different exchange rates on capital and current account transactions protect private sector repayment of foreign debt (Edwards 1989b).

What shocked the international community and prompted the implementation of the Baker Plan for debt relief was the declaration by President Alan Garcia in Peru in 1985 that the country's responsibility to its citizens took precedence over its responsibility to creditors (Collas-Monsod 1989). US Treasury Secretary James

Baker further pushed for growth-oriented structural adjustment, deregulation, and export promotion in developing nations. After 2 years, it was clear that the Baker plan was not working: The economies experienced ongoing distress; the prices of nontradeables in indebted countries collapsed, leading to a profitability crisis in the production of nontraded goods; and banking systems in developing countries deteriorated, resulting in banking crises (Sachs 1989).

In 1987, Brazil announced its suspension of interest payments to protect its diminishing supply of hard currency while attempting to renegotiate its debt with commercial banks (Riding 1987). In response, Citicorp, the largest commercial bank of the time, signaled its decision of not making new loans to developing nations by adding US$3 billion to its loan loss reserves; other banks followed the lead, and lending to the indebted nations dried up (Kapstein 1994). Brazil and Mexico jointly accounted for over 72% of reduced external debt transactions.

To recover the debt, innovative debt reduction structures were employed: Chile retired nearly 15% of its medium- and long-term liabilities to commercial banks through debt-equity swaps (Larrain and Velasco 1990); Bolivia used debt buybacks to reduce its debt (Mohanty 1992); and Mexico used securitization to offer creditors the opportunity to exchange Mexican debt for a smaller amount of debt that would be backed by US Treasury bonds and carry a higher spread (Newman 1989). By 1989, many banks had recovered about 40% of their original loans (Cohen 1992). Then in 1989, Nicholas Brady, the US Treasury Secretary, introduced a new approach for debt reduction, which used the IMF and World Bank to collateralize debt-for-bond exchanges at large discounts, to replenish reserves after cash buybacks of debt took place, and to underwrite payment of new and modified debt contracts (Mohanty 1992). With some resistance from the commercial banks, the secondary market responded well to the plan.

In short, neither the Baker Plan nor the Brady Plan was able to prevent a net transfer of resources from developing to developed nations (da Costa 1991). Between 1981 and 1988, per capita income in Latin America declined; living standards fell; triple and quadruple digit inflation raged as seigniorage was employed to replace capital inflows (Sachs 1989). For more details, see Hsu (2013), and for how the 1980s was viewed differently, please consult with Bilginsoy (2015).

7.7 Early 1990s: Advanced Countries Crises

During this time period, what occurred include the Western Europe Exchange Rate Mechanism crisis in 1992, the Nordic country crises, and the Japanese crisis that continued throughout the decade.

The Western Europe Exchange Rate Mechanism was created in 1979 when the European Monetary System (EMS) was established to smooth out exchange rate shocks after Bretton Woods failed. The EMS consisted of the European Currency Unit (ECU) and a system of managed float exchange rates, the Exchange Rate

Mechanism (ERM). The ERM was created for producing an orderly internal market for goods and assets without barriers to trade by stabilizing exchanges rates between the member countries (Higgins 1993). It was coordinately adjusted to suit individual countries' macroeconomic fundamentals without any unilateral realignment allowed.

The European Monetary Union (EMU) was created in stages starting in 1990. When capital controls were removed by the participating nations, the ERM became at once less flexible and more subject to exchange rate pressures, two critical safety valves of capital and exchange controls. At this critical moment, German reunification occurred and West Germany worked to raise the living standards of East Germany. That caused the ERM crisis because excessive funds were transferred from West to East Germany and West Germany's public sector financed its budget deficit (Buiter et al. 1998). The increased consumption led to demand-driven inflation and increased interest rates in Germany, which in turn transmitted inflation and higher interest rates to other partner countries in the EMU. That caused the macroeconomic fundamentals in terms of unemployment, output gaps, inflation, and debt, in France, Spain, Italy, Sweden, the United Kingdom, and jointly in the ERM to deteriorate, providing cause for later devaluation of local currencies and floatation of individual exchange rate systems (Krugman 1996). Loss of competitiveness according to price and cost indicators occurred in Spain, Portugal, and Italy, while the United Kingdom entered its worst recession since World War II.

When the Finnish peg collapsed in 1991 due to the Nordic crisis, the markka depreciated against the deutschmark by 15%, indicating that there were intra-European exchange rate disequilibria. Denmark's rejection of the Maastricht Treaty, which intended to lead to further European monetary and economic integration, started a downward spiral in the ERM in 1992 (Eichengreen 2000). An outflow of capital followed. The appreciation of the British pound and Italian lira was insufficient, and speculative attacks on the pound and other non-German ERM currencies occurred, forcing Italy, the United Kingdom, Norway, and Sweden out of the ERM. On July 1993, almost all currencies were at the bottom of their bands against the deutschmark, and on August 1, under persistent pressure, the "hard" ERM was replaced with a much softer ERM policy (Buiter et al. 1998). Speculative attacks lessened, as Europe's commitment to monetary unification allowed member countries to recover their exchange rate credibility.

Let us now turn our attention to the Nordic country crises.

Norway, Sweden, and Finland, three largest Nordic countries, experienced a period of large boom and bust in the 1980s and 1990s. They had tight control of their banking systems until the 1980s (Drees and Pazarbasioglu 1998). Rising inflation and restrictions on nominal interest rates created further constraints on the financial system. To prepare for the development of a European-wide financial system, regulators decided to deregulate in order to increase efficiency so that interest rate restrictions were removed and the financial markets opened up to foreign competition. In step with the liberalization, the economy grew and credit demand climbed. Both household and corporate borrowers incurred debt to purchase assets, pushing the housing and equity prices higher in the late 1980s.

Because no party knew how to respond to the deregulation and associated downside risks, each just acted in self-interest to maximize perceived profitability. When the business cycle turned, it became clear that the boom was in fact a bubble, which burst in the late 1980s and early 1990s. Responding to the crises, capital was injected into banks and government takeovers of banks followed (Mai 2008). Creditor guarantees were issued in both Sweden and Finland; and the crisis was brought under control quickly.

Similar to the Nordic crises, Japan's financial crisis began in the early 1990s with the bursting of the real estate bubble developed in the 1980s as a consequence of deregulation and culminated in 1997 and 1998 (Nakaso 2001). However, for Japan, its problem was structurally grounded in the real economy.

After very rapid economic growth in the 1950s and 1960s supported by historically large rates of investment and major government involvement, Japan's growth slowed in the 1970s. The oil shocks of the time strongly affected the US economy, while Japan, an export-oriented economy, suffered from a rising yen in relation to the dollar (Brenner 2006). So, since the mid-1970s, Japanese companies had engaged in stocks and bonds to increase profits. Coupled with the liberalization of finance, that led to a period of speculation in real estate and others, creating a growing bubble through the 1980s. The Plaza Accord in 1985 allowed yen to appreciate. As an export-oriented economy, that set the stage for economic decline in Japan. The financial deregulation in the late 1980s led to an expansion of risk-taking activities with poor ongoing risk evaluation. The growing government spending and loose monetary policy created an overheated economy (Gao 2001).

Recognizing by 1990 that the lending boom at the end of the 1980s had led to the real estate bubble, Japan's Ministry of Finance imposed temporary lending restrictions for the real estate sector. That deflated the real estate bubble, led to a decline in economic growth and an immediate asset-price crash (Bernanke 2000). The tightening until 1994 created continued asset price decline. GDP contracted over the decade, while nonperforming loans became a monstrous issue from 1992 until 2000, cumulatively forming 17% of the GDP. In 1994, the crisis began to strike harder and Yasushi Mieno, the Governor of the Bank of Japan, stated that the government would not save all failing financial institutions (Nakaso 2001).

After 1994, the overnight call rate was lowered by the Bank of Japan and eventually reached zero in 1999 in attempts to revive the economy (Hoshi and Kashyap 2004). Deflation began in 1994 and continued for years in the face of yen appreciation, lowering interest rates. That caused decreased investment in local industry and consumers to hold cash due to uncertainty of the future. By the mid-1990s, it became clear that the economy would not recover on its own and restore viability to nonperforming loans and flagging businesses. Starting in 1997 when major financial institutions faced solvency issues, taxpayer funds were used to assist failing banks; and deposit insurance was extended to fully insure depositors until March 2001 (Fukao 2003).

The crisis spread into security houses in the fall of 1997, resulting in a freeze of the entire interbank market, into which the Bank of Japan injected large amounts of liquidity. At the end of 1997, when Tokuyo City Bank failed, bank runs began. The market confidence was weakened further as the Asian financial crisis occurred in Southeast Asia.

Major steps were taken in 1997 and 1998 to curb the crisis as part of a "Big Bang" financial system liberalization and reform. The Financial Crisis Management Committee was organized in 1998 to direct newly legislated public funds to handle the crisis. Legislation was passed under the Financial Reconstruction Law to deal with failed financial institutions; economic measures were implemented in April 2001 to resolve corporate debt and deal with nonperforming loans (Okubo 2003).

Several reasons existed for Japan's financial meltdown. Because of deep economic structural problems (Gao 2001; Bernanke 2000), Japan's economy became unproductive; the consequent lack of profitability led firms and individuals to speculations. At the same time, Japan had insufficient provisions against loan losses and an antiquated financial system. Although banking accounted for most of the financial sector, banks lacked measures sufficient to deal with risks. After the crisis broke out, there was still an optimistic expectation that the problems would disappear on their own and asset prices would automatically rise. Until the late 1990s, the policy changed from preventing failure to accepting inevitable failures while limiting the repercussions. Then, risk management played a critical role.

For a more detailed discussion, please consult with Hsu (2013).

7.8 The Mid-1990s: Mexican Crisis and Asian Financial Crisis

In the mid-1990s with the continuing liberalization, countries opened themselves up to volatile capital flows and experienced worsening financial crises. Because the prevailing belief was that liberalization was the path to growth, Mexico was eager to pick up its speed of economic development. Similarly, industrializing economies in Asia also followed the path. Although the initial stage seemed to be working beautifully, the wonder did not last with capital flows switched direction, causing currency and banking crises and threatening the financial stability of the world.

First, let us look at the Mexican crisis.

From a balance of payments crisis and political events in 1994, Mexico was led to a financial crisis, dramatic currency devaluation, and crisis of confidence (Springer and Molina 1995). In particular, policies implemented in the late 1980s were attempted to increase the competitiveness of the economy through liberalization, known as El Pacto, a pact between government, industry, and labor organizations (Gallagher 2007). The peso was pegged to the US dollar and later allowed to float within a band. As expected, Mexico's direct and portfolio investment increased with capital inflows during 1991–1993 equal to about 15 times of those of the previous decade (World Bank 2012). However, when adverse conditions developed, the capital flows changed course after the first half of the 1990s. Mexican commercial banks owed a lot of short-term debt to foreign creditors

(Cypher 1996). The growth of loans between 1988 and 1994 was mainly for consumer credit and did not generate growth, while foreign capital inflows pushed the interest rate higher in the face of falling inflation. Unemployment increased as the nominal exchange rate was maintained at the cost of economic growth. That opened up the possibility of devaluation. Political instability set in when the Zapatista movement declared war against the government and seized several cities and when two important political figures were assassinated. The Salinas administration started to loosen monetary policy as 1994 set in; Mexican tesobonos, short-term bonds issued by the government and indexed to the dollar, were designed to allow investors to reduce their peso risk without losing their position in Mexico but essentially shielded foreign investors from the risk they took (Ramirez de la O 1996). The tesobono problem became clear with the rising prospect of devaluation.

Additionally, President Zedillo did not seem to continue the ongoing economic reform, while his administration did not recognize that the ballooning current account deficit, wrongfully seen as the result of foreign capital inflows, was partially financed by using international reserves in the second half of 1994. The Bank of Mexico assumed that a developing country could carry large external deficits over a long period of time, while bankers were undertaking risky practices to increase their profits in a slow-growth environment. When the government had to spent international reserves to defend the peso in November, capital flight started massively. On December 22, 1995 (a year later), the peso was allowed to float by 15% and immediately depreciated (Springer and Molina 1995), which pushed Mexican economy into crisis. After the peso lost 50% of its value, emergency measures were finally announced, touting austerity, sell of public enterprises, and cuts in government spending (Smith 1996). An international relief package was put forward at the end of January 1995. But the trouble was not over Mexico proceeded to suffer from a banking crisis through September 1995 with the number of nonperforming loads nearly doubling from the previous year (Cypher 1996).

The immediate impact of the crisis was painful, including failures of business enterprises, drastic fall in the overall production, rising unemployment, and inflation. Even so, the policies implemented to overcome the crisis eventually yielded a recovery: the GDP fell by over 6% in 1995 but increased to 5.6% in 1996; the unemployment rate decreased from 7% in 1995 to 3.5% in 1998; and the inflation skyrocketed to 52% in 1995 right after the crisis but decreased in sequent years. The current account deficit benefitted from the adoption of the new exchange rate regime and dropped down to 1% in 1997. And, the public debt declined and international reserves increased.

This Mexican crisis, however, also severely affected Argentina by reversing the foreign capital inflows with bank deposits and central bank's international reserves falling drastically (Bouzas 1996). And there appeared speculative attacks against the dollar-convertible Argentine peso, making the overall situation dire by February 1995. In response, the monetary base was dollarized, and monetary authorities used excess reserves to aid institutions with liquidity problems. The IMF extended a loan in 1995, fiscal spending was cut, and the tax base was extended. All these measures curtailed the crisis (Bouzas 1996).

Next, let us look at the Asian crisis.

This financial crisis which began in 1997 was both a banking and a currency crisis, caused by large-scale short-term yen and dollar capital inflows into Thailand, Indonesia, South Korea, and Malaysia and to lesser extent into Singapore, the Philippines, and Hong Kong, along with fixed, overvalued exchange rates. Asset price bubbles in all these countries developed with the increased demands; the crisis officially began when the Thai baht started to float on July 2, 1997 and continued until the year-end by the floating of the Indonesian rupiah, the Korean won, the Malaysian ringgit, and the Philippine peso as the asset price bubbles burst. In particular, capital inflows increased with these countries' financial liberalization, which lifted the established capital controls and resulted in current account convertibility of currencies. For example:

- The Indonesian liberalization led to a threefold increase in the number of private banks between 1988 and 1996 (Haggard 2000), while foreign investors were allowed to participate in the stock market up to 49% of the ownership of listed stocks and foreign direct investment in additional sectors (Desai 2003).
- Thailand in 1989 initiated the Bangkok International Banking Facility (BIBF), allowing banks to borrow abroad and lend domestically in order to make Bangkok a regional financial center. That took place during a period of political strife so that the newly deregulated banking sector was not closely monitored (Wade and Veneroso 1998). During 1992–1996, BIBF led to Thailand's two-thirds of the increase in external debt (Hanna 2000).
- Malaysia since the early 1990s allowed foreign investors to own domestic corporations up to 30%, removed interest rate control in 1991, and liberated capital controls in 1995, in order to establish Kuala Lumpur into a leading financial center in Asia (Desai 2003). As a result, banks lent aggressively in real estates; privatization took place (Perkins and Woo 2000).
- South Korea decontrolled interest rates, lifted controls on foreign borrowing and foreign investment in commercial and financial securities, and directed large business conglomerates to focus on core industries to acquire exemptions of credit controls and barriers to investment and entry. The government continued liberalization of the capital account by not implementing prudential regulations and supervisions.

Combined with the growth frenzy, these countries became attractive to foreign investors. Short-term capital flowed into the region quickly and massively, making monitoring impossible (Alba et al. 1999). At the same time, foreign borrowing was used for investment rather than consumption (Goldstein 1998). And other than firm-level weaknesses that deteriorated the corporate sector (Claessens et al. 2000), leverage skyrocketed to 200% of GDP in 1997 (Hanna 2000). The appreciation of the US dollar, therefore Asian currencies, in 1996 led to decline in export growth in Thailand and Korea. That made cost competiveness erode due to the increase in prices of nontraded goods and services, forcing the real exchange rate to appreciate. The cyclical correlation between each of these countries' economies created regional multiplier effects that amplified the difficulties (Wade 2001). Additionally, residential real estate prices in Thailand, Indonesia, and Malaysia began to fall, indicating the real estate bubble in these countries was starting to burst (Berg 1999). Percentage of profits going to cover interest expenses increased to somewhere between 30% in Indonesia and 85% in South Korea.

The tsunami of the crisis started when a South Korean conglomerate declared bankruptcy in January 1997; Somprasong Land, a Thai company, became delinquent on foreign debt in February; and Indonesia's growth reversed 18% (Radelet and Woo 2000). The stock market and bank lending remained strong until mid-1997 when they suddenly reversed. With increasing outflow of foreign exchange in Southeast Asia, Thailand and South Korea tried to defend their currency pegs (Berg 1999). In May 1997, the Thai baht was attacked by international hot money, which drained Thailand's reserves. On July 2, 1997 when Thailand devalued its currency and placed the baht on float, other countries in the region felt the pressure to devalue or face speculative attacks. Most affected by the crisis were Thailand, South Korea, and Indonesia.

To have the crisis under control, several measures were employed (Berg 1999):

- Rolled short-term debt into medium term
- Closed down insolvent institutions while specific institutions were created to take over, manage, and strengthen the banking system
- Exercised fiscal disciplines
- Gradually tightened the relatively loose monetary policy when the local currencies became more stable

For more detailed analyses of these crises, please consult with Hsu (2013), Bilginsoy (2015), and Moro and Beker (2016).

7.9 Late 2000s: The Great Recession of 2008

The great recession began in December 2007 and ended in June 2009. It was related to the financial crisis of 2007–2008 and US subprime mortgage crisis of 2007–2009. The great recession had resulted in the scarcity of valuable assets in the market economy and the collapse of the financial sector in the world economy. The crisis was caused by an excessive rise in asset prices and associated boom in economic demand. The US securities backed by mortgages were issued largely. Additionally, the shadow banking system in the United States was expanding and made the financial system vulnerable. Because many of these securities were backed by subprime mortgages, when house price drops much, homeowners would default on their mortgage payments.

According to Figs. 7.1 and 7.2, the house price in the United States rose quickly during 2005–2006 and then declined suddenly afterward. When the housing bubbles burst, private residential investment, such as housing construction, fell by as much as nearly 4% of the national GDP, and consumption enabled by bubble-generated housing wealth also slowed. That created a gap in annual demand (GDP)

Fig. 7.1 All-transaction house price index for the United States (Source of data: Federal Reserve Economic Data)

Fig. 7.2 House debt to GDP for the United States (Source of data: Federal Reserve Economic Data)

of nearly $1 trillion. The US government was unwilling to make up for this private sector shortfall (Wisman 2012). With loan losses mounting and the fall of Lehman Brothers on September 15, 2008, a major panic broke out on the interbank loan market, while a bank run on the shadow banking system appeared, resulting in many large and well-established investment and commercial banks in the United States and Europe to suffer from huge losses and even facing bankruptcy. What followed is the global recession, which resulted in a sharp drop in international trade, rising unemployment, and slumping commodity prices.

During the Great Recession, the United States suffered from persistent high unemployment, drop of real GDP and house price, increase in foreclosures and personal bankruptcies, and increase in federal debt and inflation. Table 7.1 shows that the real gross domestic product (GDP) began declining in 2008 and reached the lowest level in the second quarter of 2009. In 2009 the US GDP was at $14.38 trillion. By the final quarter of 2012, the US GDP had grown in the amount of 7.02%, equal to $15.38 trillion. The unemployment rate was only 5.01% at the start of 2008. When the crisis began, it rose to 10.08% by the third quarter of 2009 and then declined very slow to 7.95% by late 2012.

This crisis forced Europe to develop from its banking system crises to sovereign debt crises. Other than Germany, most Europe countries had an increasing government debt-to-GDP ratio. For Greece, for instance, the government debt-to-GDP

Table 7.1 Real GDP and unemployment rate of the United States

Time	Real GDP (USD billions)	Rate of change compared to 2006-01-01	Unemployment rate: aged 15–64: all persons for United States
2006-01-01	14546.1		4.79%
2006-04-01	14589.6	0.30%	4.74%
2006-07-01	14602.6	0.39%	4.70%
2006-10-01	14716.9	1.17%	4.52%
2007-01-01	14726.0	1.24%	4.58%
2007-04-01	14838.7	2.01%	4.56%
2007-07-01	14938.5	2.70%	4.71%
2007-10-01	14991.8	3.06%	4.86%
2008-01-01	14889.5	2.36%	5.01%
2008-04-01	14963.4	2.87%	5.41%
2008-07-01	14891.6	2.38%	6.11%
2008-10-01	14577.0	0.21%	6.98%
2009-01-01	14375.0	−1.18%	8.39%
2009-04-01	14355.6	−1.31%	9.38%
2009-07-01	14402.5	−0.99%	9.74%
2009-10-01	14541.9	−0.03%	10.08%
2010-01-01	14604.8	0.40%	9.96%
2010-04-01	14745.9	1.37%	9.83%
2010-07-01	14845.5	2.06%	9.60%
2010-10-01	14939.0	2.70%	9.69%
2011-01-01	14881.3	2.30%	9.17%
2011-04-01	14989.6	3.05%	9.20%
2011-07-01	15021.1	3.27%	9.11%
2011-10-01	15190.3	4.43%	8.80%
2012-01-01	15291.0	5.12%	8.36%
2012-04-01	15362.4	5.61%	8.26%
2012-07-01	15380.8	5.74%	8.10%
2012-10-01	15384.3	5.76%	7.95%

Source data: Federal Reserve Economic Data

ratio increased from 143% in 2010 to 165% in 2011 to 185% in 2014; and the public-debt-to-GDP ratio increased from 143% in 2010 to 165% in 2011 to 185% in 2014. Eurostat reported that Eurozone unemployment reached record levels in September 2012 at 11.6%, up from 10.3% of the prior year; and the unemployment varied significantly by countries (Smith 2012).

Poland and Slovakia are the only two members of the European Union that avoided a GDP recession during the years affected by the Great Recession. Although India, Uzbekistan, China, and Iran experienced slowing economic growth, they did not materially enter recessions.

This financial crisis did not affect developing countries because, to a great extent, these countries were not fully integrated in the world market. For a great reference, see Grusky et al. (2011).

7.10 Some Remarks

The purpose for us to list in this chapter some of the major financial crises that occurred since 1929 is for the reader to learn how each of these disasters had brought forward hardships for the people who experienced any of the crises. At the same time, such exhibition of the relevant history provides a solid reason for why one needs to investigate the mechanism for how financial disasters occur, how such crises could be potentially avoided, or, if not possible to avoid, how the disastrous consequences could be potentially lessened.

This chapter is not intended to be exhaustive. In fact, there is no way anyone could provide an exhaustive list of all crises, because from different angles, crises can be defined differently. For example, Bilginsoy (2015) considers how financial events and various economic theories do not agree; Moro and Beker (2016) presented modern time financial crises that appeared in Argentina, the United States, and Europe; Hein et al. (2016) look at how financialization and financial and economic crises are related; Dimsdale and Hotson (2014) presented collective views of various British financial crises since 1825; and Skrobec (2015) listed 100 most important American financial crises.

Beyond what are listed in this chapter, other major and severe financial crises will be discussed in other chapters of this book, while some of the listed crises in this chapter will be looked at again in different lights.

Chapter 8
Effects of Foreign Capital on Economic Security

Jeffrey Yi-Lin Forrest, Yirong Ying, Zaiwu Gong, Kurt Schimmel, Sifeng Liu, and Jeananne Nicholls

Contents

History indicates that foreign capital provides development funds for economies and brings along advanced technology, equipment, and management so that the receiving economies benefit greatly. With these positive spillover effects for the domestic economies, one should also realize that excessive and disproportionate use of foreign capital also creates serious negative effects on the economic safety of the domestic economy. To guarantee the health and stable development (or the security), this chapter shows the necessity for the receiving economy to constantly monitor and forecast the movement of foreign capital within itself so that appropriate methods of regulation could be established.

By taking the approach of systems analysis in general and the systemic yoyo model in particular, this chapter critically analyzes the existing literature on positive and negative effects of foreign capital. The analysis shows that although the

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positive effects of foreign capital are desirable, the negative effects of foreign capital and consequent disastrous aftermath cannot be ignored. That is, the effect on the economic security of the receiving economy cannot be overlooked.

This chapter indicates that the intuition provided by the yoyo model can be beneficially employed in the study of money and its movement, and what is concluded in this chapter is expected to bring forward practically meaningful consequences in the relevant economic policy making.

8.1 Introduction

Along with the acceleration of globalization and the formation and development of international production systems of multinational corporations, both international trades and international direct investments promote and develop mutually with each other. And the trade effect of international direct investments has become one of the important research topics in the theory of international trades. In the 1950s and 1960s, Mundell (1957), Hirschman (1958), Vernon (1966), and others conducted preliminary studies on this topic. In the 1980s, Kojima and Osawa (1984), Hennart (1982), Cushman (1985), Dunning (1988), Brouthers et al. (2015), and others furthered the investigation along this line and integrated the traditional theories of trade effects of international direct investments. Starting in the middle of the 1980s, Bhagwati et al. (1992), Boddewyn (2015), and others looked at this issue from the angle of political economics. The relevant works indicate that the effects of foreign direct investments on the international trades of a nation or a region are not isolated (Edmund and Zou 2015). Instead, the faster the scale of international trades develops, the greater the attraction there is to foreign capital, while the foreign capital also plays an obvious leading role in increasing the growth of exports of the hosting country. For a good survey on the studies of foreign direct investment theories, see (Denisia 2010).

Along with the influx of foreign capital, there come not only advanced production technology and scientific management methods, which increasingly stimulate the economic development of the economic system, but also promotion for optimal adjustments, to a certain degree, to the existing industrial structure within the economic system. This development and adjustments are beneficial to the entire economic system for its healthy growth and operation (Forrest and Tao 2014). Hence, an influx of foreign capital has its positive significance. However, at the same time, we recognize that as industrial capital, the essence of foreign direct investments is in their constant movement (in similar fashions as "flowing water") and always goes after the optimization of return. In other words, the only goal for foreign capital to enter an economic system is to seek the maximum return instead of being a gift or doing charity. Therefore, along with the influx of a lot of foreign capital, the effect of the foreign capital on the economic security of the receiving economic system is complex and multifaceted, and there are inevitably some factors that affect the economic security of the hosting economic system.

Safeguarding national economic security is seen as a priority for nations (Blanchard et al. 2014; Hacker et al. 2014). In 1980 the Research Institute for Peace and Security of Japan published a comprehensive report on national security, which posed the question of economic security for the first time in history, and treated economic and military securities as important components of national security. Since then, many countries around the world, such as the United States, Germany, France, Canada, South Korea, Russia, and others, have formed government entities, such as that of foreign investment review board, to safeguard their national economic security by reviewing business mergers and acquisitions by foreign entities and capital (Gen-hua 2011; Buzan et al. 1998). The fourth session of the tenth National People's Congress of China, held in Beijing during March 5–14, 2006, emphasized the need to "continuously improve the quality of opening to the outside world . . . and at the same time pay attention to the maintenance of the national economic security" (Reports on Government Works 2006). So, "economic security" has been a big issue of general importance for various economies. Also, because different economies have correspondingly different specifics, the main focuses of their economic securities are different. For relevant discussions, please see UNCTAD (2012).

The importance of economic security to the economic system is obvious, because the former is in fact the material foundation for the existence and development of the latter. It can be said that without the necessary economic security, the economic system would not have its economic and political independence. Especially since the time when the world entered the 1990s, with the dismantlement of the Soviet Union, the cold war ended; the world configuration changed from military standoff to economic collaborations and struggles. Therefore, when economic systems employ foreign capital to promote their economic development, they have to be vigilant and place their economic security and independence into a position of paramount importance. Hence, for foreign investments, we should take a positive and prudent attitude by making use of the advantages while avoiding the weaknesses: At the same time, when we actively introduce foreign investments for the purpose of promoting economic development, we also need to have a clear understanding of the adverse effects of utilizing foreign investments by formulating relevant countermeasures and by following appropriate procedures to ensure a healthy and orderly development of the economic system. That is, we need to protect the economic security of the receiving economic system.

This chapter is organized as follows: Sect. 8.2 discusses the positive roles of foreign capital on a nation's economic security. Section 8.3 looks at some of the adverse effects of foreign capital on the receiving nation's economic security. Section 8.4 concludes the presentation of this chapter by posting a challenging question of how the receiving economy could monitor and forecast the state of motion of foreign capital.

8.2 Positive Effects of Foreign Capital on Economic Security

Before any foreign capital enters into the (receiving) economic system, we can see the economic system as a closed system. Because of the differences in the bases on which economies develop, geographic conditions, labor qualities, capital levels, etc., there is unevenness in the distribution of resource within the development of the economic system. According to the yoyo model of the general systems theory, everything in the physical world, no matter whether it is a materialistic entity or a theoretical abstraction, no matter whether it is a form of life or an organization of humans, can be abstractly viewed as a yoyo body with its spin field in a multidimensional space. As such, a yoyo body stays in a constant spinning motion. If the yoyo structure of a certain system stops its spinning movement, then the system no longer exists substantively. For relevant detailed discussions, please consult with Lin (2007, 2008). Now, using systems theory if we can view the economic system as a yoyo body with its spin field, then the distributional unevenness of resources within the economic system makes gradient forces emerge between different economic regions (in other words, this distributional unevenness creates differences in the economic development momentums of the economic regions). The existence of such gradient forces keeps the economic system maintaining its spinning speed, which in turn promotes the development of the economic system. However, due to the limitation of resources that naturally exists within the economic system, the speed of development of the economic system, as maintained by the gradient forces, is relatively slow. Hence, to speed up the economic development of the system and narrow the gap with other developed economies, one of the most efficient ways is to adopt the policy of actively attracting foreign investments and capital from other sources for the purpose of increasing the gradient forces of economic development that exist within the economic system. Additionally, along with the globalization of the world economy, relevant standards within the economic system are modified in order to stay in line with the international practice, and the economic system also gradually implements an opening-up policy to the outside world in order to attract a lot of foreign capital based on the potential of the domestic market and major economic development. The opening-up policy brings forward development in the economic strength of the economic system.

First, the influx of foreign investments increases the amount of available capital that is necessary for the development of the economic system. In his volumes, entitled *Capital*, Karl Marx (1906, published by C.H. Kerr & Co) pointed out that capital plays the roles of “the first impetus” and “sustained impetus” in the production of physical materials and even in economic operations. It is also as what Ronald I. McKinnon said (McKinnon 1973): “It is easy for the entrepreneurs, who are helpless in obtaining financing, to fall into an equilibrium trap at a low level, where technological innovation is completely restricted except a few very wealthy people.” As a matter of fact, when important factors of production, such as capital, technology, etc., are in short supply within the economic system, sustained direct foreign investments provide profuse capital and inject into the hosting economy a large amount of investment funds. Such investments directly increase the capital stock of the regional economic system so that the system acquires the “driving force” and “sustained impetus” for an accelerated economic development.

Additionally, from V. Bjerknes circulation theorem (Wu and Lin 2002), it follows that the reason why an object moves is because its internal density is uneven or, in other words, its internal structure is uneven, and the more uneven the internal structure is, the greater the torsional force the object is under so that the faster the object spins. That is, we have:

$$\frac{dV}{dt} = \iint_{\sigma} \nabla\left(\frac{1}{\rho}\right) \times (-\nabla p) \cdot \delta\sigma - 2\Omega\frac{d\sigma}{dt} \tag{8.1}$$

which is the well-known V. Bjerknes circulation theorem. From this equation, it follows that the unevenness of the density ρ within the object creates a torsional force for the object, where the spinning direction of the object under the torsional force is determined by the p-plane (pressure plane) and the ρ-plane (density plane). Therefore, in terms of foreign investments, because capital is mostly driven by profit, foreign capital will mainly focus on short-term, high-yielding industries. When these industries acquire relatively large amounts of capital support, the distribution of capital resources and industry resources within the economic system becomes more uneven. That is, changes in the density ρ become greater than before. So, according to V. Bjerknes circulation theorem, it follows (here we treat the movement of capital as that of fluid of some sort; for the related argument, please consult with Chap. 2) that when some sector or industry of the regional economic system acquires a relatively abundant amount of capital, it causes the distributional unevenness of the capital resource within the region to increase, making the development of the regional economic system accelerate. That is, the rising degree of the distributional unevenness causes the gradient force of development of the region to increase, which helps to speed up the economic development of the region so that the capital size of the entire society is visibly increased.

Second, foreign investments help to raise the levels of management quality and technology. From V. Bjerknes circulation theorem, it follows that because of the stirring forces, as created by the uneven density of “materials,” spin fields naturally appear. According to the systemic yoyo model, when a system is affected by a force, the external acting force comes from the spin field of another yoyo structure (Lin 2007, 2008). This acting force compels the acted upon system to alter its original form of movement and to formulate a new spin field. Projects with direct foreign investments generally enjoy advanced levels of management and technology, including, along with the foreign direct investments introduced, some of the newer equipment and technology, which in turn brings into the regions new industries and new information. Therefore, it can be seen that when foreign capital enters into an economic system, the accompanying technology of production, level of management, newer equipment, new information, etc., all come from a yoyo

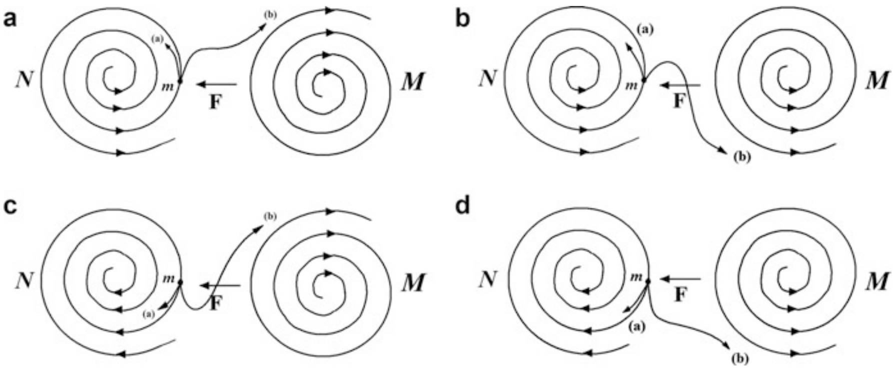

Fig. 8.1 How a foreign entity M affects a domestic entity m through capital investments. (**a**) Object m in a divergent field is pushed and pulled by a divergent entity M. (**b**) Object m in a divergent field is pushed and pulled by a divergent entity M. (**c**) Object m in a convergent field is pushed and pulled by a divergent entity M. (**d**) Object m in a convergent field is pushed and pulled by a divergent entity M

field that is more advanced than the original yoyo field structure of the economic system. The torsional forces and spin fields of these different yoyo structures interact with each other and influence each other, so that the development of the relevant industries and sectors of the economic system is stimulated, while the competiveness of these industries and sectors is promoted. Based on the systemic yoyo model, when some of the internal enterprises of the economic system are acted upon by the forces of foreign businesses, these domestic enterprises are actually acted upon by the spin fields of the foreign yoyo bodies so that the forms of motion of the enterprises internal to the economic system are altered and new forms of motion are formulated under the pressure of the external yoyo fields. That is why these domestic enterprises appear to follow a certain state of motion and nature. How one enterprise m that is internal to the economic system is affected by an external company M that has invested in m can be depicted in Fig. 8.1 by using the systemic yoyo model's field structures.

Without loss of generality, let us assume that if an industry or a sector or a company of the economic system has a certain level of competiveness, then the yoyo field of this industry or sector or company is divergent (because the competiveness tends to mean that the industry or sector or company is more readily to export its quality management and established technology). That is why in Fig. 8.1, all the fields of M are divergent. Let us also assume that if an industry or sector or a company is either newly emerging or still in its period of growth, then the yoyo field of the industry or sector or company is convergent (because such an industry or sector or company tends to be at the receiving end of more developed management skills and well-employed technology). Speaking generally, the area into which foreign investments enter is either a relatively mature sector or industry which has a higher level of management quality and advanced technology or a set of relatively newly emerging industries in the economic system (Forrest and Tao

2014). So, when the sector or industry foreign capital enters into is relatively mature, the yoyo field of the enterprise foreign capital enters can be seen as divergent; when the sector or industry foreign capital enters is newly emerging, the yoyo field of the enterprise foreign capital enters can be seen as convergent. Based on this understanding, in Fig. 8.1, the yoyo field N stands for that of the relevant industry or sector of the economic system into which foreign capital enters, while the yoyo field M represents that of the corresponding industry or sector from which the foreign capital comes. In the following paragraphs, the yoyo fields N and M are assigned with slightly different meanings.

Figure 8.1a–d depicts how the economic entity m that is originally located in the spin field of the relevant sector of the economic system is pushed by the field M formed with foreign investments along direction (a) and pulled along direction (b). When m is pushed along direction (a), m speeds up its spinning intensity by absorbing the energy that is given off by the divergent field of M of the foreign investments. That means that the development of m is accelerated. However, when m is pulled along direction (b), m might be captured by the divergent field M of foreign investments. In this case, if the spinning strength of the field M is not strong enough, then the entity m will not be pulled out of its original yoyo field N. So, what this discussion means is that at the initial stage of foreign investments, some of the industries or enterprises within the economic system that already have certain degrees of competiveness speed up their business performances by absorbing the "energies" released by the foreign investment field M and further increase their competiveness by riding on the pulling effect of M, materializing accelerated development of these economic entities within the economic system. If we use China as an example, we can see that under the effect of the spin field of foreign investments, some domestic enterprises have grown rapidly and eventually become excellent competitors of their foreign counterparts; and these enterprises have soon stepped beyond the national border and started making investments in other economic systems. Such Chinese companies include China Haier Group, China's Huawei, China ZTE (Zhongxing Telecommunication Equipment Corporation), etc. Similar to the discussion above, what is depicted in Fig. 8.1d along direction (b) is about how an entity m located in a convergent field N is captured by another harmonically spinning yoyo structure M, where other than the spinning directions, when two fields have the same field structure, these two fields are known as harmonic.

Speaking more particularly, only when the spin field M of foreign investments is much greater than the entity m that is located within the spin field of the economic system, the action of M on m (Fig. 8.1a–d) will visibly affect the state of motion of m, and M has a chance to capture m. In order to either visibly affect the state of motion of m or capture m, the fields of M and m must belong to different levels with different magnitudes. If they belong to the same level and have the same or similar magnitude, then m cannot be depicted as a particle. Also explained is that during the process of the initial foreign investments, and because the magnitude of the involved foreign capital is relatively small, the spin field M that is made up of all foreign investments comes from the same level as the entity m from the economic system. The economic system then aids and supports the development of some of the internal enterprises that have good degrees of competiveness through adopting certain measures and policies. This process makes these domestic enterprises grow into ones with similar competiveness of their corresponding foreign counterparts. Such rapid growth also provides a certain degree of protection for the economic security of the economic system.

Therefore, speaking generally, the projects that are invested with direct foreign capital play an exemplary role for other business entities within the economic system in the areas of technology, information, and management. The enterprises in which foreign capital invests directly are introduced with advanced equipment and newer technology that helps to carry the content of science and technology of the economic system to a higher level. At the same time, the enterprises of direct foreign investments also bring with them the awareness and concept of competition and play an exemplary role in the area of management. All these factors help to produce a large number of advanced scientific management personnel and technically advanced labor force for the economic system. Additionally, the entering foreign capital can help the market competition within the economic system to converge to a reasonable and effective level, while eventually eliminating inferior enterprises and lifting the quality of surviving enterprises.

Third, the introduction of foreign capital helps to stimulate sustained, rapid economic growth of the economic system that in turn increases the fiscal revenue of the government. Direct foreign investments inevitably pay local income taxes. In general, all the projects directly invested with foreign capital tend to have strong competitive edge in the market place and are in good operational conditions, which help to increase the tax revenue for local government. At the same time, these projects make the relevant regions' economic strength stronger, which in turn increases the fiscal revenue of the economic system. Additionally, direct foreign investments also increase the disposable income of consumers, which helps to expand the scope and extent of consumption. All of these help to increase the value of the products produced and sold by the relevant enterprises, while the public demand is satisfied. Without an increase in the disposable income, as created by economic growth, the research and development of new products and new services will lose their momentum.

Last, direct investments of foreign capital create more jobs for the receiving economic system. If the nation of our discussion represents a developing economy, then the increasing number of jobs facilitates the domestic economy system to shift the original agricultural population to an industrial population. Additionally, enterprises with foreign investments also indirectly generate additional employment opportunities both forwardly and backwardly along the industrial chains. Especially for those newly emerging economies with insufficient modernization and development, because the scale of the domestic industry is not large enough, it is difficult for the economic system to reasonably absorb the abundant surplus labor released from agriculture. By adding the existing unemployment in urban areas, the problem of sufficient employment becomes an even greater challenge to the economic system. If a large population of young age people stays unemployed, it might well evolve into a destabilizing factor for the society, which might eventually become a threat to the entire economic and societal system. To this end, enterprises with foreign investments, especially those involving high labor intensities, will no doubt beneficially absorb these surplus labors within the economic system, ease the challenge of the employment problem, and reduce the societal pressure of the labor market.

8.3 Negative Effects of Foreign Capital on Economic Security

From what is discussed above, it follows that along with the influx of large amounts of foreign capital, what is brought into the receiving economic system are newer technologies and time-tested management knowledge and skills. Also, to a certain extent, these imports help to fill the technology gap and management gap that exist in the receiving economic system and carry the technological sophistication and economic performance of the economic system to a higher level. However, foreign capital also creates various negative effects on the receiving economic system, such as increasing the intensity of the market competition within the economic system, extruding local businesses and brands, widening the development gap of different geographic regions, etc.

Since the geographic distribution of foreign investments is not even, it is easier to widen the development gap of different districts within the economic system. Generally speaking, the districts with past direct foreign investments have shown the characteristics of clear uneven distribution. The appearance of such patterns of uneven distribution has something to do with not only the gradient development strategy of the adopted policies on how to attract foreign capital within the economic system but also the interregional distribution of talents, existing technologies, infrastructures, industry gatherings, specifics of various regions, etc. Because the conditions of infrastructure are different from one region to another and because capitals are of the profit-driven characteristics, foreign capitals tend to relatively concentrate in certain regions, while some other regions have great difficulties to attract foreign capital. That is, regions that receive direct foreign investments tend to be purposefully chosen.

Let us use modern China as an example. Since the time when China started its economic reform and began to implement its open-door policy, the main regions that successfully attracted foreign capital investments are along China's east coast, concentrating especially in two China's most economically developed areas: the Pearl River delta and the Yangtze River delta (Forrest and Tao 2014). Based on the available statistics, no matter whether we look at the number of projects with foreign investments or the number of contracts of joint ventures or the actual amount of foreign capital invested, both the Pearl River delta and Yangtze River delta have occupied over 80% of all foreign investments in China. When such

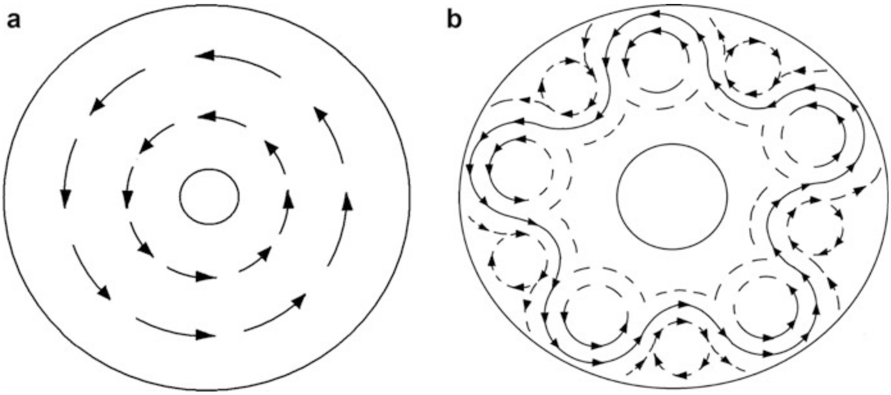

Fig. 8.2 Cyclic transformation between order and chaos

regional unevenness in the scale of foreign investments accumulates over a long period of time, it will create a much greater unevenness in the gradient forces that are behind the spin or development of the economic system. Such difference in regional abilities of attracting foreign capital makes the development gradient forces within the economic system vary more widely from one region to another and widens the difference between the regional development velocities within the economic system (He 2003).

From the systemic yoyo model, it follows that when the difference between the spinning strengths of different regions increases, the entire economic system might enter into a period of chaotic state of development (Fig. 8.2b) from a relatively orderly state of motion (Fig. 8.2a). This chaotic state of economic development not only exacerbates the differences in regional economic performances and in residential incomes but also further encourages the "backflow" of resources from some regions without much direct foreign capital within the economic system to those with rich foreign capital resources, making the internal structure of the economic system experience great instability. When such instability reaches a certain threshold, it will lead to the appearance of forces that are destructive to the health of the economic system. That surely compromises the economic security of the entire economic system.

When the amount of foreign capital increases massively, it is very possible that the foreign capital could potentially seek a monopoly position and weaken the independent innovation capability of the domestic firms of the economic system. That would further danger the economic security of the system. Because of its driving for profit, foreign capitals tend to focus on the sectors or industries that have high profit potentials. With the rapid expansion in the number of companies with foreign investments within the economic system, on one hand, the foreign capital would start to limit, suppress, and squeeze out competitors within the economic system by first establishing a strong competitive edge through taking majority controls, mergers, and acquisitions. On the other hand, the foreign capital would attempt to obtain much larger amounts of profits by seeking monopoly on one particular industry or industries through implementing the strategy of brand names while strangling local brands. All these potentials of foreign capital could objectively make the domestic industries of the economic system weakened and eventually eliminated so that the foreign capital could dominantly affect the economic system with external fluctuations by employing its monopoly advantage. All of these possibilities would surely place the development of the economic system under the mercy of uncontrollable uncertainties, and the system's stable evolution would be greatly damaged.

On one hand, although direct foreign investments might actively encourage the emergence of independent innovation capabilities for some domestically funded companies, such positive role of direct foreign investments is materialized indirectly through the intensifying market competition and how well these domestically funded companies could deal with the increasing level of competition. And on the other hand, at the same time, when large amounts of foreign direct investments are absorbed and utilized, the independent innovation capabilities of many domestically funded companies are clearly weakened. One fundamental objective of direct foreign investments is to acquire as long term as possible, stable, high levels of returns. Therefore, foreign merchants would attempt to defeat their competitors by maximizing their technological monopoly and market monopoly instead of fostering competition, strengthening the independent innovation capabilities of domestically funded companies. From the systemic yoyo model and how yoyo fields interact with each other, it follows that there are three main ways, as outlined below, for direct foreign investments to undermine the independent innovation capabilities of domestically funded companies

1. When there are large differences in the areas of technology, quality, and scale, defeat domestically funded companies by producing goods right at the location of the market and by selling the goods at extremely low prices while circumventing tariff barriers. Because there are large differences between enterprises with foreign investments and those funded only by domestic resources, these economic entities can be seen as located at different levels of their respective larger yoyo fields. From Fig. 8.3a–d, it follows that because yoyo field M of foreign capital possesses much greater spinning power and magnitude than those of the yoyo field N of the economic system within which an economic entity m is located, M could possibly materialize the acquisition of the domestic company m from within the economic system N by relying on M's strong capability. That gradually leads to the formation of monopoly. When the yoyo structures of m and M are not harmonic, the models for their action and reaction are given in Fig. 8.3a, c.
2. The companies with direct foreign investments, especially those either funded entirely by foreign capital or foreign controlled, can poach talents from domestic companies within the economic system by using above-the-market salaries and benefits. In the competition with domestic companies, foreign capital will inevitably compete for corresponding resources, especially scarce resources and strategic resources. With their strong economic strength, the enterprises

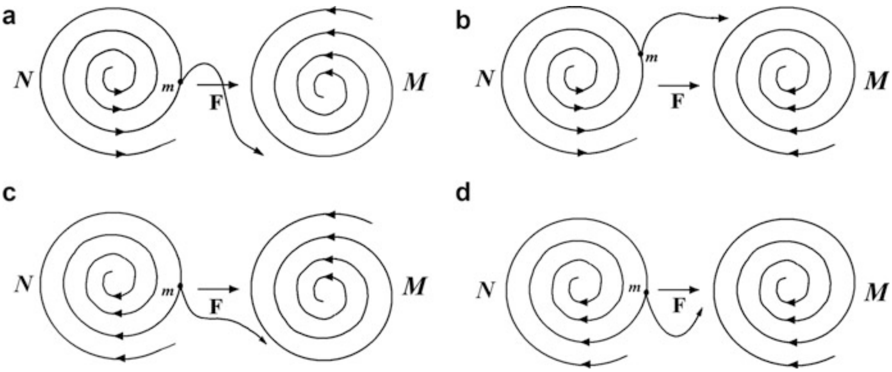

Fig. 8.3 How a domestic entity could be acquired by foreign capital. (**a**) Entity *m* located in a divergent field is absorbed by a convergent *M*. (**b**) Entity *m* located in a divergent field is absorbed by a convergent *M*. (**c**) Entity *m* located in a convergent field is absorbed by a convergent *M*. (**d**) Entity *m* located in a convergent field is absorbed by a convergent *M*

with foreign investments tend to have advantage in the competition. From the systemic yoyo model, it follows that when the difference between the yoyo field of foreign capital and that of the economic system is large, domestic companies within the economic system can be relatively easily acquired by foreign capital; and when the difference is small, the field of foreign capital and that of the economic system will form the interactive pulls and pushes, as shown in Fig. 8.1a–d. In particular, Fig. 8.1a depicts how an entity *m* located within a divergent spin field *N* experiences a pushing force by *M* along direction (a) and a pulling force along direction (b). If *m* actually starts to move along direction (b), then it will be captured by the divergent field *M*. If the spin intensity of the field *M* is insufficient, then the entity *m* will not be pulled by field *M* out of its original yoyo field *N*. During the process of pushing and pulling between the fields *M* and *N*, because foreign-invested companies have relatively better conditions, such as competitive remuneration package, flexible employment mechanism, etc., the particular entity *m* might be torn into pieces by field *M* along direction (b). That means that the excellent resources of *m* will be taken by foreign capital *M*, which weakens the innovation capability and competiveness of the domestic company *m* located within the economic system. When the yoyo structures of the entities *m* and *M* are harmonic, the systemic models for their action and reaction with each other are given in Fig. 8.1b, d.

3. Foreign capital, due to its nature of seeking optimal returns, tends to hold back its invested companies from the development of new products and new technologies. Within such foreign-invested companies, because they import and utilize foreign products and technology, they generally have only the production license without the validation right for new product design, which costs good amounts of resources without potentially producing quick returns. So, they have no need to and cannot make changes to the imported products and technology. This end

causes a good number of foreign-invested companies to split their originally existing research and development units, leading to losses of technological strength and talents. In our modern era of knowledge economy, such economic losses as caused by losing human resources can be difficult to estimate, whose long-term effect to the domestic economic system will be significant; for relevant empirical data, please see Forrest and Tao (2014).

With the gradual expansion of the scale of foreign capital that the receiving economic system uses, and with the increasing contribution of foreign capital on the growth of the economic system, the position of foreign capital also becomes more important than ever before, and the degree for the economic system to depend on foreign capital also deepens over time, which is essentially manifested through the foreign capital control of the core technologies. When the development of the economic system is overreliant on foreign capital, it will gradually cause foreign capital to take part in the economic policy making and implementation within the economic system. That will in turn gradually cause the domestic economic system to lose its economic development independence, which will not only affect the economic security of the economic system but also the political and military securities. That will eventually affect the development and societal stability of the economic system. From the experiences of developed countries and those industrialized nations, it follows that the development and powerfulness of an economic system cannot merely depend on foreign capital and technology (Caves 1974; Vasconcellos and Kish 1998; Borensztein et al.1998; Markusen and Venables 1999; Ratnayake 1999; Chung 2001; McCann 2001; Hunya 2002; Zhou et al. 2002b; Akbar and McBride 2004).

Making use of foreign capital might cause imbalances in the industrial structure that is internal to the receiving economic system, while restricting necessary adjustment and optimization of the internal economic arrangement. Although using foreign capital should be beneficial to the adjustment and optimization of the domestic product structure and the industrial structure of the economic system, the objective of foreign capital is always about increasing its value, and its flow is motivated by the potential of profits. So, the velocity of flow is always positively proportional to extraordinary profits, and the distribution of industries that attract foreign investments is mainly determined by profit needs of the foreign merchants. When capital flows from advanced economies into developing economies, it mainly concentrates on those mature industries that have short operational cycles, produce quick results, and have high levels of potential profits. Such capital does not play much role in such areas as guiding the introduction of new industries and the development of trailing industries. It rarely invests in such basic industries as agriculture, transportation, energy, etc. Hence, when looking at the situation holistically, we can conclude that foreign capital might instead worsen the imbalance in the industrial structure of the domestic economic system. It is not only that the distribution of foreign capital is not reasonable across industries but also that its structure within any industry is not reasonable. The unreasonableness exists due to reasons of the market instead of the need of adjusting the structure of the economic system. Let us use China as an example. Because of the introduction of foreign capital, the technology-intensive processing industry of the general technology, which was behind China's originally dominant light and basic industries, was advanced a great deal. However, the introduced foreign capital did not play much role to enhance the development of agriculture, basic industries, high-tech industries, and education and culture industry, even though these industries and sectors have continued their growth with or without foreign investments. This reality further widens the development gap between agriculture, light industries, and heavy industries and exacerbates the irrationality of industrial structure of the economic system. Therefore, if the possibility that foreign capital might cause imbalances in the internal industrial structure of the economic system is not controlled, it will surely affect the coordinated development of the economic system and delay the upgrade of the system's industrial structure. That will definitely affect the security of the economic system (He 2003).

Substantial increases in foreign investment can weaken the effectiveness of implementation of monetary policies and may create shocks to the domestic fiscal and financial systems. If any of the shocks is sufficiently severe, it might lead to financial crises for the economic system. The ability for foreign-invested companies to balance foreign exchange is relatively weak. With large investment profits remitted abroad and the establishment of non-foreign currency earning enterprises, the pressure that foreign investments created on the balance of international payments of the domestic economic system becomes increasingly heavy. When foreign-invested companies start to pay dividends, large amounts of profits in foreign currencies will be remitted overseas. That, together with other factors, will cause adverse effects on the balance of international payments of the domestic economic system (He 2003).

Excessive use of foreign capital increases the inflationary pressure of the receiving economic system, which weakens the economic regulatory capability of the monetary authority of the economic system. When a large influx of foreign capital enters into the real estate market and the stock market of the economic system, the magnitude of the base currency will have to increase in order to include the funds that are outstanding for foreign exchange. That of course leads to substantial increase in the money supply and excess liquidity so that the monetary authority would in turn reduce loan investment. That correspondingly makes it more difficult to implement monetary policies.

The impact on the financial system is mainly caused by short-term inflow and outflow movements of capital. The inflow of short-term capital is mostly for the purpose of speculation and taking quick profits instead of making investment. Such capital would initially look for loopholes that exist in the operation and regulation of a nation's economic system and then launch attacks; and as soon as the receiving financial system shows signs of a crisis, the speculative capital will quickly flow outward. That may very well play the role of fueling the formation of a financial crisis. That is, free flows of international hot money greatly increase the cost and difficulty for the economic system to deal with crises. This end has been clearly shown in the Southeast Asian financial crisis of the 1990s. For relevant details, please see Forrest (2014).

8.4 Conclusion

Because foreign capital can greatly enhance the development of a nation's economy, international investments have been mostly seen positively until recent years. Contemporary financial crises, as caused by the flow of international hot money, have provided strong evidence that money can be and have been employed as a weapon of mass destruction (Forrest 2014). So, a natural question appears: while taking advantage of foreign investments, how can a nation protect itself against the potential disastrous aftermath in case some of the foreign investments were actually part of an active currency war raged against the nation?

Aiming to resolve this important question, this chapter discussed the positive and negative roles foreign capital could play on a nation's economic prosperity and security. As been discussed above, if not prepared, the consequence of a currency war can be extremely disastrous. In order to prevent such potentially undesirable consequence, there is an urgent need to investigate how to monitor the movement of foreign capital within a nation's economy and then how to design measures that can be useful for countering the adverse effects of foreign investments on the national economy. This end will be the topic for our next presentation.

Because a good amount of the discussion in this chapter is based on a figurative analysis of the yoyo model, the validity and scientificality of such analysis need to be addressed. For this end, the interested reader should consult with Lin (2008).

Chapter 9
Economic Security Under Disturbances of Foreign Capital

Jeffrey Yi-Lin Forrest, Yirong Ying, Zaiwu Gong, Kurt Schimmel, Sifeng Liu, Jeananne Nicholls, and Nicholas A. Nechval

Contents

Considering both positive and negative spillover effects of foreign capital, this chapter establishes a method for the receiving economy of foreign capital to constantly monitor and forecast the movement of foreign capital within itself so that appropriate methods of regulation could be established in order to guarantee the health and stable development (or the security) of the domestic economy.

This chapter uses the methods of control theory to model and estimate the movement of foreign capital, to estimate the initial state of foreign capital's movement within the receiving economic system. Based on the estimation method

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established herein and the thinking logic of the systemic yoyo model, this chapter introduces several ways to prevent foreign capital from adversely impacting the receiving economic system for the purpose of establishing a theoretical guidance for insuring the healthy development of the economic system.

What is implied by this chapter is that more in-depth research is needed for further understanding of how the economic security of the receiving economic system could be protected against disturbing flows of foreign capital. What is established is a complete theory on how to estimate the state of movement of foreign capital within the receiving economic system. And on the basis of the estimations, appropriate strategies and measures can be designed to counter the adverse effects of foreign investments while insuring the economic security of the economic system.

It is theoretically possible to design strategies that could not only materialize their purpose of regulation within a limited time interval but also consume as little amount of resource as possible. This chapter, mostly based on (Schimmel et al. 2017), provides several practically useful strategies that could counter disturbances caused by foreign capital within the receiving economy and protect the economic security of the system in order to avoid the disastrous aftermath of the currency war that occurs along with large-scale withdraw of foreign capital that was initially invested within the system in friendly terms.

9.1 Introduction

Continuing the previous chapter, this chapter establishes a theoretical model on how to monitor the movement of foreign capital within a nation's economy in order to keep the economic security of the economy intact. In particular, this chapter is organized as follows: Sect. 9.2 establishes a theoretical model for monitoring the dynamics of foreign capital within a nation's economy. Section 9.3 studies how to estimate the state of motion of foreign capital within the domestic economy. Section 9.4 fills the need of estimating the initial state of foreign capital's movement. Section 9.5 explores some potential measures useful for countering the fluctuations of foreign capital within a national economy. Section 9.6 concludes the presentation of this chapter.

9.2 A Model for Monitoring Dynamic Foreign Capital Within an Economic System

The receiving economic system foreign investment is really a double-edged sword. It can not only provide sufficient capital, advanced technological equipment, and excellent management experience for the development of the economic system but also seriously constrain the development of domestic enterprises, weaken the innovation capacity of the economic system, and create serious security risks for the economic system (previous chapter). Hence, practically speaking, there is an urgent need to appropriately formulate and implement strategic measures regarding foreign investments in order to accelerate the economic development by sufficiently taking advantage of foreign capital while lowering the security risk that accompanies the influx of foreign capital to a certain level or within the controllable range of the economic system. This section attempts to provide theoretically sound suggestions regarding the design of foreign capital policies and strategies for the receiving economic system by modeling the scale, regions, and areas of foreign investment and by constructing a control-theory model for foreign investment.

Generally speaking, the investment within an economic system by foreign capital may be maintained at a certain stable speed without being affected by regional economic development cycles, financial shocks, and major changes in the environment of the economic system. For example, since 1992, China has continuously attracted a large scale of foreign investment (Cheng and Kwan 2000). And only in some very particular situations, such as major financial shocks, drastic changes in the political environment of the economic system, etc., the invested foreign capital would show speculative, withdrawal, and other behaviors.

From what has been discussed in the previous chapter, it follows that foreign capital affects the economic security of the receiving economic system in three different ways: One is the magnitude of the invested foreign capital, two is the geographic distribution of the foreign investments, and three the difference between the actual distribution of invested foreign capital and the need distribution for foreign capital investment of the economic system.

In terms of the magnitude of invested foreign capital, a rising magnitude increases the holding of foreign currencies of the economic system while it also increases the internal base money supply. That might affect adversely the effectiveness of the adopted monetary policies of the economic system. Additionally, the rising amount of foreign investment also increases the uncertainty of how the economic system would be influenced by the external world. Because of its drive for profit, foreign capital might leave the economic system in large scales within a short period of time when the economic system experiences shocks from the external environment. That exit could cause disastrous consequences for the healthy development of the economic system, and such effects had been sufficiently manifested in the Southeast Asian financial crises of the 1990s. In terms of the geographic distribution of foreign investments, when the imbalance in the geographic distribution of foreign investment goes up, the internal development imbalance within the economic system will expand, which might cause chaos in the regional development of the economic system so that the orderly domestic allocation of resources will be disrupted, such wasteful phenomena of resources as duplicated constructions, production overcapacity, etc., will likely to appear. In terms of the difference between the actual distribution of invested foreign capital and the need distribution for foreign capital investment of the economic system, it creates an imbalanced local distribution of regional industries within the economic system. That causes the internal industrial structure of the economic system to lose its balance so that when affected by external uncertainties, the development of the economic system will be badly hindered by production imbalances and insufficient productions of some industries. For example, in some of the emerging economies, foreign investment is relatively concentrated in a few industries. When such an economic system is affected by financial shocks, a quick withdraw of foreign capital generally leaves behind damaging effects for the development and stability of the economic system (Forrest 2014). Therefore, in the following, we use $r(k)$ to stand for the magnitude of foreign investment at time t_k within the economic system, $\alpha(k)$ the geographic distribution of foreign investment at time t_k, and $\beta(k)$ the difference between the actual industrial distribution of foreign investment and the actual distribution of areas that need foreign investment at time t_k. Here, we utilize the difference $\beta(k)$ to measure the effect of foreign capital on the economic security of the economic system at time t_k. Next, let us establish a control and monitor equation of these three variables in order to materialize the estimation and regulation of the state of foreign capital at any chosen time moment.

Additionally, in order to produce meaningful anticipation on the state of investment of foreign capital, let us use $\dot{r}(k)$, $\dot{\alpha}(k)$, and $\dot{\beta}(k)$ to, respectively, denote the rate of change of the investment magnitude $r(k)$ of foreign capital, the rate of change of the geographic distribution of foreign investment $\alpha(k)$, and the rate of change in the difference $\beta(k)$ between the actual industrial distribution of foreign investment and the actual distribution of areas that need foreign investment at time t_k.

If we let $x(k)$ be the state vector of foreign capital within the economic system, where

$$x(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \\ x_3(k) \\ x_4(k) \\ x_5(k) \\ x_6(k) \end{bmatrix} = \begin{bmatrix} r(k) \\ \dot{r}(k) \\ \alpha(k) \\ \dot{\alpha}(k) \\ \beta(k) \\ \dot{\beta}(k) \end{bmatrix}$$

$$= \begin{bmatrix} \text{magnitude of investmnent at } t_k \\ \text{rate of change in investment at } t_k \\ \text{geographic distribution of investment at } t_k \\ \text{ratre of change in geo} - \text{distribution at } t_k \\ \text{difference between investment and need at } t_k \\ \text{rate of change in investment/need difference at } t_k \end{bmatrix}.$$

Then we can use the following state equation to describe the movement of foreign capital within the economic system:

$$x(k) = \Phi x(k-1) \tag{9.1}$$

where Φ is a matrix defined below with T representing the time interval between consecutive observations:

$$\Phi = \begin{bmatrix} 1 & T & & & & \\ 0 & 1 & & & & \\ & & 1 & T & & \\ & & 0 & 1 & & \\ & & & & 1 & T \\ & & & & 0 & 1 \end{bmatrix}.$$

However, due to the existence of various disturbances and errors in real life, the movement, when seen as a system, of foreign capital within the economy is constantly affected somehow. For example, no matter how we establish the dynamic equation, it will not be an accurate expression of the realistic system; because of the interferences of the environment that is external to the economic system, exchange rate, politics, etc., the state of foreign capital movement is affected by countless many random factors. Let us aggregate all these various known and unknown factors into one concept: process (or dynamic) noise. In order to more realistically reflect the true dynamics of the foreign capital movement, let us add a noise term $w(k)$ that describes all kinds of interferences into the previous equation. So, the state equation in Eq. (9.1) can be rewritten as follows:

$$x(k) = \Phi x(k-1) + Tw(k-1) \tag{9.2}$$

where $w(k) = [w_1(k), w_2(k), w_3(k)]^T$ is the random interference of the foreign capital movement system within the economic system with w_1, w_2, and w_3, respectively, being the random accelerations in the directions of r, α, and β, and matrix T is given below where T is the time interval between two consecutive observations:

$$T = \begin{bmatrix} T^2/2 & & \\ T & & \\ & T^2/2 & \\ & T & \\ & & T^2/2 \\ & & T \end{bmatrix}.$$

Of particular interest is that the interference $\{w(k)\}$ as introduced above is a stochastic sequence, which comprehensively (and approximately) reflects the interference as experienced by the foreign capital when it moves within the economic system. Although there might be a large number of factors that interfere with the movement of foreign capital within the economic system, the effect of each factor might be quite small, which is likely unclear to the regulator of the system and cannot be readily measured. Even so, the total effect of all the interfering factors on the system's dynamics can be described by using a stochastic sequence (or a stochastic process if the movement system is modeled by a continuous model).

However, it is still not enough for us to only employ Eq. (9.2) to describe the movement system of foreign capital within the economic system. For the general scenario, the economic system can acquire and observe some traces of the movement of the foreign capital by using various methods of statistics. However, what is acquired and observed tends to be only about some components of the state variable or the values of some linear transformations of the state variable. For example, when using econometric data to observe or measure the state of foreign capital, only the magnitude, locations of investment, and industries of investment of foreign capital can be observed and measured. However, the acceleration and other parameters of movement of foreign capital are difficult to measure directly. Let us denote the data values that are actually observed as $y(k)$, where

$$y(k) = \begin{bmatrix} y_1(k) \\ y_2(k) \\ y_3(k) \end{bmatrix} = \begin{bmatrix} r(k) \\ \alpha(k) \\ \beta(k) \end{bmatrix}$$
$$= \begin{bmatrix} \text{observed magnitude of investment at } t_k \\ \text{observed geo} - \text{distribution of investment at } t_k \\ \text{observed difference of investment/need at } t_k \end{bmatrix}$$

Hence, the observation (or measurement) equation that describes the movement system of foreign capital within the economic system can be established as follows:

$$y(k) = Hx(k) \tag{9.3}$$

where

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0. \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

It can be expected that when econometric data are employed as observations of the movement of foreign capital, there is always error. Such error could be originated either from the inaccuracy of the observation equation or the method used during the statistical process or the random error that exists in the available data (Liu and Lin 2006). Let us refer this sort of error as observation (or measurement) noise. To realistically reflect the relationship between the observed variables regarding the movement of foreign capital within the economic system, let us add a random variable $v(k)$ into Eq. (9.3) to describe such random interference. Hence, the observation (or measurement) equation becomes

$$y(k) = Hx(k) + v(k) \tag{9.4}$$

where $v(k) = [v_1(k), v_2(k), v_3(k)]^T$, and $v_1(k)$, $v_2(k)$, and $v_3(k)$ are, respectively, the observed values of r, α, and β at time moment t_k, and $\{v(k)\}$ is a stochastic sequence.

Now, if we combine Eq. (9.2), which is the state equation that describes the movement system of foreign capital within the economic system, and the observation Eq. (9.4), which describes how the movement system of foreign capital is measured, we then obtain the following state equation of the foreign capital that expresses how the capital moves within the economic system:

$$\begin{cases} x(k) = \Phi x(k-1) + Tw(k-1) \\ y(k) = Hx(k) + v(k) \end{cases}. \tag{9.5}$$

Because the movement system of foreign capital within the economic system, as described by Eq. (9.5), contains random interferences, we will refer the system described by Eq. (9.5) as a stochastic control system. For each of such systems, all obtained information (data) is "polluted" by noise. In order to obtain relatively more accurate information of the state, we will have to make our best estimation of the true state of the system from the available information (that is generally a sequence of observations) with interfering noise, which might even be incomplete. Additionally, for stochastic control systems, the process of movement itself and the observation of the system's output are all contaminated with noise (Liu and Lin 2006). So, to study the movement of the system quantitatively, we must first describe the interfering noise quantitatively.

From the knowledge of stochastic processes, it follows that the distribution of the given stochastic sequence determines all the statistical characteristics of the sequence (Cinlar 2013). However, generally it is difficult to fully know the distributional structure of a stochastic sequence. Therefore, when solving practical problems, it will be mostly enough to simply know some of the main statistical characteristics of the given stochastic sequence. Assume that $\{v(k)\}$ is a stochastic sequence. If for any positive integer n and t and n arbitrary time moments $k_1 < k_2 < \cdots < k_n$, $v(k_1), \cdots, v(k_n)$, and $v(k_1 + t), \cdots, v(k_n + t)$ have the same joint distribution function, then the sequence $\{v(k)\}$ is known as stationary. If the mean of the stationary stochastic sequence $\{v(k)\}$ is 0, and its auto-covariance satisfies

$$R(i,j) = \sigma^2 \delta_{ij}, \quad \delta_{ij} = \begin{cases} 0, & \text{if } \ i \neq j \\ 1, & \text{if } \ i \neq j \end{cases} \tag{9.6}$$

then $\{v(k)\}$ is known as a white noise sequence. Here, a white noise sequence can be fathomed as a pure stochastic sequence, satisfying that the values of any two consecutive terms are independent.

If in Eq. (9.5), which describes the movement of foreign capital within the economic system, we know the state equation and the statistical characteristics of the noise, then we can move ahead to estimate the state of the movement system of foreign capital. In order to establish a formula to estimate the state of the state equation in Eq. (9.5), let us impose some conditions on the noises $\{w(k)\}$ and $\{v(k)\}$. First, let us assume that the observation noise $\{v(k)\}$ and the process dynamic noise $\{w(k)\}$ are completely independent of each other; otherwise, they can no longer be known as noise. That is, we have

$$E\left[w_k v_j^T\right] = 0, \quad \text{for any } k > 0, j > 0. \tag{9.7}$$

Secondly, we assume that both $\{w(k)\}$ and $\{v(k)\}$ are zero mean white noise stochastic sequences. That is, these sequences satisfy the following: For $\{w(k)\}$, we have

$$E\left[w(k)w^T(j)\right] = Q(k)\delta_{kj},$$

where

$$Q(k) = \begin{bmatrix} Q_1(k) & & \\ & Q_2(k) & \\ & & Q_3(k) \end{bmatrix}, \quad \delta_{kj} = \begin{cases} 1, k = j \\ 0, k \neq j \end{cases}$$

which is known as the covariance matrix of the process noise, and $Q_1(k)$, $Q_2(k)$, and $Q_3(k)$ are, respectively, the stochastic acceleration variances of the objective along the directions r, α, and β at time moment t_k, which can be selected based on how freely foreign capital can move within the economic system and how accurate the estimate of the state needs to be.

And for $\{v(k)\}$, we have

$$E\left[v(k)v^T(j)\right] = R(k)\delta_{kj},$$

where

$$R(k) = \begin{bmatrix} R_1(k) & & \\ & R_2(k) & \\ & & R_3(k) \end{bmatrix}$$

which is known as the covariance matrix of the measurement; and $R_1(k)$, $R_2(k)$, and $R_3(k)$ are, respectively, the observation noise variances of the objective along the directions of r, α, and β at time moment t_k. Their values are related to the accuracy of the observation statistics and the state of foreign capital. As a matter of fact, if the noises are not of zero means or if $\{w(k)\}$ and $\{v(k)\}$ are not independent stochastic sequences, etc., then necessary mathematical treatments will be needed. Of course, that will surely involve a lot of computational complexities.

Other than the aforementioned basic assumptions about the random inference variables, we also need to assume that the initial state x_0 is also a random vector satisfying $E[x_0] = \bar{x}_0$, $E\left[\left(x_0 - \bar{x}_0\right)\left(x_0 - \bar{x}_0\right)^T\right] = P_0$, and that x_0 and w_k and v_k are independent.

9.3 Estimate the State of Motion of Foreign Capital

At the initial time moment $t = 0$, the ideal estimate of x_0 is of course $\hat{x}_0 = Ex_0 = \bar{x}_0$. If we assume that we have already obtained $\bar{x}_0$, and let $\hat{x}_0 = \bar{x}_0$, then the covariance matrix of the estimation error of the state is $P_0 = E\left[\left(x_0 - \bar{x}_0\right)\left(x_0 - \bar{x}_0\right)^T\right]$. By employing the thinking logic of mathematical induction, we can derive the needed recursive formula.

Assume that we have obtained the observations up until time moment k: $y_1, \cdots, y_k$, and the optimal (unbiased) estimate $\hat{x}_k$ of the state x_k at time moment k. Before the next new measurement data value y_{k+1} becomes available, to estimate the state x_{k+1} at time moment $k + 1$, we have to start with $\hat{x}_k$ by making use of the evolutionary rule described in Eq. (9.5). Because w_k is a zero mean white noise, we cannot know what value it takes. So, the most reasonable choice is let $w_k = 0$, the mean value. On this basis, we obtain the predicted estimation as follows:

$$\hat{x}_{k+1|k} = \phi_{k+1,k}\hat{x}_k. \tag{9.8}$$

Because $Ew_k = 0$, $E\hat{x}_k = Ex_k$, and $E\hat{x}_{k+1|k} = \phi_{k+1,k}E\hat{x}_k + T_{k+1,k}Ew_k = Ex_{k+1}$, we conclude that $\hat{x}_{k+1|k}$ is an unbiased estimate of x_{k+1}. So, an optimal estimation is provided by Eq. (9.8). And by using the measurement expression in Eq. (9.4) and by letting $v_{k+1} = 0$ (for the same reason as above), we obtain the following predicted output value that corresponds to $\hat{x}_{k+1|k}$:

$$\hat{y}_{k+1|k} = H_{k+1}\hat{x}_{k+1|k} = H_{k+1}\phi_{k+1,k}\hat{x}_k \cdot . \tag{9.9}$$

At the time moment $t = k + 1$, we immediately obtain the actual output value y_{k+1} of the economic system. By comparing this actual value with the predicted value $\hat{y}_{k+1|k}$, we can compute the error of the predicted output:

$$\tilde{y}_{k+1|k} \triangleq y_{k+1} - \hat{y}_{k+1|k} = y_{k+1} - H_{k+1}\hat{x}_{k+1|k} \tag{9.10}$$

This expression includes not only the comprehensive information of the system's noise w_k, measurement noise v_k, filtering error, and other random variables but also some new information about the state x_{k+1} as the measurement value y_{k+1} at time moment $k + 1$ becomes available. Hence, let us refer to $\tilde{y}_{k+1|k}$ as a vector of new information (innovation). It is now natural for us to think about employing the new information at moment $k+1$ to correct the predicted state $\hat{x}_{k+1|k}$. That is, we can now derive a better estimate (filtering estimate) for the state at moment $k+1$. So, the estimation for the state at moment $k+1$ should consist of the following two parts: one is to derive the predicted estimate $\hat{x}_{k+1|k}$ of the state based on the observations up to time moment k, and the other is to correct the prediction $\hat{x}_{k+1|k}$ by employing the newly collected observation at moment $k+1$. When these two parts are put together, we establish our estimation for the state x_{k+1} at the time moment $k+1$. Symbolically, we have

$$\hat{x}_{k+1} = \hat{x}_{k+1|k} + K_{k+1}\left[y_{k+1} - H_{k+1}\hat{x}_{k+1|k}\right], \tag{9.11}$$

where K_{k+1} is referred to as a gain matrix or a correction factor. It is a real matrix. The key for our optimal filtering is to select correctly the gain matrix K_{k+1} so that the estimation $\hat{x}_{k+1}$ of the state obtained from Eq. (9.11) has the minimum covariance matrix of error. That is, we have

$$P_{k+1} = E\left[\left(x_{k+1} - \hat{x}_{k+1}\right)\left(x_{k+1} - \hat{x}_{k+1}\right)^T\right] = \min. \tag{9.12}$$

Next, we need to establish a formula from which we can produce the optimal gain matrix K_{k+1} that satisfies Eq. (9.12) so that a complete recursive computational scheme can be developed for the purpose of estimating the state of movement of foreign capital within an economic system.

Let $\tilde{x}_{k+1} = x_{k+1} - \hat{x}_{k+1}$. Then the covariance matrix P_{k+1} of the filtering error can be written as $P_{k+1} = E\left[\tilde{x}_{k+1}\tilde{x}_{k+1}^T\right]$. From

$$\begin{aligned}
\tilde{x}_{k+1} &= x_{k+1} - \hat{x}_{k+1} = x_{k+1} - \left[\hat{x}_{k+1|k} + K_{k+1}\left(y_{k+1} - H_{k+1}\hat{x}_{k+1|k}\right)\right] \\
&= \tilde{x}_{k+1|k} - K_{k+1}\left[H_{k+1}x_{k+1} + v_{k+1} - H_{k+1}\hat{x}_{k+1|k}\right] \\
&= \tilde{x}_{k+1|k} - K_{k+1}\left[H_{k+1}\tilde{x}_{k+1|k} + v_{k+1}\right] \\
&= [I - K_{k+1}H_{k+1}]\tilde{x}_{k+1|k} - K_{k+1}v_{k+1}
\end{aligned} \tag{9.13}$$

where $\tilde{x}_{k+1|k} = x_{k+1} - \hat{x}_{k+1|k}$, it follows that

$$\begin{aligned}
P_{k+1} &= E\left[\tilde{x}_{k+1}\tilde{x}_{k+1}^T\right] \\
&= E\left[\left((I - K_{k+1}H_{k+1})\tilde{x}_{k+1|k} - K_{k+1}v_{k+1}\right)\left((I - K_{k+1}H_{k+1})\tilde{x}_{k+1|k} - K_{k+1}v_{k+1}\right)^T\right] \\
&= [I - K_{k+1}H_{k+1}]E\left[\tilde{x}_{k+1|k}\tilde{x}_{k+1|k}^T\right][I - K_{k+1}H_{k+1}]^T + K_{k+1}E\left[v_{k+1}v_{k+1}^T\right]K_{k+1}^T \\
&\quad - [I - K_{k+1}H_{k+1}]E\left[\tilde{x}_{k+1|k}v_{k+1}^T\right]K_{k+1}^T - K_{k+1}E\left[v_{k+1}\tilde{x}_{k+1|k}^T\right][I - K_{k+1}H_{k+1}]^T.
\end{aligned}$$

Because $\hat{x}_{k+1|k} = \phi_{k+1,k}\hat{x}_k$ only depends on $\hat{x}_0$ and $y_1, y_2, \cdots, y_k$, from the knowledge of statistics, it follows that $E\left[v_{k+1}\tilde{x}_{k+1|k}^T\right] = 0$ and $E\left[\tilde{x}_{k+1|k}v_{k+1}^T\right] = 0$. So, the formula for computing the covariance matrix P_{k+1} of the filtering error can be simplified as follows:

$$P_{k+1} = [I - K_{k+1}H_{k+1}]P_{k+1|k}[I - K_{k+1}H_{k+1}]^T + K_{k+1}R_{k+1}K_{k+1}^T, \tag{9.14}$$

where $P_{k+1|k} = E\left[\tilde{x}_{k+1|k}\tilde{x}_{k+1|k}^T\right]$ is referred to as the covariance matrix of the prediction error, and $R_{k+1} = E\left[v_{k+1}v_{k+1}^T\right]$.

If we expand Eq. (9.14) and regroup the terms, where, without causing confusion, we omit all the subscripts of H_{k+1}, K_{k+1}, and R_{k+1}, we have

$$\begin{aligned} P_{k+1} &= P_{k+1|k} + KHP_{k+1|k}H^TK^T - KHP_{k+1|k} - P_{k+1|k}H^TK^T + KRK^T \\ &= P_{k+1|k} + K\left(HP_{k+1|k}H^T + R\right)K^T - KHP_{k+1|k} - P_{k+1|k}H^TK^T. \end{aligned} \tag{9.15}$$

Our purpose here is to derive the gain matrix K such that P_{k+1} reaches its minimum. Therefore, we rewrite Eq. (9.15) as a complete square, such as the form of $(KS - A)(KS - A)^T$. Because

$$(KS - A)(KS - A)^T = KSS^TK + AA^T - KSA^T - AS^TK^T, \tag{9.16}$$

By comparing Eqs. (9.16) and (9.15), we can see that because $HP_{k+1|k}H^T$ is a nonnegative definite matrix and R is positive definite, $HP_{k+1|k}H^T + R$ is a positive definite matrix. So, from matrix theory (Horn and Johnson 2012), it follows that each positive definite matrix can be expressed as the square of a certain symmetric positive definite matrix. So, let us assume

$$HP_{k+1|k}H^T + R = SS^T \tag{9.17}$$

where S is a symmetric positive definite matrix. Next let $SA^T = HP_{k+1|k}$, where matrix A actually exists because the square matrix S is of full rank.

By substituting Eqs. (9.16) and (9.17) into Eq. (9.15), we obtain the following:

$$\begin{aligned} P_{k+1} &= P_{k+1|k} - KSS^TK^T - KSA^T - AS^TK^T \\ &= P_{k+1|k} + (KS - A)(KS - A)^T - AA^T. \end{aligned} \tag{9.18}$$

From Eq. (9.18), we see that only the second term on the right-hand side has something to do with the gain matrix K, while this term is a nonnegative definite matrix. Hence, to make P_{k+1} reach its minimum, we only need to select such a matrix K so that the second term in Eq. (9.18) is equal to zero. So, we have

$$\begin{aligned} K &= AS^{-1} = P_{k+1|k}H^TS^{-T}S^{-1} = P_{k+1|k}H^T\left(SS^T\right)^{-1} \\ &= P_{k+1|k}H^T\left(HP_{k+1|k}H^T + R\right)^{-1} \end{aligned} \tag{9.19}$$

If we select K according to Eq. (9.19), then the covariance matrix P_{k+1} of the filtering error is

$$\begin{aligned} P_{k+1} &= P_{k+1|k} - AA^T = P_{k+1|k} - AS^{-1}HP_{k+1|k} \\ &= P_{k+1|k} - KHP_{k+1|k} \\ &= (I - KH)P_{k+1|k} \end{aligned} \tag{9.20}$$

Next, let us derive a computational formula for the covariance matrix $P_{k+1|k}$ of the prediction error. From the formula for $P_{k+1|k}$, it follows that

$$\begin{aligned} P_{k+1|k} &= E\left[\tilde{x}_{k+1|k}\tilde{x}_{k+1|k}^T\right] = E\left\{\left[\phi_{k+1|k}\tilde{x}_k + T_{k+1,k}w_k\right]\left[\phi_{k+1|k}\tilde{x}_k + T_{k+1,k}w_k\right]^T\right\} \\ &= \phi_{k+1,k}E\left[\tilde{x}_k\tilde{x}_k^T\right]\phi_{k+1,k}^T + T_{k+1,k}E\left[w_k w_k^T\right]T_{k+1,k}^T \\ &= \phi_{k+1,k}P_k\phi_{k+1,k}^T + T_{k+1,k}Q_kT_{k+1,k}^T \end{aligned} \tag{9.21}$$

By combining what is obtained above, for the system in Eq. (9.5), we have obtained all the recursive formulas necessary for estimating the state of movement of foreign capital within the economic system. However, to employ this theory to practically estimate the magnitude of foreign capital's investment, regional distribution, and differences between industries within the economic system at any chosen time moment, we still need to estimate the initial state.

9.4 Estimate the Initial State of Foreign Capital's Movement

From our discussions above, it follows that once we have the knowledge of the initial state of the movement of foreign capital within the economic system of our concern or a good estimation of that initial state, we then can estimate the state of foreign capital's movement system step by step. To this end, the general method is to determine the initial state $x(0)$ by using the prior (known) knowledge and then calculate the initial covariance matrix $P(0)$ by employing the degree of accuracy of $x(0)$. In this section, we assume that we have the initial observations at time moments t_1 and t_2. We then roughly estimate the state of the foreign capital's movement system at moment t_2 and its variance. These values will be used as the initial state of foreign capital's movement within the economic system. In particular, assume that the initial two observations are, respectively,

$$y(1) = [y_1(1), y_2(1), y_3(1)]^T \text{ and } y(2) = [y_1(2), y_2(2), y_3(2)]^T.$$

Then we calculate the following estimation of the initial state:

$$\hat{x}(0) = [\hat{x}_1(0), \hat{x}_2(0), \hat{x}_3(0), \hat{x}_4(0), \hat{x}_5(0), \hat{x}_6(0)]^T,$$

where

$$\hat{x}_{2i-1}(0) = y_i(2), \;\; \hat{x}_{2i}(0) = [y_i(2) - y_i(1)]/T, \;\; i = 1, 2, 3 \tag{9.22}$$

and

$$P(0) = E\left[(x_2(0) - \hat{x}(0))(x_2(0) - \hat{x}(0))^T\right] = \begin{bmatrix} P_1(0) & & \\ & P_2(0) & \\ & & P_3(0) \end{bmatrix},$$

where

$$P_i(0) = \begin{bmatrix} R_i(2) & R_i(2)/T \\ R_i(2)/T & [R_i(1) + R_i(2)]/T^2 \end{bmatrix}, \;\; i = 1, 2, 3, \tag{9.23}$$

In the following, we use a sub-matrix $P_1(0)$ as an example to illustrate the detailed steps of computation.

Because $\hat{x}_1(0) = y_1(2) = x_1(2) + v_1(2)$, we have

$$\begin{aligned} \hat{x}_2(0) &= [y_1(2) - y_1(1)]/T \\ &= [x_1(2) + v_1(2) - x_1(1) - v_1(1)]/T \\ &= \{[x_1(2) - x_1(1)] + [v_1(2) - v_1(1)]\}/T. \end{aligned}$$

Because $x_2(2) = [x_1(2) - x_1(1)]/T$, we have

$$x_1(2) - \hat{x}_1(0) = -v_1(2), \;\; x_2(2) - \hat{x}_2(0) = -[v_1(2) - v_1(1)]/T,$$

$$\begin{aligned} P_1(0) &= E\left\{ \begin{bmatrix} x_1(2) - \hat{x}_1(0) \\ x_2(2) - \hat{x}_2(0) \end{bmatrix} \begin{bmatrix} x_1(2) - \hat{x}_1(0) \\ x_2(2) - \hat{x}_2(0) \end{bmatrix}^T \right\} \\ &= E\left\{ \begin{bmatrix} -v_1(2) \\ -[v_1(2) - v_1(1)]/T \end{bmatrix} \begin{bmatrix} -v_1(2) \\ -[v_1(2) - v_1(1)]/T \end{bmatrix}^T \right\} \\ &= \begin{bmatrix} R_1(2) & R_1(2)/T \\ R_1(2)/T & [R_1(1) + R_1(2)]/T^2 \end{bmatrix}. \end{aligned}$$

Similarly, we can obtain the other sub-matrices of Eq. (9.23).

As of this point in our presentation, we have established a complete theory on how to estimate the state of movement of foreign capital within the economic system. And on the basis of the estimations, we can design appropriate strategies and measures to counter the adverse effects of foreign investments while insuring the economic security of the economic system.

9.5 How Disturbances of Foreign Capital Affect Economic Security

Because of the entry of foreign capital, the money supply within the receiving economic system is increased, making the system have additional resources to produce so that the economic strength of the system consequently grows rapidly. However, with the accumulation of foreign capital to a large magnitude, when the foreign capital suddenly withdraws, a severe shock to the economic activities of the economic system will be created. For example, let us look at a fictitious economic system whose financial system is open to the outside world. Assume that at a certain time moment, the nation's total money supply is $50,000, including domestically invested foreign capital of $7500. That is, the foreign investment occupies 15% of the entire national money supply. With the additional money supply, as created by the foreign capital, the circulation speed of money within the economic system accelerates, which indicates that this nation spends more on various economic activities and on the promotion of its economic level. If at a later time moment the capital invested by foreign merchants is suddenly withdrawn from the economic system, then it will inevitably, to a great extent, cause the liquidity of money within the economic system to drop suddenly, affecting adversely over 15% of all the economic activities within the economy. Hence, the economic system has to strengthen the monitoring of foreign capital in order to prevent the disastrous aftermath created by the currency war into which the initial friendly investment was evolved by sudden large-scale withdraw.

The essential reason why an economic system introduces foreign capital is to stimulate its economic development. That is to say, there is a predefined purpose within the economic system for how the entering foreign capital will develop. This predefined purpose is referred to as the ideal trajectory of the movement of foreign capital. On the other hand, the fundamental reason for foreign capital to enter the economic system is to make profit, which includes taking advantage of the promised preferential conditions, low-priced resources available from within the economic system, developing the market resources of the new economy, etc. In the process of materializing the desired profit, the actual state of movement of foreign capital most likely deviates from the ideal trajectory that is predefined by the economic system. When such deviation expands, it might gradually erode the economic security of the economic system that is additional to the significant damage that might occur to the economic system when a collective withdraw of foreign capital happens at certain time moment. Based on what has been discussed and analyzed earlier, the economic system could acquire "truthful estimations" of the state of domestic movement of foreign capital and possible trends of future development. So, for the policy makers of the economic system, they must design and introduce a series of policies to guide the "truthful estimations" to approach the ideal trajectory in order to materialize the desired control of the adverse effect of foreign capital on the economic security of the economic system. Such dynamic adjustment on the part of policy makers could also potentially prevent a currency war created by large-scale sudden withdraws of foreign capital although the capital initially entered the economic system in friendly terms.

When applying a strategy to regulate the state of movement of foreign capital, it is inevitable that some of the limited resources of the economic system will have to be occupied and exhausted. So, a control strategy is considered ideal if it could not only reach its purpose of control within a limited time interval but also consume as little amount of resource as possible. To this end, as a form of expression for energy consumption, quadratic functions will be used due to their excellent properties. These functions can describe not only how resources are wasted by implementing excessive control but also the distance from the target as caused by insufficient control. Therefore, in the following, we will choose a quadratic function as our evaluation standard to measure control strategies.

Let us define the objective function as follows:

$$J_N = \sum_{k=0}^{N-1} \left[(\hat{x}(k+1) - \bar{x}(k+1))^T Q(k)(\hat{x}(k+1) - \bar{x}(k+1)) + u(k)^T R(k) u(k) \right]$$

where N stands for the final time moment when the actual state $x(N)$ could approach the predefined ideal state $\bar{x}(N)$ "perfectly," $Q(k)$ the effect on the economic system as caused by the difference between the "truthful estimation" and the "ideal trajectory" at moment k, and $R(k)$ the price that has to be paid for adopting control strategy $u(k)$ at moment k.

Because this objective function contains the effect on the economic system of the difference between the "truthful estimation" and the "ideal trajectory" and the price paid to implement the control strategy u, the policy makers should design an optimal control strategy that makes the previous objective function reach its minimum. However, the design of any policy strategy is constrained by the resources available within the economic system, that is, $u(k) \in \Omega$, where Ω stands for the space of constraints of all strategies. So, the purpose of the entire control problem is to find a control sequence $u^*(k) \in \Omega$ such that

$$J(u^*(0), u^*(1), \cdots, u^*(N-1)) = \min_{\Omega} J_N.$$

Because the effect of policies can lead to changes in the state of foreign capital movement system, the "truthful estimation" $\hat{x}(k+1)$ is a function of policy $u(k)$. According to the necessary conditions for a function to reach its extreme values, we have

$$\frac{\partial J_k}{\partial u_k} = 0.$$

That is,

$$Q(k)(\hat{x}(k+1) - \bar{x}(k+1))^T \frac{\partial \hat{x}(k+1)}{\partial u(k)} + R(k)u(k) = 0$$

So, we have

$$u(k) = -R^{-1}(k)Q(k)(\hat{x}(k+1) - \bar{x}(k+1))\frac{\partial \hat{x}(k+1)}{\partial u(k)}.$$

Theoretically speaking, the feasible region of the constraint variables is bounded, and the objective function is nonnegative and convex. Therefore, generally there is an optimal control sequence $u^*(k) \in \Omega$ such that J_N reaches its minimum. However, because it is difficult to quantitatively or analytically describe the feasible region of the constraint variables, it is also difficult to provide a formal expression for an optimal strategy. Even so, we will try to develop a general description of the necessary control strategy by using the state equation and possible evolution tendencies of foreign capital movement within the economic system combined with the systemic yoyo model. Therefore, in the following we will provide several strategies based on logical analysis and reasoning strategies that could counter disturbances caused by foreign capital within the economic system and protect the economic security of the system in order to avoid the disastrous aftermath of the currency war that occurs along with large-scale withdraw of foreign capital that was initially invested within the system in friendly terms.

First, moderately monitor and supervise the activities of foreign investments, and strengthen the control of foreign capital if it attempts to enter the virtual economy, such as the financial market, stock market, etc. Although the assets of foreign capital that enters the virtual economy could provide investment capital for the economic system, such capital can often perturb the operation of the domestic financial system through unconventional ways, disrupt the smooth operation of the system, and withdraw from the system as soon as a high rate of return is acquired within a short period of time by making use of its scale and other advantages. Such short-term rapid movement of capital can cause turbulence to the otherwise normal operation of the domestic financial market of the economic system, which in practice materializes damage to the domestic financial system. The Southeast Asian financial storm of the year of 1998 was an example of how foreign capital acquired short-term high rates of returns by making use of the imperfections of the regional financial systems. This financial storm ransacked the economic achievements of the past several decades of the relevant regions within a short time period while leaving the development of these economies on the verge of collapse (Forrest 2014). Therefore, the receiving economic system must strengthen its supervision of those foreign capital investments that intend to enter the domestic financial market or the virtual economy, crackdown any illegal entry behaviors of foreign capital, and improve the control mechanism over the foreign capital that flows into any of the non-real economies. At the same time, receiving economic systems must constantly perfect emergency plans and formulate control measures for temporary, abnormal capital movements by considering the potentially most severe scenarios based on the logic of balancing the abnormal inflow and outflow of foreign investment capital.

Second, implement a flexible exchange rate mechanism in order to maintain investment grade foreign capitals while expelling those that are speculative in nature. Among all the capital of foreign investments, the portion that enters into the real economy is the one needed by the domestic economic system for its economic development. This capital intends to acquire relatively long-term profits by valuing the development potential of the economic system and by actively investing in the economic system. On the other hand, this capital could be relied on for the construction and development of the real economy and for its relatively long-term stay within the economic system. However, the entry of the speculative portion of foreign capital into the domestic economic system is mainly for the purpose of obtaining speculative profits by making use of the imperfections that exist in the market place and the financial system of the receiving economy. Hence, the economic system should employ its flexible exchange rate mechanism to discourage the influx of such foreign capital and to convert the influx of such foreign capital into investments in the real economy. For example, assume that merchant C is an international speculator and that he is upbeat about the stock market of the particular economic system and enters the stock market with an amount of US$1 billion. If the exchange rate between the US dollar and the domestic currency is 1:5, then his entry into the stock market represents 5 billion units of the local currency. After obtaining a short-term speculative profit in the stock market, C wants to close out his positions. If at this time moment the monetary authority of the economic system has somehow changed the exchange rate to 1:6 by making use of their flexible exchange rate policy, then C's original speculation amount of 5 billion units of the local currency can only be converted to US$5/6 billion = US$0.833 billion, where US$0.167 billion has evaporated. That is, the flexible exchange rate mechanism has discouraged C's speculation in the stock market, while the short-term varying exchange rate has little adverse effect on the foreign capital that is invested in the real economy. Hence, when a relatively large amount of foreign capital enters into the economic system, the receiving economy could employ a flexible exchange rate mechanism to discourage speculative capital while retaining the capital that is invested in the real economy.

Third, implement a flexible foreign investment policy to guide foreign investment capital into the target industries and geographic regions by making use of the economic system's market demand, cost advantage, and other resources. The profit-driven characteristics of foreign capital determine where and which industries foreign capital will enter; from how foreign capital flows into the economic system to obtain its desired profit, the investment types of foreign capital can generally be classified into the following five categories: cost seeking, policy seeking, resource seeking, market seeking, and technology seeking. With increasing economic strength of the economic system, the accumulation of investment capital, and the rising of labor cost, the foreign-invested enterprises of policy-seeking and cost-seeking types and some of the market-seeking types with relatively weak competitiveness will have to leave the economic system or remake themselves into different types, while those foreign capital assets of market-seeking and technology-seeking types might very well occupy the high-end positions of their individual markets and supply chains. Hence, the receiving economic system of foreign capital should sufficiently utilize its consumer market and related fundamental advantages, such as opening its domestic market, already established supporting industries, existing resource conditions, etc., to guide the investment capital of market-seeking, technology-seeking, and other types into the high-tech areas that are needed by the development of the economic system. These investments will not only stay within the economic system for the long term but also strengthen their collaboration with the economic system and improve the position of the economic system within the machining and manufacturing chain. Additionally, by making use of the differences between investment policies internal to the economic system, such as the various preferential policies in terms of taxation, land use, regulations, etc., as introduced by different regions with varying degrees of capital scarceness, the receiving economic system could direct the foreign-invested enterprises of policy-seeking and cost-seeking types and some of the investment assets of market-seeking type with less competitiveness to migrate into regions with less foreign investment capital. These different investment policies could also be used to improve the uneven investment distribution within the economic system while decreasing the disparity between the development gradient forces of different regions.

Last, promote the capability of innovation and creativity of the enterprises within the economic system and the public of the entire society. According to the systemic yoyo model, the competition between foreign capital and domestic business entities makes some domestic firms been absorbed by foreign capital, while some others been pushed and pulled (or bullied), where some of these bullied entities grow with the intensified competition and eventually become able competitors while some others are eliminated out of the existence. Those economic organizations that are either absorbed by foreign capital or eliminated are mainly those that are less competitive, and the competitiveness of an organization is mainly originated from the organization's creativity. When an economic organization possesses a strong capability of innovation, the yoyo field of this organization has a strong force of attraction and a steady ability to stand and take shocks from the environment. That strong capability of innovation can help promote the magnitude of the organization's yoyo field, while carrying the field to a higher level. As soon as the magnitude of the yoyo field of the organization rises to a new level, it would generally have acquired additional energy to better counteract the attraction and pressure of the yoyo field of foreign capital, while it might conversely absorb the yoyo field of foreign capital and make this external field a part of itself. In other words, improving the endogenous creativity is the fundamental way for the economic system to increase the magnitude of its yoyo field. To this end, the economic system can improve its internal innovation environment by fostering a good atmosphere for innovation, increasing investment in innovation, encouraging innovative behaviors, and providing innovators with conditions to materialize their creativities. On top of all these suggested remedies, the economic system would be able to reach a new level of creativity of the entire society.

9.6 Concluding Remarks

Because foreign capital can adversely affect the security of the receiving economy (Forrest 2014; previous chapter), this chapter addresses the following challenging question: While taking advantage of foreign investments, how can a nation protect itself against the potential disastrous aftermath in case some of the foreign investments were actually part of an active currency war against the nation?

To this end, this chapter establishes a theoretical model for monitoring the movement and dynamics of foreign capital within a nation's economy. Then potential measures that are useful for countering the adverse effects of foreign investments on the national economy are developed.

Part III
Observability: Initiating Currency Wars

Chapter 10
Inevitability of Currency Wars

Contents

As the title indicates, the objective of this chapter is to establish the fact that currency conflicts (or wars) are inevitable and each and every economic system is vulnerable to financial attacks. This end was practically confirmed by the case of Drexel Burnham Lambert, where the bankers could and were able to attack any business entity if they deemed the hostile acts were profitable (Sobel 1999).

For the completeness of this presentation, although all technical results in this chapter are known in control theory, versions of proofs are still provided. For related details, see Perko (2013).

The rest of this chapter is organized as follows: Section 10.1 looks at how currencies interact with each other in the presently globalizing economy. Section 10.2 studies the concepts of controllability and observability of economic systems while showing how these concepts are fact duals of each other. Section 10.3 explores the structural forms of economic systems' controllability and observability. Section 10.4 shows how each constant coefficient linear economic system can be decomposed into subsystems, where only one of them can be controlled and observed. Section 10.5 concludes this chapter by providing an explanation for how each general economic system is vulnerable to external influences.

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10.1 Interactions of Currency in the Globalizing Economy

With the development of human civilization, economies, and societies, after World War II, several of the world's major military powers have found that the use of force, including nuclear weapons, has become increasingly handicapped in resolving disputes between countries and regions. So, the economy has become a battleground; currency wars have already been referred to as a frequent agenda through news outlets. Removing all potential threats in the global monetary system has been the goal of the globalized economy of the modern world. Previous reports on defense strategy toward currency wars can be categorized into active defense and negative defense. Gagnon (2013) indicated that 22 countries had boosted their economy and created employment opportunities by intervening in foreign-exchange markets. Gagnon and Bergsten (2012) estimated that 91 economies increased their external deficits as some other countries manipulated their currencies so that they had to devalue their currencies as a hedge.

Due to the different weights of countries in the globalized world economy, national monetary and fiscal policies have great bearings on other nations. For example, as the world's largest economic empire, the United States has the most extensive worldwide currency system based on the dollar, occupies a strategic position in the world, and dominates the center of integration of the free economy. Therefore, the dollar, which is a symbol of American economic strength, helps to not only strengthen the American economic power in the world but also curb its domestic inflation. At the same time, the United States, as an international currency system, is also vulnerable in its dominant position and is surrounded by potentially irresponsible borrowing advantages – the ability to borrow unlimitedly from the world. Although that does not mean that the debts do not need to be repaid, because of the inequality in debt repayments, the United States has no monetary restraint on quantitative easing that can cause continued depreciation of the dollar, thereby reducing the burden of dollar-denominated debts (including domestic and external debts). Additionally, the United States can more easily than other countries stimulate exports, improve the international balance of payments situation, and pass on the domestic inflation to other countries.

On the contrary, developing countries have been gradually blocking the loose money policy of the United States by employing the strategy of marginalizing the impact of the dollar. This strategy was initiated by some countries of the Eastern and Southern Asia and then adopted by other countries of the Western Asia, by some countries in Eastern Europe, and then by countries in Africa and Latin America. These countries are gradually moving away from the influence of the American currency (Wang 2012a).

In terms of the international reserves, the United States has always been the champion from its initial race with the British pound, to the gold standard/dollar standard, and later to the euro. Currently, Chinese RMB also signed currency swap agreements with 19 countries and regions, totaling more than 1.67 trillion RMB (Wang 2012a). If the Bank of England also signs such an agreement, it will be the first time in history that the RMB currency swap covers a member of the Group of Seven. In the future, in the stability of and competition for international reserves, China will play an increasingly important role because the euro zone also promotes for diversification of international reserves at the same time. In the foreseeable future, the interaction between the RMB and the dollar will be the game in town. The evolution of this game will kick off an inevitable wave of currency conflicts as directly caused by flows of the international hot money and other forms of capital flows.

The capitalist world is bound to the outbreak of economic crises, which represent the best time to repudiate debts. For example, in 1847, the then wealthy British even got out of its debts in China and the United States by using bankruptcy, creating a precedent example of how debts could be repudiated (Marx and Engels 2009). This technic can be surely employed today more readily than any time in history, creating more pains and uncertainties in the world.

10.2 Controllability and Observability of Economic Systems

Mathematically, an economic system can be written approximately in the following form of an n-dimensional constant coefficient linear system (Chap. 3):

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx + Du \end{cases} \tag{10.1}$$

where its state space is assumed to be X.

The concepts of controllability and observability of the economic system are very important. They respectively describe the relationship between the policy input and the state of the economy and the relationship between the output and the state of the economy. If the matrices A, B, C, and D are constant, meaning that the control system's representation of the economy in Eq. (10.1) only approximately describes the economy within a neighborhood of the initial time moment, then the pair of matrices (C, A) describes the relationship of the economic system between the output y and the state x when there is no policy input, while the pair of matrices (A, B) describes the relationship between the policy input u and the state x.

When A, B, C, and D are constant matrices, the controllability of the system in Eq. (10.1) roughly means whether or not for any given state x there is always a policy control u such that within a limited time interval, the state x can be transformed to the desired state. As for the observability of the economic system, it is about whether or not the initial state of the system can be determined by the knowledge of some known output of the system.

10.2.1 The Controllability of an Economic System

Before seeing the formal definition of controllability, let us first look at a simple example.

Example 10.1 Assume that a simple economic system can be described as follows:

$$\begin{cases} \dfrac{dx}{dt} = \begin{bmatrix} -2 & 1 \\ 1 & 2 \end{bmatrix} x + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u \\ \quad y = [0 \;\; 1] x \end{cases}$$

where $x = [x_1 \quad x_2]^T$.

When $x_1(0) = x_2(0) = 0$, we have

$$x(t) = \int_{t_0}^{t} e^{A(t-\tau)} B u(\tau) d\tau$$

where $A = \begin{bmatrix} -2 & 1 \\ 1 & 2 \end{bmatrix}$ and $B = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$. Because $e^{At} = \frac{1}{2} \begin{bmatrix} e^{-t} + e^{-3t} & e^{-t} - e^{-3t} \\ e^{-t} - e^{-3t} & e^{-t} + e^{-3t} \end{bmatrix}$, we obtain

$$\begin{aligned} x(t) &= \frac{1}{2} \int_{t_0}^{t} \begin{bmatrix} e^{-(t-\tau)} + e^{-3(t-\tau)} & e^{-(t-\tau)} - e^{-3(t-\tau)} \\ e^{-(t-\tau)} - e^{-3(t-\tau)} & e^{-(t-\tau)} + e^{-3(t-\tau)} \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} u(\tau) d\tau \\ &= \begin{bmatrix} 1 \\ 1 \end{bmatrix} \int_{t_0}^{t} e^{-(t-\tau)} u(\tau) d\tau. \end{aligned}$$

That is, no matter what policy input u is employed, the fact that the state $x = [x_1 \quad x_2]^T$ always satisfies $x_1 = x_2$ cannot be altered. QED

Definition 10.1 If the state $x(t_0)$ of the economy at a given time t_0 can reach the expected state $x(t_f)$ within a finite time interval $[t_0, t_f]$ by adopting an appropriate policy input, then the economic system is said to be controllable at time moment t_0. If any of the state of the economy, as represented by the constant matrix system given by the first equation in Eq. (10.1), is controllable, then the economy is known as completely controllable, written as (A, B) controllable.

The following result (Perko 2013) provides several equivalent conditions for the controllability of the economy if it can be represented by a constant matrix system. This result also reveals some characteristics of economic controllability. For the completeness of this presentation, a version of the proof is also given here.

Theorem 10.1 Each of the following is a sufficient and necessary condition for the economy, which is modeled by the n-dimensional constant matrix system in Eq. (10.1), to be completely controllable:

1. The controllability matrix $U = [B|AB|A^2B|\ldots|A^{n-1}B]$ is of rank n.
2. All rows of $e^{-At}B$ are linearly independent on the interval $[0, \infty)$.
3. For any $t_1 > t_0$, the controllability Cramer's matrix $W(t_0, t_1) = \int_{t_0}^{t_1} e^{-A\tau}BB^Te^{-A^T\tau} d\tau$ is non-singular.
4. For every eigenvalue λ of A (hence for any complex number), the rank of the matrix $[\lambda I - A|B]$ is n.

Proof (1) Assume (A, B) controllability and show that condition (1) holds true. From definition, for any initial state x_0, there are $t_1 > 0$ and $u(t)$, for $0 \leq t \leq t_1$, such that

$$0 = x(t_1) = e^{At_1}x_0 + \int_0^{t_1} e^{A(t_1-\tau)}Bu(\tau)d\tau$$

That is,

$$x_0 = -\int_0^{t_1} e^{A\tau}Bu(\tau)d\tau \tag{10.2}$$

Because e^{At} can be expressed as

$$e^{At} = a_0(t)I + a_1(t)A + a_2A^2 + \ldots + a_{n-1}(t)A^{n-1} \tag{10.3}$$

Eq. (10.2) is simplified into

$$x_0 = \sum_{k=0}^{n-1} A^kB \int_0^{t_1} (-1)^{k+1}a_k(\tau)u(\tau)d\tau$$

By letting $\int_0^{t_1} (-1)^{k+1}a_k(\tau)u(\tau)d\tau = \tilde{u}_k, k = 0, 1, \ldots, n-1$, the previous expression can be rewritten as follows:

$$x_0 = \sum_{k=0}^{n-1} A^kB\tilde{u}_k = \left[B|AB|\ldots|A^{n-1}B\right]\tilde{u} \tag{10.4}$$

where $\tilde{u} = \left[\tilde{u}_0^T, \tilde{u}_1^T, \ldots, \tilde{u}_{n-1}^T\right]^T$. Because the equation in Eq. (10.4) has a solution for any x_0, it follows that the rank of $[B|AB|\ldots|A^{n-1}B]$ is n.

Next, we show (1) $\Rightarrow$ (2). By contradiction, assume that (1) holds true while (2) does not. Then there is $t_1 > t_0$ and non-zero constant vector α such that for any $t \in [t_0, t_1]$, $\alpha^T e^{-At} B = 0$. By differentiating this equation consecutively, we obtain:

$$\alpha^T e^{-At} AB = 0;$$
$$\alpha^T e^{-At} A^2 B = 0;$$
$$\alpha^T e^{-At} A^{n-1} B = 0.$$

So, we have $\alpha^T e^{-At}[B, AB, \ldots, A^{n-1}B] = 0$. That is, $\text{rank}\{e^{-At}[B, AB, \ldots, A^{n-1}B]\} < n$. Because e^{-At} is invertible, that implies $\text{rank}\{[B, AB, \ldots, A^{n-1}B]\} < n$, which contradicts with (1).

Now, we show (2) $\Rightarrow$ (3). By contradiction, assume that (2) holds true while (3) does not. So, there is $t_1 > t_0$ such that $|W(t_0, t_1)| = 0$. Hence, there is a non-zero vector α such that $W(t_0, t_1)\alpha = 0$. So, $\alpha^T W(t_0, t_1)\alpha = 0$. That is, we have

$$\int_{t_0}^{t_1} \left(\alpha^T e^{-A\tau} B\right)\left(\alpha^T e^{-A\tau} B\right)^T d\tau = 0$$

which implies that $\alpha^T e^{-A\tau} B = 0$, for $t_0 \le \tau \le t_1$, a contradiction with (2).

Next, we show that from (3) (A, B) controllability is guaranteed. Assume that (3) holds true. Then for any $t_1 > t_0$, we have $|W(t_0, t_1)| \neq 0$; and for any x_0,

$$u(t) = -B^T e^{-At}\left[W^{-1}(t_0, t_1) e^{-At_0} x_0\right], t_0 \le t \le t_1,$$

transfers the state of the system $x(t_0) = x_0$ at time t_1 to the origin. In fact,

$$\begin{aligned} x(t_1) &= e^{A(t_1 - t_0)} x_0 + \int_{t_0}^{t_1} e^{A(t_1 - \tau)} B u(\tau) d\tau \\ &= e^{A(t_1 - t_0)} x_0 - \int_{t_0}^{t_1} e^{At_1} e^{-A\tau} B B^T e^{-A^T \tau} d\tau W^{-1}(t_0, t_1) e^{-At_0} x_0 \\ &= e^{A(t_1 - t_0)} x_0 - e^{A(t_1 - t_0)} x_0 = 0 \end{aligned}$$

So, as of this step, we have shown that conditions (1), (2), and (3) are sufficient and necessary conditions for (A, B) controllability. As for (4) to be a sufficient and necessary condition, we will prove it later. QED

The concept of controllability of the economic system in Eq. (10.1) can also be defined as follows: Assume that x_0 is the state of the economic system at time t_0 and x_1 an arbitrary state of the system. If there are a finite time moment $t_1 > t_0$ and $u(t)$, for $t_0 \le t \le t_1$, such that under the effect of $u(t)$ the state x_0 of the system can be transformed into x_1, then the state x_0 is known as controllable.

It can be shown this definition as the earlier definition are equivalent. In fact, it can be shown that for a controllable economic system under Definition 10.1, for any given $t_1 > t_0$ and two arbitrary states x_0 and x_1, there is a control vector $u(t)$, for $t_0 \le t \le t_1$, such that under the effect of $u(t)$ the system's state $x(t_0) = x_0$ is transformed to the state $x(t_1) = x_1$. The control vector that materializes this state transformation is

$$u(t) = B^T e^{-A^T t}\left\{W^{-1}(t_0, t_1)\left[e^{-At_1}x_1 - e^{At_0}x_0\right]\right\} \tag{10.5}$$

10.2.2 The Observability of an Economic System

Before seeing the definition of the observability of an economic system, let us first look at an example.

Example 10.2 Assume that the control-theory model of a simple economic system is given as follows:

$$\begin{cases} \dfrac{dx}{dt} = \begin{bmatrix} -2 & 1 \\ 1 & -2 \end{bmatrix} x + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \\ y = \begin{bmatrix} 1 & -1 \end{bmatrix} x \end{cases}$$

where $x = \begin{bmatrix} x_1 & x_2 \end{bmatrix}^T$.

For this economic system, we have

$$e^{At} = \frac{1}{2}\begin{bmatrix} e^{-t} + e^{-3t} & e^{-t} - e^{-3t} \\ e^{-t} - e^{-3t} & e^{-t} + e^{-3t} \end{bmatrix}$$

So, for $u = 0$, we can obtain

$$x(t) = \begin{bmatrix} 1 & -1 \end{bmatrix}\frac{1}{2}\begin{bmatrix} e^{-t} + e^{-3t} & e^{-t} - e^{-3t} \\ e^{-t} - e^{-3t} & e^{-t} + e^{-3t} \end{bmatrix}\begin{bmatrix} x_{10} \\ x_{20} \end{bmatrix} = (x_{10} - x_{20})x_{20}e^{-3t}$$

So, for this economic system, as long as $x_{10} = x_{20}$, we will be able to produce the output $y(t) = 0$. That is, from the output $y(t) = 0$ of a certain time, we cannot determine the values of x_{10} and x_{20}. In other words, on the straight line $x_1 = x_2$ of the $x_1 - x_2$ plane, one cannot uniquely determine the initial state of the system through a period of output from the system. QED

Definition 10.2 For the economic system

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \end{cases} \tag{10.6}$$

assume the input is zero. If for any given initial state x_0 there is finite time $t_1 > t_0$ such that the initial state x_0 can be uniquely determined by the output $y(t)$ on the time interval $[t_0, t_1]$, then the economic system is known as completely observable, or (C, A) observable in short.

The economic system given in Example 10.2 is clearly not completely observable, because the state of the system on the subspace $x_1 = x_2$ of the plane cannot be uniquely determined by the output of the system. In general, for constant coefficient linear economic system in Eq. (10.6), the following theorem holds true (Perko 2013). And for the completeness of this presentation, a version of the proof is also given.

Theorem 10.2 The following are sufficient and necessary conditions for the n-dimensional constant coefficient linear system in Eq. (10.6) to be completely observable:

1. The rank of the observability matrix $V = [C^T | A^T C^T | (A^T)^2 C^T | \ldots | (A^T)^{n-1} C^T]^T$ is n.
2. All rows of the matrix Ce^{At} are linearly independent on the internal $[0, \infty)$.
3. For any $t_1 > t_0$, the observability Cramer's matrix $W(t_0, t_1) = \int_{t_0}^{t_1} e^{A\tau} C^T C e^{A^T \tau} d\tau$ is non-singular.
4. For each eigenvalue λ of A, the rank of the matrix $\begin{bmatrix} \lambda I - A \\ C \end{bmatrix}$ is n.

Proof Show (C, A) observability $\Rightarrow$ (1). Assume (C, A) observability. Let $u(t) = 0$. Then we have $y(t) = Ce^{At}x(0)$. If the minimum polynomial of matrix A is of order m, then e^{At} can be written as follows:

$$e^{At} = \sum_{i=0}^{m-1} a_i(t) A^i$$

where the coefficients $a_i(t)$ are uniquely determined by A and $a_0(t)$, $a_1(t)$, …, $a_{m-1}(t)$ are linearly independent. Substituting this expression of e^{At} into $y(t)$ leads to

$$y(t) = \sum_{k=0}^{m-1} a_k(t) CA^k x(0)$$

If we denote

$$Cx(0) = \beta_0, CAx(0) = \beta_1, \ldots, CA^{m-1}x(0) = \beta_{m-1}$$

then the previous expression is simplified into

$$y(t) = a_0(t)\beta_0 + a_1(t)\beta_1 + \ldots + a_{m-1}(t)\beta_{m-1}$$

where $\beta_0, \beta_1, \ldots, \beta_{m-1}$ are uniquely determined by $y(t)$, because if there is another group $\beta'_0, \beta'_1, \ldots, \beta'_{m-1}$ satisfying the previous equation, then we have

$$a_0(t)\left(\beta_0 - \beta'_0\right) + a_1(t)\left(\beta_1 - \beta'_1\right) + \ldots + a_{m-1}(t)\left(\beta_{m-1} - \beta'_{m-1}\right) = 0$$

Because $a_0(t)$, $a_1(t)$, …, $a_{m-1}(t)$ are linearly independent, we have $\beta_0 - \beta'_0 = 0$, $\beta_1 - \beta'_1 = 0$, …, $\beta_{m-1} - \beta'_{m-1} = 0$. That is, we have $\beta_0 = \beta'_0$, $\beta_1 = \beta'_1$, …, $\beta_{m-1} = \beta'_{m-1}$. Therefore, $[\beta_0, \beta_1, \ldots, \beta_{m-1}]$ corresponds to $y(t)$ one to one and we have

$$\begin{bmatrix} C \\ CA \\ \vdots \\ CA^{m-1} \end{bmatrix} x(0) = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_{m-1} \end{bmatrix} \tag{10.7}$$

Because of (C, A) observability, the initial value $x(0)$ is uniquely determined by $y(t)$. That is, Eq. (10.7) has a uniquely solution. Therefore, the rank of the following matrix is n.

$$V_1 = \begin{bmatrix} C \\ CA \\ \vdots \\ CA^{m-1} \end{bmatrix}$$

From Cayley-Hamilton theorem, it follows that the rank of V is equal to that of V_1. So, the rank of V is n.

Now, we show (1) $\Rightarrow$ (2). Assume that the rank of V is n, while condition (2) does not hold true. That is, there are non-zero vector α_0 and $t_1 > t_0$ such that on the interval $[t_0, t_1]$ we have $Ce^{At}\alpha_0 = 0$. Differentiating this equation consecutively provides the following:

$$\begin{gathered} CAe^{At}\alpha_0 = 0 \\ CA^2e^{At}\alpha_0 = 0 \\ \vdots \\ CA^{n-1}e^{At}\alpha_0 = 0 \end{gathered}$$

That is, we have

$$\begin{bmatrix} C \\ CA \\ \vdots \\ CA^{m-1} \end{bmatrix} e^{At}\alpha_0 = 0$$

So, the rank of the matrix V is less than n, a contradiction with condition (1).

Now, we show (2) $\Rightarrow$ (3). Assume that condition (2) holds true while (3) does not. That is we assume there is $t_1 > t_0$ such that $|W(t_0, t_1)| = 0$, or there is a non-zero vector α such that $\alpha^T\ W(t_0, t_1) = 0$. Hence we have either $\alpha^T\ W(t_0, t_1)\alpha = 0$ or

$$\int_{t_0}^{t_1} \alpha^T e^{A^T\tau} C^T C e^{A\tau} \alpha d\tau = \int_{t_0}^{t_1} \left(Ce^{A\tau}\alpha\right)^T \left(Ce^{A\tau}\alpha\right) d\tau = 0$$

Therefore, we can obtain the result that on the interval $[t_0, t_1]$ $Ce^{A\tau}\alpha = 0$, where α is a non-zero vector, a contradiction with condition (2).

Now, we show (3) $\Rightarrow$ (C, A) observability. For any $t_1 > t_0$ such that $W^{-1}(t_0, t_1)$ exists, when $u(t) = 0$, we have $y(t) = Ce^{A(t-t_0)}x(t_0) = Ce^{A(t-t_0)}x_0$. Multiplying both sides of this equation by $e^{A^T t}C^T$ produces $e^{A^T t}C^T y(t) = e^{A^T t}C^T Ce^{A(t-t_0)}x_0$; and integrating this expression leads to

$$\begin{aligned} \int_{t_0}^{t_1} e^{A^T t} C^T y(t) dt &= \int_{t_0}^{t_1} e^{A^T t} C^T C e^{A(t-t_0)} x_0 dt \\ &= W(t_0, t_1) e^{-At_0} x_0 \end{aligned}$$

Therefore, we obtain that $x_0 = e^{At_0}\ W^{-1}(t_0, t_1) \int_{t_0}^{t_1} e^{A^T t} C^T y(t) dt$. That is, x_0 is uniquely determined by $y(t)$; so it is (C, A) observable.

So, as of this junction, we have shown that conditions (1), (2), and (3) are individually sufficient and necessary conditions for (C, A) observability. As for condition (4) we will prove it later. QED

10.2.3 Duality Between Controllability and Observability

The similarities between the proofs of results on controllability and observability suggest that these two concepts should be somehow related. As a matter of fact, there is a duality relationship between controllability and observability.

In particular, for the following continuous time constant coefficient linear economic system

$$S:\begin{cases}\dfrac{dx}{dt}=Ax+Bu\\ y=Cx\end{cases}$$

define its dual system as follows:

$$S^T:\begin{cases}\dfrac{dx}{dt}=A^Tx+C^Tu\\ y=B^Tx\end{cases}$$

Then for the dual systems, we have the following result (Perko 2013):

Theorem 10.3 If the system S is completely controllable, then its dual system S^T is observable; and if the system S is observable, then its dual system S^T is completely controllable. The opposite of these statements also hold true. QED

Let U and U_T respectively stand for the controllability matrices of S and S^T, and V and V_T respectively the observability matrices of S and S^T. Then the following relationships hold true:

$$U_T=V^T \text{ and } V_T=U^T$$

From Theorems 10.1 and 10.2 it follows that controllability of $S \Leftrightarrow \text{rank}U=n \Leftrightarrow \text{rank}U^T=n \Leftrightarrow \text{rank}V_T=n \Leftrightarrow S^T$ is observable. Similarly, we have that observability of $S \Leftrightarrow \text{rank } V=n \Leftrightarrow \text{rank}V^T=n \Leftrightarrow \text{rank}U_T=n \Leftrightarrow S^T$ is controllable.

10.3 Structural Forms of Economic Systems' Controllability and Observability

When investigating a real-life economic system, its control-theory model might not be controllable or observable. In such a situation, it will be difficult to obtain the system's controllability through the method of altering the input vector, and difficult to know the state of the system through observing the output. So, a natural question is: Can we somehow decompose the control-theory model of the economic system into two or more subsystems such that one of the subsystems is observable or controllable, and so, the original system can be investigated through the analysis of regional observability and controllability? In this section, we will address this question fully.

10.3.1 Controllable Subspaces

Based on the analysis above, it follows that the state x_0 is controllable, if and only if there are t_1 and $u(t)$, $0 \leq t \leq t_1$, such that

$$x_0 = -\int_0^{t_1} e^{-A\tau} Bu(\tau)d\tau$$

Therefore, the following lemma follows (Perko 2013):

Lemma 10.1 All controllable states form a subspace of the state space.

Proof Assume that x_1 and x_2 are two arbitrary controllable states, and α and β two arbitrary real numbers. Then there are t_1, $u_1(t)$, and t_2, $u_2(t)$ such that

$$x_1 = -\int_0^{t_1} e^{-A\tau} Bu_1(\tau)d\tau$$

and

$$x_2 = -\int_0^{t_2} e^{-A\tau} Bu_2(\tau)d\tau$$

Without loss of generality, let

$$\tilde{u}_1 = \begin{cases} u_1(\tau), & \tau \leq t_1 \\ 0, & \tau > t_1 \end{cases}$$

then we have

$$x_1 = -\int_0^{t_2} e^{-A\tau} B\tilde{u}_1(\tau)d\tau$$

Therefore, we have

$$\alpha x_1 + \beta x_2 = -\int_0^{t_2} e^{-A\tau} B[\alpha\tilde{u}_1(\tau) + \beta u_2(\tau)]d\tau = -\int_0^{t_2} e^{-A\tau} Bu(\tau)d\tau$$

where $u(\tau) = \alpha\tilde{u}_1(\tau) + \beta u_2(\tau)$.

This equation indicates that $\alpha x_1 + \beta x_2$ is also controllable. So, the set of all controllable states is a subspace of the state space, known as the controllable subspace, denoted as X_c. QED

Theorem 10.4 The controllable subspace X_c is generated by B, AB, …, $A^{n-1}B$, that is,

$$X_c = span\left\{B, AB, \ldots, A^{n-1}B\right\}$$

Proof For any $x_0 \in X_c$, there are t_1, $u(t)$, $0 \le t \le t_1$, such that

$$x_0 = -\int_0^{t_1} e^{-A\tau} B u(\tau) d\tau$$

From Cayley-Hamilton theorem, it follows that

$$e^{At} = a_0(t)I + a_1(t)A + \ldots + a_{n-1}(t)A^{n-1}$$

So, we have

$$x_0 = -\int_0^{t_1} \left[\sum_{k=0}^{n-1} a_k(\tau)(-A)^k\right] B u(\tau) d\tau = B\tilde{u}_0 + AB\tilde{u}_1 + \ldots + A^{n-1}B\tilde{u}_{n-1}$$

where

$$\tilde{u}_k = (-1)^{k+1} \int_0^{t_1} a_k(\tau) u(\tau) d\tau, k = 0, 1, \ldots, n-1$$

So, $x_0 \in span\{B, AB, \ldots, A^{n-1}B\}$.

In the following, we show that the dimension of X_c is equal to that of $span\{B, AB, \ldots, A^{n-1}B\}$. To this end, assume that the dimension n_1 of X_c satisfies $n_1 \le n$.If $n_1 = n$, then $X_c = X = span\{B, AB, \ldots, A^{n-1}B\}$. If $n_1 < n$, let $n_0 = n - n_1$. Then there are n_0 linearly independent vectors $q_1, q_2, \ldots, q_{n_0} \in X$ such that for any $x_0 \in X_c$, $q_i^T x_0 = 0$, $i = 1, 2, \ldots, n_0$. It is because for any $t_1 > 0$ and $u(t)$,

$$-\int_0^{t_1} e^{-A\tau} B u(\tau) d\tau = x_0 \in X_c$$

Therefore, for any t_1 and $u(t)$,

$$q_i^T x_0 = -\int_0^{t_1} q_i^T e^{-A\tau} B u(\tau) d\tau = 0$$

implies that $q_i^T e^{-A\tau} B = 0$. Differentiating this equation consecutively provides

$$\begin{aligned} & q_i^T A e^{-A\tau} B = 0 \\ & q_i^T A^2 e^{-A\tau} B = 0 \\ & \vdots \\ & q_i^T A^{n-1} e^{-A\tau} B = 0 \end{aligned}$$

Letting $\tau = 0$ leads to $q_i^T B = 0$, $q_i^T AB = 0$, ..., $q_i^T A^{n-1} B = 0$. That is,

$$q_i^T \left[B, AB, A^2B, \ldots, A^{n-1}B\right] = 0, i = 1, 2, \ldots, n_0$$

which implies that the dimension of $span\{B, AB, A^2B, \ldots, A^{n-1}B\}$ is less than $n - n_0 = n_1$. Now, from the fact that the dimension of X_c is n_1 and that $x_0 \in span\{B, AB, \ldots, A^{n-1}B\}$, it follows that the dimension of $span\{B, AB, A^2B, \ldots, A^{n-1}B\}$ is also n_1. So, we have $X_c = span\{B, AB, A^2B, \ldots, A^{n-1}B\}$. QED

Theorem 10.5 The controllable subspace is an invariant subspace.

Proof From $X_c = span\{B, AB, A^2B, \ldots, A^{n-1}B\}$, it follows that

$$AX_c = \mathrm{A}span\left\{B, AB, A^2B, \ldots, A^{n-1}B\right\} = span\left\{AB, A^2B, \ldots, A^nB\right\}$$

So, from Cayley-Hamilton theorem, it follows that if

$$|sI - A| = s^n + a_{n-1}s^{n-1} + \ldots + a_1 s + a_0$$

then

$$A^n = -\left(a_{n-1}A^{n-1} + \ldots + a_1 A + a_0 I\right)$$

Therefore, we have

$$\begin{aligned} AX_c &= span\left\{AB, A^2B, \ldots, -\left(a_{n-1}A^{n-1} + \ldots + a_1 A + a_0 I\right)B\right\} \\ &\subseteq span\left\{B, AB, A^2B, \ldots, A^{n-1}B\right\} = X_c. \text{ QED} \end{aligned}$$

10.3.2 Separation of the Controllable Part

Consider the constant coefficient linear economic system in equation (10.6).

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \end{cases} \tag{10.6}$$

If $x^{'} = Tx$ is a non-singular transformation, then this given system can be rewritten as follows:

$$\begin{cases} \dfrac{dx'}{dt} = A'x' + B'u \\ y = C'x' \end{cases}$$

where $A^{'} = TAT^{-1}$, $B^{'} = TB$, and $C^{'} = CxT^{-1}$.

The controllability matrix of this second system is $U^{'} = [B^{'}, A^{'}B^{'}, \ldots, A^{'n-1}B^{'}] = TU$. Similarly, the observability matrix is $V^{'} = T^{-1}V$. Hence, non-singular linear transformations do not change the controllability and observability of the economic system.

Assume that X_C is the subspace of X that consists of all controllable states and X_{Nc} the subspace that consists of all non-observable states. Let e_1', e_2', …, e_{n_c}' and e_{n_c+1}', …, e_n', respectively, be a base of X_C and X_{Nc}. Then $\Sigma_c = \left\{e_1', e_2', \ldots, e_{n_c}', e_{n_c+1}', \ldots, e_n'\right\}$ constitutes a new base of the state space X. Let the base transformation from the original coordinate system to the new system be $x = Tx^{'}$, where

$$T = \begin{bmatrix} t_{11} & t_{12} & \ldots & t_{1n} \\ t_{21} & t_{22} & \ldots & t_{2n} \\ \ldots & \ldots & & \\ t_{n1} & t_{n2} & \ldots & t_{nn} \end{bmatrix}$$

so that the ith column is the coordinate of e_i' in the original coordinate system of X, and for any $x \in X$, its coordinate in the new base system Σ_c is $x' = \left[x_c', x_{Nc}'\right]^T$, $x_c' \in X_C$ and $x_{Nc}' \in X_{Nc}$.

Assume that the original economic system is written in the base system Σ_c as follows:

$$\begin{bmatrix} \dfrac{dx_c'}{dt} \\ \cdots\cdots \\ \dfrac{dx_{Nc}'}{dt} \end{bmatrix} = \begin{bmatrix} A_1 & \vdots & A_{12} \\ \cdots & \cdots & \cdots \\ A_{21} & \vdots & A_2 \end{bmatrix} \begin{bmatrix} x_c' \\ \cdots \\ x_{Nc}' \end{bmatrix} + \begin{bmatrix} B_1 \\ \cdots \\ B_2 \end{bmatrix} u, y = \begin{bmatrix} C_1 & \vdots & C_2 \end{bmatrix} \begin{bmatrix} x_c' \\ \cdots \\ x_{Nc}' \end{bmatrix}$$

Then the following result holds true:

Theorem 10.6 The constant coefficient linear system in Eq. (10.6) takes the following form in the new base system Σ_c:

$$\begin{bmatrix} \frac{dx'_c}{dt} \\ \cdots\cdots \\ \frac{dx'_{Nc}}{dt} \end{bmatrix} = \begin{bmatrix} A_1 & \vdots & A_{12} \\ \cdots & \cdots & \cdots \\ 0 & \vdots & A_2 \end{bmatrix} \begin{bmatrix} x'_c \\ \cdots \\ x'_{Nc} \end{bmatrix} + \begin{bmatrix} B_1 \\ \cdots \\ B_2 \end{bmatrix} u \tag{10.8}$$

$$y = \begin{bmatrix} C_1 & \vdots & C_2 \end{bmatrix} \begin{bmatrix} x'_c \\ \cdots \\ x'_{Nc} \end{bmatrix} \tag{10.9}$$

and is (A_1, B_1) controllable.

Proof Denote $T_1 = \left[e'_1, e'_2, \ldots, e'_{n_c}\right]$ and $T_2 = \left[e'_{n_c+1}, \ldots, e'_n\right]$. Then $T = [T_1, T_2]$. If $T^{-1} = [Q_1, Q_2]^T$, then we have

$$A' = T^{-1}AT = \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} A[T_1, T_2] = \begin{bmatrix} Q_1AT_1 & Q_1AT_2 \\ Q_2AT_1 & Q_2AT_2 \end{bmatrix}$$

and

$$B' = T^{-1}B = \begin{bmatrix} Q_1B \\ Q_2B \end{bmatrix}$$

Because

$$T^{-1}T = \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} [T_1, T_2] = \begin{bmatrix} Q_1T_1 & Q_1T_2 \\ Q_2T_1 & Q_2T_2 \end{bmatrix} = \begin{bmatrix} I_{n_c} & 0 \\ 0 & I_{n-n_c} \end{bmatrix}$$

we have $Q_2T_1 = 0$. Because T_1 consists of the base vectors of X_c as columns, $Q_2T_1 = 0$ implies that for any $x \in X_c$, $Q_2x = 0$. Because the columns of B belong to X_c, we have $Q_2B = 0$. That is, $B_2 = 0$. Because X_c is an invariant subspace of A, AT_1 belongs to X_c so that $Q_2T_1 = 0$ implies that $Q_2AT_1 = 0$, that is $A_2 = 0$.

In the following, we show the (A_1, B_1) controllability. The controllability matrix of the system in Eq. (10.8) is

$$U' = \begin{bmatrix} B_1 & A_1B_1 & \cdots & A_1^{n-1}B_1 \\ 0 & 0 & \cdots & 0 \end{bmatrix}$$

From Theorem 10.4, it follows that rank U' = the dimension of $X_c = n_c$. So, rank $\left[B_1|A_1B_1|\ldots|A_1^{n-1}B_1\right] = n_c$. That is, rank$\left[B_1|A_1B_1|\ldots|A_1^{n_c-1}B_1\right] = n_c$. So, the (A_1, B_1) controllability follows. QED

The expression $X = X_c \bigoplus X_{Nc}$ means that the state space X can be decomposed into controllable subspace X_c and non-controllable subspace X_{Nc}. Therefore, the economic system in Eq. (10.6) can be decomposed into controllable subsystem

$$S_c : \frac{dx'_c}{dt} = A_1 x'_c + B_1 u + A_{12} x'_{Nc}$$

and non-controllable subsystem

$$S_{Nc} : \frac{dx'_{Nc}}{dt} = A_2 x'_{Nc}$$

where these two subsystems are coupled together through the matrix A_{12}, Fig. 10.1.

Theorem 10.6 guarantees that the system

$$\frac{dx'_c}{dt} = A_1 x'_c + B_1 u$$

is controllable; and by letting $f(t) = A_{12} x'_{Nc}$, we see the controllability of the subsystem S_c.

Now, let us conclude this subsection by finishing up the proof of Theorem 10.1: a sufficient and necessary condition for (A, B) controllability is that for each eigenvalue λ of A, the rank of the matrix $[\lambda I - A | B]$ is equal to n.

Proof Because $\lambda I - A$ is non-singular for each complex number λ except when λ is an eigenvalue of A, the rank of $[\lambda I - A | B]$ is equal to n for each complex number λ except when λ is an eigenvalue of A.

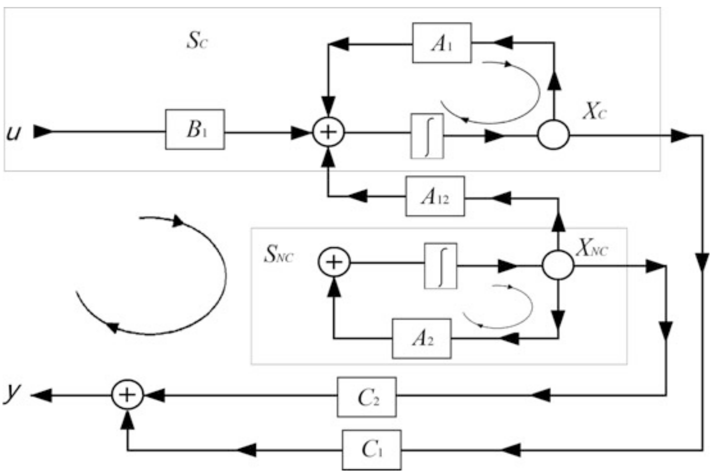

Fig. 10.1 The structural form of the economic system's controllability

Now, we show that if the system is (A, B) controllable, then for each eigenvalue λ of A, the rank of the matrix $[\lambda I - A | B]$ is equal to n.

By contradiction, assume there are an eigenvalue λ of A and a non-zero vector α such that $\alpha[\lambda I - A | B] = 0$. Then we have $\alpha\lambda I = \alpha A$ and $\alpha B = 0$. That implies $\alpha A^2 = \alpha\lambda A = \lambda\alpha A = \lambda^2\alpha$. Similarly reasoning can be used to obtain

$$\alpha A^i = \lambda^i \alpha, i = 1, 2, \ldots,$$

Therefore, we have

$$\alpha\left[B|AB|\ldots|A^{n-1}B\right] = \left[\alpha B|\lambda\alpha B|\ldots|\lambda^{n-1}\alpha B\right] = 0$$

which contradicts with the assumption of (A, B) controllability.

In the following, we show that if the system is not (A, B) controllable, then there is an eigenvalue λ of A such that the rank of $[\lambda I - A | B]$ is less than n.

If the system is not (A, B) controllable, then there is a non-singular transformation T that transforms (A, B) into (A', B'), where

$$A' = T^{-1}AT = \begin{bmatrix} A_1 & A_{12} \\ 0 & A_2 \end{bmatrix}, B' = T^{-1}B = \begin{bmatrix} B_1 \\ 0 \end{bmatrix}$$

Next, we show that for the eigenvalue λ of A_2, the rank of $[\lambda I - A | B]$ is less than n.

Because λ is an eigenvalue of A_2, there is vector $\beta \neq 0$ such that $\beta A_2 = \lambda\beta$. Define the following n-dimensional vector $\alpha = [0, \beta]$. Then we have

$$\alpha[\lambda I - A'|B'] = [0, \beta]\left[\begin{array}{cc|c} \lambda I - A_1 & -A_{12} & B_1 \\ 0 & \lambda I - A_2 & 0 \end{array}\right] = 0$$

So, we have

$$0 = \alpha[\lambda I - A'|B'] = \alpha\left[T^{-1}(\lambda I - AT)|T^{-1}B\right]$$

or

$$\alpha T^{-1}[(\lambda I - AT)|B] = 0$$

Define $\overline{\alpha} = \alpha T^{-1}$. Because $\alpha \neq 0$ and T^{-1} is non-singular, we have $\overline{\alpha} \neq 0$. So, the previous equation implies $\overline{\alpha}(\lambda I - A)T = 0$ and $\overline{\alpha}B = 0$. And because $\overline{\alpha}(\lambda I - A)T = 0$ is equivalent to $\overline{\alpha}(\lambda I - A) = 0$, $\overline{\alpha} \neq 0$ implies $\overline{\alpha}[(\lambda I - A)|B] = 0$.

If the system is not completely (A, B) controllable, then there is an eigenvalue λ of A such that the rank of $[(\lambda I - A)| B]$ is less than n. QED

10.3.3 The Not-Observable Subspace

When $u(t) = 0$ and the initial state is x_0, assume that the state trajectory that corresponds to the initial state x_0 is $x(t)$. If the corresponding output of the system is $y(t) = Cx(t) = 0$, then the output $y(t)$ cannot uniquely determine the initial state x (except for the zero state). In this case, x_0 is known as a not-observable state.

Lemma 10.2 The totality of all not-observable states forms a subspace of the state space.

Proof Assume that $u(t) = 0$ and that x_0^1 and x_0^2 are two arbitrary not-observable states. If the state trajectories that correspond to these initial states are, respectively, $x^1(t) = e^{At}x_0^1$ and $x^2(t) = e^{At}x_0^2$, their corresponding outputs are, respectively, $y^1(t) = Ce^{At}x_0^1 = 0$ and $y^2(t) = Ce^{At}x_0^2 = 0$.

Assume that α and β are two real numbers. Then the state trajectory that corresponds to the initial state $\alpha x_0^1 + \beta x_0^2$ is

$$x(t) = e^{At}\left(\alpha x_0^1 + \beta x_0^2\right) = \alpha e^{At}x_0^1 + \beta e^{At}x_0^2 = \alpha x^1(t) + \beta x^2(t)$$

and the corresponding output is

$$y(t) = Cx(t) = \alpha Cx^1(t) + \beta Cx^2(t) = \alpha y^1(t) + \beta y^2(t)$$

So, $\alpha x^1(t) + \beta x^2(t)$ is a not-observable state. This end proves that the set of all not-observable states within the state space forms a subspace, which is known as not-observable subspace, denoted as X_{No}. For the structure of the not-observable subspace, we have the following result:

Theorem 10.7 The not-observable subspace X_{No} is equal to the intersection of all the kernels of the matrices C, CA, ..., CA^{n-1}. That is, the following holds true:

$$X_{No} = \bigcap_{i=0}^{n-1} \ker\left(CA^i\right)$$

Proof From the definition of kernels, it follows that for any $x_0 \in \bigcap_{i=0}^{n-1} \ker\left(CA^i\right)$, we have

$$Cx_0 = CAx_0 = \ldots = CA^{n-1}x_0 = 0$$

The state, which corresponds to x_0, is $x(t) = e^{At}x_0$, and the corresponding output is

$$y(t) = Ce^{At}x_0 = x(t) = C\left[\sum_{i=0}^{n-1} a_i(t)A^i\right]x_0 = \sum_{i=0}^{n-1} a_i(t)CA^i x_0 = 0$$

So, $x_0 \in X_{No}$. That proves $\bigcap_{i=0}^{n-1} \ker\left(CA^i\right) \subseteq X_{No}$.

Conversely, if $x_0 \in X_{No}$, then $y(t) = Ce^{At}x_0 = 0$. Differentiating this equation $n-1$ times produces the following:

$$\begin{aligned} &CAe^{At}x_0 = 0 \\ &\vdots \\ &CA^{n-1}e^{At}x_0 = 0 \end{aligned}$$

Letting $t = 0$leads to $Cx_0 = CAx_0 = \ldots = CA^{n-1}x_0 = 0$, which implies $x_0 \in \bigcap_{i=0}^{n-1} \ker\left(CA^i\right)$. So, we have $X_{No} = \bigcap_{i=0}^{n-1} \ker\left(CA^i\right)$. QED

Theorem 10.8 The economic system in Eq. (10.6) is observable, if and only if $X_{No} = \{0\}$.

Proof (C, A) observability $\Leftrightarrow$ the rank of the observability matrix $= n \Leftrightarrow$ the system of linear equation

$$\begin{bmatrix} C \\ CA \\ \vdots \\ CA^{n-1} \end{bmatrix} x = 0$$

has a uniquely solution $\Leftrightarrow X_{No} = \{0\}$. QED

10.3.4 Separation of the Observable Part

Theorem 10.9 The not-observable subspace X_{No} of the economic system in Eq. (10.6) is an invariant subspace of A.

Proof From Theorem 10.8, it follows that if $x \in X_{No}$, then $Cx = CAx = \ldots = CA^{n-1}x = 0$. Under the transformation A, the image of x is Ax. We need to show $Ax \in X_{No}$. To this end, it suffices to show $C(Ax) = CA(Ax) = \ldots = CA^{n-1}(Ax) = 0$. So, we only need to show $CA^n x = 0$.

From Cayley-Hamilton theorem, it follows that

$$\begin{aligned} CA^n x &= C\left(-a_{n-1}A^{n-1} - \ldots - a_1 A - a_0 I\right)x \\ &= -a_{n-1}CA^{n-1}x - \ldots - a_1 CAx - a_0 CIx = 0 \end{aligned}$$

That completes the proof of $Ax \in X_{No}$. QED
Assume that the dimension of the not-observable subspace X_{No} is n_1. Let us select a base of X_{No} as follows: $e_1', e_2', \ldots, e_{n_1}'$, a subspace X_O of the state space X such that $X = X_O X_{No}$ and a base of X_O: $e_{n_1+1}', \ldots, e_n'$. Let the coordinate system of X based on the base $e_1', e_2', \ldots, e_{n_1}', e_{n_1+1}', \ldots, e_n'$, be Σ_O. Then within this coordinate system, for any state $x \in X$, it can be written as $x' = \begin{bmatrix} x_{No} \\ x_O \end{bmatrix}^T$, where

$$x_{No} = \left[x_1', x_2', \ldots, x_{n_1}'\right]^T \quad \text{and} \quad x_O = \left[x_{n_1+1}', x_{n_1+2}', \ldots, x_n'\right]^T$$

The transformation from the original coordinate system to the new system Σ_O is $x = Tx'$, where the ith column of T is the coordinate of the base vector e_i' in the original coordinate system, $i = 1, 2, \ldots, n$.

After applying this coordinate transformation, the economic system can be rewritten as follows:

$$\begin{cases} \dfrac{dx'}{dt} = \begin{bmatrix} \dfrac{dx_{No}}{dt} \\ \dfrac{dx_O}{dt} \end{bmatrix} = \begin{bmatrix} A_1 & A_{12} \\ A_{21} & A_2 \end{bmatrix}\begin{bmatrix} x_{No} \\ x_O \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}u \\ y = [C_1 \quad C_2]\begin{bmatrix} x_{No} \\ x_O \end{bmatrix} \end{cases}$$

Then, the following result holds true:

Theorem 10.10 The constant coefficient linear economic system in Eq. (10.6) under the new base system Σ_O takes the following form:

$$\begin{cases} \begin{bmatrix} \dfrac{dx_{No}}{dt} \\ \dfrac{dx_O}{dt} \end{bmatrix} = \begin{bmatrix} A_1 & A_{12} \\ 0 & A_2 \end{bmatrix}\begin{bmatrix} x_{No} \\ x_O \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}u \\ y = [0 \quad C_2]\begin{bmatrix} x_{No} \\ x_O \end{bmatrix} \end{cases}$$

and is (C_2, A_2) observable.

The proof of this result is similar to that of Theorem 10.6. All the details are omitted. Figure 10.2 depicts the observability structure of an economic system written in the form of Eq. (10.6).

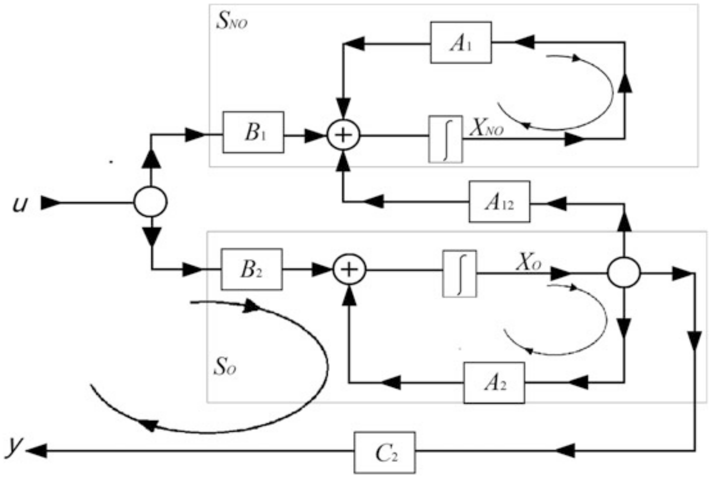

Fig. 10.2 The observability structure of a linear economic system

Similar to the controllability decomposition, the constant coefficient linear economic system in Eq. (10.6) can be decomposed by using a non-singular transformation into an observable subsystem:

$$S_O : \begin{cases} \dfrac{dx_{No}}{dt} = A_2 x_O + B_2 u \\ y = C_2 x_O \end{cases}$$

and a not-observable subsystem:

$$S_{No} : \frac{dx_{No}}{dt} = A_1 x_{No} + A_{12} x_O + B_1 u$$

These two subsystems are coupled together by A_{12}.

Next, let us conclude this subsection by seeing how the last part of Theorem 10.2 can be proved. In fact, this part of Theorem 10.2 follows from Theorem 10.10. The details are similar to those of the proof of the last part of Theorem 10.1 and are omitted.

10.4 Decomposition of Constant Coefficient Linear Economic Systems

If the state of an economic system is holistically and completely described by employing a control-theory model, the state vector most likely would contain a very good number of variables. In such a situation, the established model will be extremely complex and will be difficult to use for analyzing the characteristics of the economic system. Additionally, as a complex system, even after the state equation of the economic system is established, it will still be difficult to judge whether or not the system is observable and controllable. As a matter of fact, as a state equation that perfectly describes the complexity of an economic system, most likely the equation is neither observable nor controllable. Therefore, in this section we see how we can decompose the established state equation of the economic system into the following four parts: observable and controllable subsystem, controllable but not observable subsystem, not controllable but observable subsystem, and not observable and not controllable subsystem.

For the n-dimensional constant coefficient linear economic system in Eq. (10.6), let us decompose its state space X as follows:

$$\begin{aligned}
&X_1 = X_{No} \cap X_C,\\
&X_2 \text{ such that } X_C = X_1 \bigoplus X_2,\\
&X_3 \text{ such that } X_{No} = X_1 \bigoplus X_3, \text{ and}\\
&X_4 \text{ such that } X = X_1 \bigoplus X_2 \bigoplus X_3 \bigoplus X_4
\end{aligned}$$

If we assume the dimensionality of X_i is n_i, then we have $n_1 + n_2 + n_3 + n_4 = n$. By choosing a basis $\left\{e'_1, \cdots, e'_{n_1}\right\}$ in X_1, $\left\{e'_{n_1+1}, \cdots, e'_{n_1+n_2}\right\}$ in X_2, $\left\{e'_{n_1++n_2+1}, \cdots, e'_{n_1+n_2+n_3}\right\}$ in X_3, and $\left\{e'_{n_1+n_2+n_3+1}, \cdots, e'_n\right\}$ in X_4, we can introduce the following coordinate system:

$$\sum\nolimits_{CO} = \left\{e'_1, \cdots, e'_{n_1}, e'_{n_1+1}, \cdots, e'_{n_1+n_2}, e'_{n_1++n_2+1}, \cdots, e'_{n_1+n_2+n_3}, e'_{n_1+n_2+n_3+1}, \cdots, e'_n\right\}$$

For any $x \in X$, denote its coordinates in the new coordinate system Σ_{CO} as $x' = \left[x_1^T, x_2^T, x_3^T, , x_4^T\right]$, where $x_1 = \left[x'_1, \ldots, x'_{n_1}\right]$, $x_2 = \left[x'_{n_1+1}, \ldots, x'_{n_1+n_2}\right]$, $x_3 = \left[x'_{n_1+n_2+1}, \ldots, x'_{n_1+n_2+n_3}\right]$, and $x_4 = \left[x'_{n_1+n_2+n_3+1}, \ldots, x'_n\right]$.

Let T be the transformation from the original coordinate system to the new system Σ_{CO} so that $x = Tx^{'}$, where the i^{th} column is the coordinates of e'_i in the original system. So, T is obviously non-singular. Now, with this transformation, the original system is rewritten as follows:

$$\begin{cases}
\dfrac{dx'}{dt} = \begin{bmatrix} \dfrac{dx_1}{dt} \\ \dfrac{dx_2}{dt} \\ \dfrac{dx_3}{dt} \\ \dfrac{dx_4}{dt} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{21} & A_{22} & A_{23} & A_{24} \\ A_{31} & A_{32} & A_{33} & A_{34} \\ A_{41} & A_{42} & A_{43} & A_{44} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{bmatrix} u \\
y = \begin{bmatrix} C_1 & C_2 & C_3 & C_4 \end{bmatrix} x'
\end{cases}$$

Theorem 10.11 (Kalman canonical decomposition) The constant coefficient linear economic system in Eq. (10.6) can be simplified into the following canonical form in the new coordinate system Σ_{CO}:

$$\begin{cases} \dfrac{dx'}{dt} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ 0 & A_{22} & 0 & A_{24} \\ 0 & 0 & A_{33} & A_{34} \\ 0 & 0 & 0 & A_{44} \end{bmatrix} x' + \begin{bmatrix} B_1 \\ B_2 \\ 0 \\ 0 \end{bmatrix} u \\ y = [\, 0 \quad C_2 \quad 0 \quad C_4 \,] x' \end{cases}$$

and the original economic system is decomposed into the following four subsystems:

$$S_1 : \begin{cases} \dfrac{dx_1}{dt} = A_{11}x_1 + B_1 u + f_1, \text{where } f_1 = A_{12}x_2 + A_{13}x_3 + A_{14}x_4 \\ y_1 = 0x_1 = 0 \end{cases}$$
$$S_2 : \begin{cases} \dfrac{dx_2}{dt} = A_{22}x_2 + B_2 u + f_2, \text{where } f_2 = A_{24}x_4 \\ y_2 = C_2 x_2 \end{cases}$$
$$S_3 : \begin{cases} \dfrac{dx_3}{dt} = A_{33}x_3 + f_3, \text{where } f_3 = A_{34}x_4 \\ y_3 = 0x_3 = 0 \end{cases}$$
$$S_4 : \begin{cases} \dfrac{dx_4}{dt} = A_{44}x_4 \\ y_4 = C_4 x_4 \end{cases}$$

where the subsystem S_1 does not have any observable output, the subsystem S_2 can be completely observed and controlled, the subsystem S_3 does not have any output and cannot be affected by any control variable, and the subsystem S_4 is not influenced by any control variable.

Proof We need to show $A_{21} = A_{23} = A_{31} = A_{32} = A_{41} = A_{42} = A_{43} = 0$, $B_3 = B_4 = 0$, and $C_1 = C_3 = 0$. First of all, from $X = X_1 \bigoplus X_2 \bigoplus X_3 \bigoplus X_4$ and $X_C = X_1 \bigoplus X_2$, it follows that $X = X_{Nc} \bigoplus X_C$ and $X_{Nc} = X_3 \bigoplus X_4$. So, Theorem 10.6 implies that $A_{31} = A_{32} = A_{41} = A_{42} = 0$ and $B_3 = B_4 = 0$.

Because $X_{NO} = X_1 \bigoplus X_3$, X can be decomposed as $X = X_{NO} \bigoplus X_O$, where $X_O = X_3 \bigoplus X_4$. From Theorem 10.10, the system is rewritten as follows:

$$\begin{cases} \begin{bmatrix} \dfrac{dx_1}{dt} \\ \dfrac{dx_3}{dt} \\ \dfrac{dx_2}{dt} \\ \dfrac{dx_4}{dt} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{31} & A_{32} & A_{33} & A_{34} \\ 0 & 0 & A_{22} & A_{24} \\ 0 & 0 & A_{42} & A_{44} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} B_1 \\ B_3 \\ B_2 \\ B_4 \end{bmatrix} u \\ y = [\, 0 \quad 0 \quad C_2 \quad C_4 \,] x' \end{cases}$$

which means that $A_{21} = A_{23} = A_{41} = A_{43} = 0$ and $C_1 = C_3 = 0$.

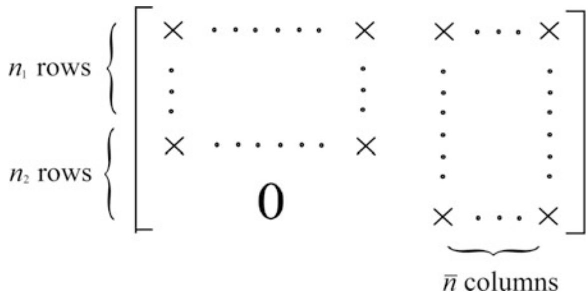

Fig. 10.3 A reduced controllability matrix

Next, we show that the subsystem S_2 is controllable and observable. To this end, we only need to show (A_{22}, B_2) controllability and (C_2, A_{22}) observability.

Theorem 10.6 implies $\left(\begin{bmatrix} A_{11} & A_{12} \\ 0 & A_{22} \end{bmatrix}, \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}\right)$ controllability. So, the rank of the corresponding controllability matrix

$$\begin{array}{r} n_1\ rows\} \\ n_2\ rows\} \end{array} \begin{bmatrix} B_1 & A_{11}B_1 + A_{12}B_2 & A_{11}(A_{11}B_1 + A_{12}B_2) + A_{12}A_{22}B_2 & \cdots \\ B_2 & A_{22}B_2 & A_{22}^2 B_2 & \cdots \end{bmatrix}$$

is $n_1 + n_2$. So, the bottom n_2 rows have to be linearly independent. Otherwise, assume the number of linearly independent rows in the bottom n_2 rows is $\bar{n} < n_2$. Then through using elementary operations, the controllability matrix can be reduced into that given in Fig. 10.3.

This end contradicts the assumption that the rank of this matrix is $n_1 + n_2$. So, the rank of the matrix $\left[B_2\ A_{22}B_2 \ldots A_{22}^{n_1+n_2-1}B_2\right]$ is n_2. So, the rank of $\left[B_2\ A_{22}B_2 \ldots A_{22}^{n_2-1}B_2\right]$ is n_2, which means (A_{22}, B_2) controllability.

Similarly, we can show (C_2, A_{22}) observability. QED

Notice that although the subsystem S_1 has control input. However, it does not guarantee that this subsystem is (A_{11}, B_1) controllable. And the subsystem S_4 has observable output. However, it is not guaranteed that this subsystem is (C_4, A_{44}) observable.

10.5 Some Final Remarks

Through the concepts of economic systems' observability and controllability, the theoretical results in this chapter imply that in the most general circumstance, each economic system is vulnerable to external influences through first the subsystem S_1 and then the subsystems $S_3$and S_4. And domestic monetary and fiscal policies can only effectively affect the subsystem S_2, and the consequent results on S_2 can also be readily observed.

Worse than that, the base vectors in Σ_{CO} are chosen by the attacker, making self-defense more challenging.

Chapter 11
Flashing with Swords: How Currency Wars Take Place

Contents

Going along with the common knowledge that money can easily destroy a person, a family, and a healthy business enterprise, this chapter investigates how a currency war can potentially take place. By making use of the systemic yoyo model and Bernanke-Gertler model of fundamental value of capital, this chapter shows how money can be purposefully and strategically employed as a weapon of mass destruction. Based on how a currency war could be possibly raged against a nation.

11.1 Introduction

The main focus of this chapter is on financial crises that are caused and/or created purposefully by certain group(s) of people in order to acquire economic and political gains. Here, financial crises include all those crises with respect to either respectively or jointly currency, credit, bank, debt, and the markets of stocks, bond, financial derivatives, etc. They generally mean severe fluctuations and chaos that appear in the financial area of a nation, interfering very negatively with the operation of the real economy. Each of these crises is accompanied by sudden deterioration of all or most financial indices, stock market crash, capital flight, credit destruction, extremely tight money supply, rising interest rate, bank runs, bankruptcy of a large number of financial institutions, major decrease in the official reserves, inability to repay the interest and principal of maturing debt, currency devaluation both internally and externally, etc.

Because the modern-day national economies have been closely intertwined with each other to a high degree of globalization, when a nation or geographic region suffers from economic and financial crises, in terms of their damaging effects and

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adverse impacts, the crises tend to possess international and global characteristics. Since the 1920s, there had appeared many large-scale financial crises. The most noteworthy of these crises include:

1. The global stock market crisis that started on October 28, 1929, in the New York Stock Exchange and spread to other nations quickly, leading to a worldwide financial and economic crisis until 1933
2. Six US dollar crises one after another during the time period from 1960 to 1973
3. A bank bankruptcy wave that started with the failure of the US National Bank in San Diego and quickly spread to many other western countries during 1973–1975
4. The debt crisis that broke out in August 1982 and quickly involved over 50 developing countries from around the world
5. The international stock market crisis that started with the plummet of the Dow Jones Industrial Average on October 19, 1987; the consequent chaos of the Wall Street that momentarily spread throughout all the major stock exchanges of the western world
6. The British pound crisis of 1992
7. Mexican financial crisis of 1994
8. The Southeast Asian financial crisis of 1997
9. The Russian currency, financial crisis of 1998
10. The Brazilian currency, financial crisis of 1999
11. The Argentinean currency, financial crisis of 2001

This chapter makes use of the systemic yoyo model and Bernanke-Gertler model of fundamental value of capital to show that when a large amount of foreign investments gathers in one place over either a long period or a short period of time and then leaves suddenly and massively, that local economy has to suffer through a positive bubble, caused by the increased money supply as a consequence of the foreign investments, and then a following negative, disastrous bubble, caused by the sudden dry out of the money supply. Because a large number of economic activities are either unexpectedly delayed or totally impossible to complete, the local investors are actually unable to continue to collect their originally expected dividends for many time periods to come. In other words, foreign investments can be employed as a weapon of mass destruction, if they leave strategically and suddenly, no matter whether they come quickly in a short period of time or slowly over a relatively longer period of time.

This chapter is organized as follows: With relevant concepts systematically gathered in Sect. 11.2, recent speculative attacks and currency crises are compared in Sect. 11.3. By focusing on the analysis of the fundamental value of capitals, Sect. 11.4 shows how potentially currency wars can be launched purposefully. Section 11.5 concludes the discussion of this chapter.

11.2 The Basic Concepts and Systemic Intuition

The general concept of financial crises includes the following four classes of crises: currency, bank, foreign debt, and systems. Here, by currency crisis, it represents such a situation that due to purposeful and targeted speculative activities against a nation, the nation's currency suffers from drastic devaluation, or the nation's government is forced to drastically increase its interest rate or spend a large amount of the foreign reserves to defend its currency. By bank crisis, it means actual and/or potential bank runs or such a scenario that a number of banks stop repaying their debts because of their falling into bankruptcy or the government is forced to interfere by providing large amounts of support. By foreign debt crisis, it implies such a case that a nation can no longer repay its foreign debts on time, no matter whether the debtors are governments or private individuals. By systematic financial crisis, it stands for the destructive effects on the real economy due to severe damages of the financial infrastructure so that the efficiency of the financial markets is greatly affected. The connotation of systematic financial crises might overlap with those of other kinds of crises, while currency and bank crises might not lead to severe damages to a nation's payment system. So, neither currency crises nor bank crises can be identified with systematic financial crises.

In many circumstances, the specific definition of financial crises simply means currency crises. The early investigation of currency crises can be traced back to at least (Krugman 1979). Paul Krugman treats a currency crisis as an international balance of payments crisis. He believes that in order to prevent their currencies to devaluate, countries with either a fixed exchange rate system or pegged exchange rate system would pay the price of either spending their international reserves or increasing inflation due to their raising domestic interest rates; when the governments give up on the fixed exchange rate system or the pegged exchange rate system, their currencies experience drastic drops in value, leading to currency crises. Currency crises are generally indicated by the collapse of the fixed exchange rate system or forced adjustment to the system, such as official devaluation of the local currency, expanded floating range of the exchange rate, drastic decrease in international reserves, noticeable rise in the interest rate of local currency, etc.

According to the literature, there are four main criteria for judging currency crises: (1) sudden and large-scale changes appear in exchange rate; (2) the weighted average of exchange rate and foreign reserves fluctuates widely; (3) the weighted average of exchange rate, foreign reserves, and interest rate vibrates wildly; (4) the import drops drastically. The second criterion was established by Kaminsky et al. (1998) who believe that a currency crisis represents such a scenario that is caused by either devaluation of the nation's currency or drastic drop in the nation's international reserve or both as a consequence of an attack on a nation's currency. Because of this reason, currency crises can be verified afterward by using the index named exchange market pressure (EMP). This index stands for a weighted average between the monthly percentage change in the exchange rate of the local currency and that of the international reserves. Because this index increases with the devaluation of the local currency and the loss of international reserve, major increases in this index indicate a strong pressure to sell off the local currency. Because this second criterion possesses very practical operationality, it has been employed most widely among these four criteria.

Most of the financial crises that occurred since the 1990s have brought along with them clear characteristics of currency crises; and another outstanding feature of recent currency crises is that they have been accompanied by bank crises. Such scenarios are referred to as twin crises.

Since the 1980s, along with the gradual strengthening of globalization of the capital markets, international flows of capital have been developed unprecedentedly with ever increasing magnitude, velocity, and accompanying dangers and risks. Large amounts of short-term capitals that are not under the watch of any national government and international financial organization have been moving freely in the international financial markets for pursuing profit opportunities by making use of various new financial tools, trading platforms, and advanced trading technologies. These new characteristics of the international capital have led to frequent occurrence of turmoil in the international financial markets; speculative attacks happen often with ever increasing strength and duration of impact. The Asian currency crises that started in 1997 further indicate that the currency crises caused by speculative attacks can also possibly develop into full-scale financial crises and deepening social crises of large magnitude.

The so-called international speculative capital or hot money represents such capital that is frequently moved within and between various markets in pursuit of short-term, high levels of profits without any particular fields of investment focus. Speculative capital tends to be short term even though there are exceptions to this rule of thumb. One of the modern characteristics of international speculative capitals is their camouflage. At the same time, these capitals can also go along with the market cycles by pursuing mid- and long-term investments. Additionally, not all short-term capitals are speculative. For example, the short-term capitals involved in the financial intermediation and settlement of international trades, short-term interbank funds, banks' short-term positions for allocation, etc., are not speculative in nature.

Along with the expansion in the size, circulation speed, and coverage of the international capital markets have international speculative capitals grown. Based on their predictions on the changes in exchange rate, interest rate, security prices, gold price, or the prices of certain commodities, speculative capitals could be suddenly involved in large scale in both long and short trades in a short period of time. By substantially altering the composites of their portfolios and by affecting the confidence of the holders of other assets, these speculative capitals cause severe instability in the market prices so that short-term high-profit opportunities could be created. Such market behaviors that disturb the market prices and appear suddenly are known as speculative attacks. As limited by the constraint of pursuing after quick gains, international speculative capitals generally choose to attack such economic sectors and geographic areas that can hold large amount of capitals and allow fast movements of funds with expected high returns and few financial regulations. These economic fields include (foreign) currencies, futures, options, precious metals, real estates, etc.

From what has happened empirically in the past, it seems that international speculative capitals have been fond of attacking the currency of one nation or the currencies of several nations at the same time. Most often seen speculative attacks are those that assault either fixed exchange rate systems or regulated exchange rate systems. Speaking generally, when a nation either employs a fixed exchange rate system or pegs a target exchange rate, the speculators often make their judgment that as long as the official parity or the target exchange rate does not conflict with the fundamental conditions and states of the economy, the official exchange rate will be maintained. However, if the speculators believe that the fundamental states of the current economy could not sustain the prevalent level of exchange rate for long, they would launch a speculative attack in order to speed up the dissolution of the fixed exchange rate system so that opportunities of quick profits would be generated.

Under the conditions of either fixed or pegged exchange rate system, as long as there appears either a domestic inflation or recession accompanied with sustained current account deficits, the governmental promise on the fixed exchange rate would lose its reliability. It is because in these situations there is a heavy pressure to devaluate the local currency; in order to maintain the promised exchange rate, the government will be forced to mobilize and spend its international reserve. Even with the support of the international financial markets, the fundamental imbalances existing in the economic states still cannot be corrected, which can most likely delay the occurrence of the devaluation of the local currency, although the devaluation will sooner or later happen inevitably. If speculators predicted this forthcoming event, they would mobilize their capitals ahead of time and launch their speculative attack in order to position themselves for quick profits. By making use of the spot and forward transactions, futures contracts, options trades, and swaps of various financial tools, speculators carry out their multidimensional speculative strategy by positioning their capitals at the same time on the markets of foreign exchanges, securities, and all different forms of financial derivatives. Because of the fixed exchange rate or the promise that the government would maintain the rate fixed, the risk to the speculators is actually quite low, because the direction along which the exchange rate would move is clear. To say the least, even if the prediction is incorrect, the worst is that the exchange rate parity did not change so that the most the speculators could lose are their minimal amounts of trade costs. Hence, once a speculative wave is started, the magnitude in general is large, leading to the expected consequences, as a self-fulfilling prophecy of a humongous scale.

11.3 Recent Speculative Attacks and Currency Crises

During the time period of Bretton Woods system after World War II, the strength and power of private capitals grew drastically; relevant speculative activities evolved with increasing levels of energy. Their attacks on various national currencies from around the world were mostly successful and amplified with ever-growing vigor and intensity. The most typical are the British pound crisis of the late 1967, French franc crisis of August 1969, and the US dollar crisis of 1971–1973. If we say that the root problem for Bretton Woods system to eventually collapse were the defects of the system itself, then the direct triggering factor for the system's collapse would be the speculative attack of the international short-term hot money on the US dollar – the base currency. When Bretton Woods system was over, the world was in a wave of deregulation, strengthening the market mechanism, and promoting economic and financial liberalization. Correspondingly, the international financial markets become further liberalized and global. Along with the application of modern technology of communication and computer networks, financial derivatives and methods of trading are developed in abundance. All these political, societal, and technological advances provided the space for international capitals to grow and to be mobilized unprecedentedly. With their greatly increased speed of mobility, international capitals have launched frequent speculative attacks. Among the most typical are the attacks on the pegged exchange rate system employed by some countries of Latin America in the early 1980s, the Mexican peso crisis of 1994, and financial crises of Eastern Asia during 1997–1998. The following provides a list of recent speculative attacks. For more details, please consult with Wang and Hu (2005).

Case 1

The attacks on the exchange rate system of Latin American countries in the early 1980s

In 1978, Chile, Uruguay, and Argentina decided to employ a crawling peg exchange rate system. Each of these national governments established its plan to gradually depreciate its local currency against US dollar. However, in their implementations, their rates of inflation were much higher than that in the United States, while their degrees of depreciation were much smaller than the difference of the US inflation rates. Therefore, the overevaluations of their local currencies made the deficits of their current accounts rise. During 1981–1982, the interest rate in the international financial markets reached an historical high, making the burdens of foreign debts and the deficits of the current accounts of these three countries difficult to sustain, so that it became inevitable for the local currencies to devaluate while departing from the targeted exchange rates. Under this background, these countries respectively experienced speculative attacks, corresponding currency devaluations and the consequent capital flights, and crises of domestic financial institutions' runs.

Case 2

Mexican peso crisis of 1994

In 1982 after having suffered from its debt crisis, under the supervision of the IMF, Mexico implemented a comprehensive policy for economic adjustment and reform while tightening its economy and dramatically reducing its fiscal deficit. In 1987, Mexico refixed its exchange rate between Mexican peso and US dollar. In January 1989, Mexico started to employ a crawling peg exchange rate system, which was changed to a moving target regional exchange rate system in December 1992 while gradually expanding the floating range for peso. This series of measures of economic reform achieved a certain degree of success; the national economy steadily recovered. However, in 1994, Mexican economy once again stalled while accompanied by political instability. Therefore, the expectation and rumor for peso to depreciate grew; capitals fled one after another. Interventions of the central bank made the market interest rate rise drastically, while the national foreign reserves were depleted quickly. On December 30, Mexican government eventually had to allow peso to depreciate. However, the new exchange rate established after the depreciation immediately suffered from speculative attacks so that Mexican government had to implement a floating exchange rate system. After then, the domestic economic conditions and the political situation made foreign investors extremely nervous, causing continued capital flight, banks subjected to runs, and the economy falling into crises. In the newly adopted floating exchange rate system, peso continued to depreciate; until the end of 1995, peso had reached consecutive historical lows one after another.

Case 3

The speculative attack on the joint floating mechanism of the European monetary system (1992–1993)

The national currencies within the European monetary system of the nations that were members of the European Community had followed a joint floating exchange rate mechanism. This mechanism had led to the creation of the European currency unit (ECU) and established the statutory central exchange rates between the individual national currencies and the European currency unit. Therefore, between these member nations, a system of fixed exchange rates was employed, while externally a joint floating rate system was implemented. In the early 1990s, the member nations of the European Community experienced varied degrees of economic turmoil. Uniformities in their respective macroeconomic states, such as inflation rates, unemployment rates, fiscal deficits, economic growth rates, etc., started to be broken. Over time, it became clear that some member nations could no longer maintain their statutory exchange rates with ECU, providing opportunities for the international speculative capitals.

In the late 1992, an initial round of speculative attacks appeared. Among the first group of victims of the attacks were Finnish marks and Swedish krona. At the time, neither Finland nor Sweden was a member of the European Community. However, they all hoped to join so that they voluntarily pegged their own currencies with ECU. Under the speculative attacks, Finland quickly gave up its fixed exchange rate and drastically depreciated its currency on September 8. On the contrary, Swedish government decided to protect its krona by raising its short-term interest rate to 500% annually. That eventually defeated the speculative attacks. At the same time, British pound and Italian lira also suffered from continued attacks. On September 11, the European monetary system agreed for lira to depreciate 7%. Although the German central bank spent around 24 billion marks to support lira, 3 days later lira was still forced out of the European monetary system. By this time, the Bank of England had lost several billions of US dollars to protect its pound. Even so, on September 16, the British pound was still forced to float freely. Although French franc also suffered from speculative attacks, through joint interventions with Germany and by greatly increasing the interest rate, the value of franc recovered.

This crisis of the European monetary system started in 1992 and lasted until 1993, during which speculative attacks often occurred. At the end of 1992, Portuguese currency escudo depreciated; Spanish currency pesetas was devalued once again, while Swedish krona and Norwegian krone started to float. In the early part of 1993, Ireland's pound depreciated, Portuguese escudo depreciated another time, and Spanish pesetas experienced its third round of depreciation. On the other side, French franc and Danish kroner successfully stood against the sporadic speculative attacks.

Case 4

1997 currency crises of East Asia (1997–1998)

In the 1980s and early 1990s, nations in Southeast Asia sped up their steps toward financial liberalization by completely opening up their domestic financial markets to attract maximal scales of foreign investments. Such fast-speed liberalization led to drastic economic growth, which was known as "Southeast Asia miracle." However, after entering the mid-1990s, the rising labor costs were translated into the decreased international competitiveness in their products so that deficits began to appear in the current accounts of some Southeast Asian countries. Because these countries did not in a timely basis upgrade their industrial structures in order to keep pace with the increasing competitiveness of their products, the continued influx of the foreign capitals together with domestic investments led to the formation of economic bubbles and overheated sector of real estates. For example, in 1996, Thailand's balance of foreign debts had reached over 90 billion US dollars with more than 40 billion dollars of short- and midterm foreign debts, both of which surpassed the corresponding levels of foreign reserves at the start of 1997. Additionally, because of the overheated investments, particularly the overheated investments in real estates, the bad debts of Thai financial institutions had amounted to more than 30 billion US dollars in early 1997. Therefore, the public and foreign investors started to worry about the economic conditions and financial order in Thailand, which inevitably helped to consolidate the expectation for baht to depreciate. At the same time, international speculators were also building up their monetary energy and preparing to launch their large-scale attacks. On February 14, Thai currency baht depreciated 5% against US dollars, making the covered speculative attacks public. After then, baht suffered from ever increasing pressure to depreciation further; and interventions of Bank of Thailand were quickly exhausting the national foreign reserves. After mid-May, speculative capitals launched their new rounds of attacks, creating an 11-year new low for the exchange rate of baht. Several nations in Southeast Asia jointly intervened in the foreign exchange markets by buying in baht, while the Bank of Thailand sacrificed 5 billion US dollars of foreign reserves and once again raised its short-term interest rate. However, all of these still could not rebuild the public confidence and drive off the speculative attacks. Eventually on July 2, the Bank of Thailand was forced to allow baht to float freely in the exchange markets, causing baht to depreciate 20% against US dollar on that single day. Subsequently, the speculative attacks quickly spread over to the neighboring nations and regions so that the Philippines, Malaysia, Indonesia, Singapore, Hong Kong, and Taiwan were all affected. Other than Hong Kong, the local currencies of these countries and regions all depreciated against US dollar with different scales. At the same time, all these nations and regions except Singapore and Taiwan fell into deep financial and economic crises. After October of the same year, the crises spread over to South Korea, causing South Korean currency won to depreciate deeply against US dollar and making the economy of South Korea fall deeply into an economic crisis.

Case 5

Russian currency crisis (1998)

At the early stage of Russian economic transition, large amounts of international capitals entered Russia. As of July 1, 1997, the accumulated foreign investments totaled 18 billion US dollars, about 10 billion dollars of which were short-term capitals and invested in the securities markets. Although the economic growth of the real economy was nearly zero, the stock market rallied rapidly in the first half of 1997; bubble expansion appeared in the prices of financial assets. When the currency crises of Southeast Asia broke out and started to spread toward the regions of Northeast Asia, the probability for Russia to experience a similar currency crisis was very big, considering the market long-term expectation of instability for Russian economy. Starting in November 1997, speculators launched their attack on ruble with many others followed. During the end of 1997 and early part of 1998, Russian government and central bank sacrificed foreign reserves to purchase ruble, while expanding ruble's floating range and increasing the interest rate from 21% to 35%. Although the situation was temporarily stabilized, large amounts of foreign reserves were lost. However, after May, another wave of speculation started, causing ruble's exchange rate to fluctuate severely again. Though Russian government raised the interest rate to 150% and sought for international assistance in order to counter the attack, the situation was never successfully under control. On August 17, Russian government had to expand ruble floating exchange corridor, that is, allowing ruble to depreciate. However, unexpectedly, the situation continued to worsen. Eventually on September 2 without a choice the exchange corridor was abandoned. That meant that Russian government gave up its over two-year-old managed target floating mechanism of ruble.

Case 6

Brazilian currency crisis (1999)

The currency crises that appeared in East Asia and Russia increased the market expectation for Brazilian currency to depreciate, causing large amounts of capital leaving Brazil since September 1998. At the end of 1998, Brazilian Congress did not pass the bills to increase the benefit taxes of civil servants and those of retired civil servants as contained in the fiscal adjustment plan, while the 1998 deficits of the fiscal balance, trades, and current accounts exceeded the expected levels. So, along with the decreasing market confidence, speculative attacks were triggered, forcing Brazilian central bank to allow its real to float freely against US dollar.

All the speculative attacks that were launched since the 1980s have shown a good number of new characteristics, including amplifying scales and forces, enhancing dimensionality in terms of their strategies of attack, covering larger geographic areas, increasing publicity of planned attacks, etc. In particular, the main reasons for the amplifying scales and forces of the speculative attacks include:

1. The size of the international speculative capital has been increasing constantly. Since the 1980s, the economic growth of the main industrialized nations has been slowed, while the reform for financial liberalization of various countries has been strengthened. That caused large amounts of capitals to enter into the international financial markets to look for new opportunities. Such continuous accumulation of international speculative capitals, together with the multiplying effect of international credit, makes the available speculative capitals increase multiple times. Based on the relevant estimates of the International Monetary Fund, there were at least 7200 billion US dollars of speculative capitals currently floating around the international financial markets. That amount is equivalent to 20% of the world GDP, and each day, over 1200 billion US dollars of speculative capitals are looking for various profit opportunities. That is nearly 100 times more than the amount of trades of real consumable goods.
2. The capitals available for speculation purposes have shown the tendency to collaborate and to take actions jointly. Along with the rapid development of communication technology and the expanding availability of internet, a 24/7 operational system for the globalized exchange markets has appeared so that capitals can be transferred from one exchange market to another instantly. That makes the once stranglers and disbanded international speculators develop into powerful speculation assemblages. As a third force different from various national currency authorities and international financial organizations, they have constituted a major thread to the stability of each nation's exchange system and the normal operation of the international currency system.
3. The introduction of financial derivatives provided a leveraged platform of trading for the speculators. Since the 1970s, financial innovations have led to the profligate development of new financial derivatives and their trades. Because of the characteristic of high leverages of the financial derivatives, speculators can trade such financial products that are valued tens or even hundreds of times of the little amounts of capital they mobilized. That enables a hedge fund to

embark on trades worth several hundreds of billions of US dollars with a small amount of capital, affecting the entire international financial markets.

Since the 1990s, the strategies of speculative attacks have been further developed. The traditional speculator would simply use the price differences between spot and future trades, while the current strategies of speculative attacks have been quite complicated. By utilizing all kinds of available financial tools, the speculator gets involved in various markets of the traditional tools and derivatives. It can be said that current speculative attacks make use of the inherent linkages among the prices of various financial products, traded in different markets, to make comprehensive and profitable arrangement of capitals.

Traditional speculative attacks have been isolated and scattered in different geographic regions. However, along with the recent deepening globalization of the international financial markets and along with the further unification of regional economies, speculative attacks have also showed clear regional characteristics. No matter whether it is the Latin American currency crisis of the early 1980s, the Mexican crisis of 1994, the European monetary system crisis of 1992, or the Southeast Asian crisis of 1997, each started with the initial shocks in such a market that contained the most concentrated imbalances. Then, the initial shocks spread over to other neighboring markets, displaying a dynamic process of mutual influences.

Traditional speculations used to be hidden or semipublic arbitrage activities. However, since the 1990s, along with the deregulation and financial liberalization of the international financial markets and the widening use of information and network technologies, originally speculative activities have been gradually evolved into open and purposeful attacks on specified currencies. Such openness and publicity could be and have been strengthening the market expectation of depreciation of the target currency. For example, at the end of 1997, George Soros published an article to openly declare that he and associates would launch another attack on Hong Kong dollars. After that, he announced in newspapers that the next currency crisis would appear in Russia, which was later shown to be accurate. Soon after then, Soros commented that Brazilian currency was evaluated too high so that Brazilian real would be his next target of attack, which was indeed what happened next.

Before we start to develop and present the main results, let us first look at the systemic intuition that lies underneath this chapter.

When von Bertalanffy (1924) pointed out that the fundamental character of living things is its organization, the customary investigation of individual parts and processes cannot provide a complete explanation of the phenomenon of life; this holistic view of nature and social events has spread over all corners of science and technology (Lin and Forrest 2011). Accompanying this realization of the holistic nature, in the past 80 some years, studies in systems science and systems thinking have brought forward brand new understandings and discoveries to some of the major unsettled problems in the conventional science (Lin 1999; Klir 1985).

Similar to how numbers are theoretically abstracted, systems can also be proposed out of any and every object, event, and process of concern. For instance, behind collections of objects, say, apples, there is a set of numbers such as 0 (apples), 1 (apple), 2 (apples), 3 (apples), etc.; and behind each organization, such as a regional economy, there is an abstract, theoretical system within which the relevant whole, component parts, and the related interconnectedness are emphasized. And, it is because of these interconnected whole and parts that the totality is known as an economy. In other words, when internal structures can be ignored, numbers can be very useful; otherwise, the world consists of dominant systems (or structures or organizations).

Historically speaking, on top of numbers and quantities has traditional science been developed; and along with systemhood comes the systems science. That jointly gives rise of a two-dimensional spectrum of knowledge, where the classical science, which is classified by the thinghood it studies, constitutes the first dimension, and the systems science, which investigates structures and organizations, forms the genuine second dimension (Klir 2001). The importance of the systems science, the second dimension of knowledge, cannot be in any way overemphasized. For example, when there are difficulties in studying dynamics in an *n*-dimensional space, one can conveniently get help from a higher-dimensional space. In particular, when a one-dimensional flow is stopped by a blockage located over a fixed interval, the movement of the flow has to cease. However, if the flow is located in a two-dimensional space, instead of being completely stopped, the one-dimensional blockage would only create a local (minor) irregularity in the otherwise linear movement of the flow (i.e., how nonlinearity appears (Lin 2008)). Additionally, if one desires to peek into the internal structure of the one-dimensional blockage, he can simply take advantage of the second dimension by looking into the blockage from either above or below the blockage. That is, when an extra dimension is available, science will gain additional strength in terms of solving more problems that have been challenging the very survival of the mankind since the start of history.

Additional to the afore-described strong promise of systems science, on the basis of the blown-up theory (Wu and Lin 2002), the systemic yoyo model (Fig. 11.1) is formally introduced by Lin (2007) for each and every system, be they tangible or intangible or physical or intellectual.

In particular, on the basis of the blown-up theory and the discussion on whether or not the world can be seen from the viewpoint of systems (Lin 1988a; Lin et al. 1990), the concepts of black holes, big bangs, and converging and diverging eddy motions are coined together in the model shown in Fig. 11.1. In other words, each system or object considered in a study is a multidimensional entity that spins about its either visible or invisible axis. If we fathom such a spinning entity in our three-dimensional space, we will have a structure as shown in Fig. 11.1a. The side of black hole sucks in all things, such as materials, information, energy, profit, etc. After funneling through the short narrow neck, all things are spit out in the form of a big bang. Some of the materials, spit out from the end of big bang, never return to the other side and some will (Fig. 11.1b). For the sake of convenience of

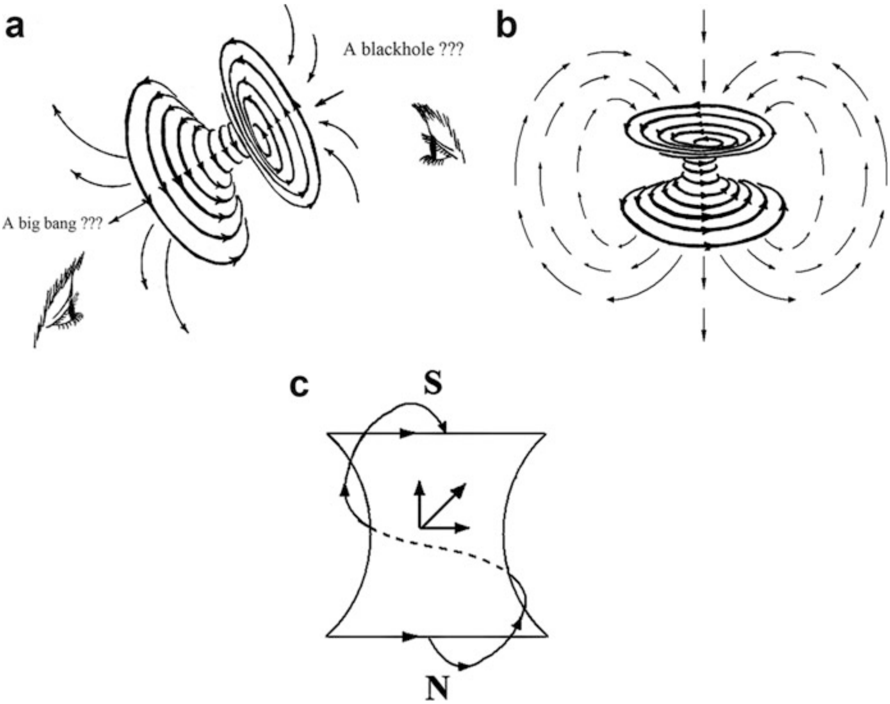

Fig. 11.1 The eddy motion model of the general system

communication, such a structure, as shown in Fig. 11.1a, is referred to as a (Chinese) yoyo due to its general shape. More specifically, what this systemic model says is that each physical or intellectual entity in the universe, be it a tangible or intangible object, a living being, an organization, a culture, a civilization, etc., can all be seen as a kind of realization of a certain multidimensional spinning yoyo with either an invisible or visible spin field around it. It stays in a constant spinning motion as depicted in Fig. 11.1a. If it does stop its spinning, it will no longer exist as an identifiable system. What Fig. 11.1c shows is that due to the interactions between the eddy field, which spins perpendicularly to the axis of spin, of the model, and of the meridian field, which rotates parallel to axis of spin, all the materials that actually return to the black-hole side travel along a spiral trajectory.

To show this yoyo model can indeed, as expected, play the role of intuition and playground for systems researchers, Lin (2008) and Lin and Forrest (2011) have successfully applied it to investigate Newtonian physics of motion, the concept of energy, economics, finance, history, foundations of mathematics, small-probability disastrous weather forecasting, civilization, business organizations, and the mind, among others.

Now, what is important to our work in hand here, which constitutes the necessary intuition for our reasoning, is that the systemic yoyo model implies that each economy is a system so that it can be investigated as a pool of rotational fluids of information, knowledge, and money. And when the world economy is concerned with, we really have a theoretical ocean of rotational pools (of fluids) that interact with other. With time, some regional pools are destroyed, while some stronger, more powerful spin fields are formed. In other words, the so-called speculative attacks, as described earlier, are natural phenomena that appear along with the globalization of the world economy. So, one natural question is how such attacks appear and how their damaging effect can be maintained at the theoretical height first and then at the level of real-life practice. In the rest of this work, we will address this question by using some of the recent results of systems research.

11.4 One Possible Form of Currency Wars

According to Bernanke and Gertler (1999), the fundamental value of a particular capital is equal to the present value of the dividends the capital is expected to generate throughout the indefinite future. Symbolically, the fundamental value Q_t of a depreciable capital in period t is given by

$$\begin{aligned} Q_t &= E_t\left(\sum_{i=0}^{\infty}\left[\frac{(1-\delta)^i D_{t+1+i}}{\prod_{j=0}^{i} R^q_{t+1+j}}\right]\right) \\ &= E_t\left(\frac{D_{t+1}}{R^q_{t+1}} + \frac{(1-\delta)^1 D_{t+2}}{R^q_{t+1}R^q_{t+2}} + \frac{(1-\delta)^2 D_{t+3}}{R^q_{t+1}R^q_{t+2}R^q_{t+3}} + \dots\right) \end{aligned} \tag{11.1}$$

where E_t stands for the mathematical expectation as of period t, δ the rate of physical depreciation of the capital, D_{t+i} the dividends, and R^q_{t+1} the relevant stochastic gross discount rate at t for dividends received in period $(t + 1)$. Then, we can rewrite Eq. (11.1) as follows:

$$Q_t = E_t\left(\frac{D_{t+1} + (1-\delta)Q_{t+1}}{R^q_{t+1}}\right) \tag{11.2}$$

Because of various reasons, such as fads, the market price S_t of the capital differs persistently from the capital's fundamental value Q_t. When $S_t \neq Q_t$, we say, as in Bernanke and Gertler (1999), there is a bubble. However, to be more specific, when $S_t > Q_t$, we say that there is a positive bubble in the marketplace and a negative bubble when $S_t < Q_t$. In the realistic market place, asset prices mostly like deviate from the fundamental values due to various reasons, such as liquidity trading or to waves of alternating optimism or pessimism.

If a bubble exists at period t with probability p to persist into the next period, then by using the mathematical expectations, the difference between the market price and the fundamental value of the capital in period (t + 1) satisfies the following:

$$p\left(S_{t+1} - Q_{t+1}\right) + (1 - p) \cdot 0 = a\left[(S_t - Q_t)R^q_{t+1}\right] + (1 - a) \cdot 0 \tag{11.3}$$

It means that the mathematically expected $(S_{t+1} - Q_{t+1})$ value with probability p for $S_{t+1} \neq Q_{t+1}$ to happen is equal to the expected growth of the t-period difference $(S_t - Q_t)R^q_{t+1}$ with probability a ($> p$) for $S_t - Q_t \neq 0$. That is, what is expected is a more severe "bubble," since $a/p > 1$. So, if we assume $a/p < 1$, it means that the bubble in period (t + 1) is expected to be less severe than in period t.

From Eq. (11.3), it follows that we know the following expression is true:

$$p \cdot \frac{S_{t+1} - Q_{t+1}}{R^q_{t+1}} = a(S_t - Q_t) \tag{11.4}$$

Now by taking the mathematical expected value for $\left(S_{t+1} - Q_{t+1}\right)/R^q_{t+1}$ in period t, we have the following:

$$\begin{aligned} E_t\left(\frac{S_{t+1} - Q_{t+1}}{R^q_{t+1}}\right) &= p \cdot \left(\frac{S_{t+1} - Q_{t+1}}{R^q_{t+1}}\right) + (1 - p) \cdot 0 \\ &= a(S_t - Q_t) \end{aligned} \tag{11.5}$$

Equation (11.2) implies that

$$\begin{aligned} Q_t &= E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1} - (1-\delta)S_{t+1} + (1-\delta)Q_t}{R^q_{t+1}}\right\} \\ &= E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}} - (1-\delta)\frac{S_{t+1} - Q_{t+1}}{R^q_{t+1}}\right\} \\ &= E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}}\right\} - (1-\delta)E_t\left\{\frac{S_{t+1} - Q_{t+1}}{R^q_{t+1}}\right\} \\ &= E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}}\right\} - (1-\delta)a(S_t - Q_t), \quad \text{(from Eq.(11.5))}. \end{aligned}$$

Therefore, we have

$$Q_t + (1-\delta)a(S_t - Q_t) = E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}}\right\}$$

which is the equivalent to

$$\frac{S_t[Q_t + (1-\delta)a(S_t - Q_t)]}{S_t} = E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}}\right\}$$

Isolating the factor $S_t$in the numerator and cross multiplying the rest from the left-hand side onto the right-hand side produce the following:

$$\begin{aligned}
S_t &= E_t\left\{\frac{[D_{t+1} + (1-\delta)S_{t+1}]S_t}{R^q_{t+1}[Q_t + (1-\delta)a(S_t - Q_t)]}\right\} \\
&= E_t\left\{\frac{[D_{t+1} + (1-\delta)S_{t+1}]S_t}{R^q_{t+1}\{[a(1-\delta)S_t - a(1-\delta)Q_t] + Q_t\}}\right\} \\
&= E_t\left\{\frac{[D_{t+1} + (1-\delta)S_{t+1}]S_t}{R^q_{t+1}[bS_t + (1-b)Q_t]}\right\}, \text{where } b = a(1-\delta) \\
&= E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}\left[b + (1-b)\dfrac{Q_t}{S_t}\right]}\right\} \\
&= E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^s_{t+1}}\right\}
\end{aligned}$$

Therefore, we have derived at

$$S_t = E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^s_{t+1}}\right\} \tag{11.6}$$

where the return on stocks R^s_{t+1} is related to the fundamental return of the capital R^q_{t+1} as follows:

$$R^s_{t+1} = R^q_{t+1}\left[b + (1-b)\frac{Q_t}{S_t}\right] \tag{11.7}$$

If $S_t > Q_t$, then $R^s_{t+1} < R^q_{t+1}$, meaning that the expected stock return $S_t = E_t \left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^s_{t+1}}\right\}$ is less than the fundamental return of $S_t = E_t\left\{\frac{D_{t+1} + (1-\delta)S_{t+1}}{R^q_{t+1}}\right\}$.

From Eq. (11.3), it follows that

$$(S_t - Q_t) = \frac{p}{a} \times \frac{\left(S_{t+1} - Q_{t+1}\right)}{R^q_{t+1}} \tag{11.8}$$

which implies that at period $(t + 1)$, there is a positive bubble if and only if there is a positive bubble at period t. Because $0 < p < a < 1$, if $S_{t+1} > Q_{t+1}$ (assuming a positive bubble), then from $0 < \frac{p}{a} < 1$, Eq. (11.8) implies that the current bubble $(S_t - Q_t)$ is smaller than the fundamental return of the bubble in period $(t + 1)$. In other words, the bubble in period $(t + 1)$ gets more severe than when in period t.

Now, if $S_{t+1} < Q_{t+1}$ with $0 < p < a < 1$, then Eq. (11.8) implies that the underpricing S_{t+1} of the asset Q_{t+1} in period $(t + 1)$ is more severe than that in period t. Moreover, this equation also indicates that at period $(t + 1)$, there is a negative bubble if and only if there is a negative bubble at period t.

These two conclusions evidently contradict the efficient market hypothesis, because these analogies indicate that if in period t the market over prices the asset, then the overpricing will continue forever; and if in period t the market underprices the asset, then the underpricing will also continue forever. That is, neither positive nor negative bubble will ever crash. So there are two possibilities: (1) The model in Eq. (11.8) does not hold true in general, or (2) the efficient market hypothesis is not *ever* true.

Evidence appears to show that the efficient market hypothesis holds true at least occasionally and also bubbles, both positive and negative, do burst (Beechey et al. 2000; Smith et al. 1988). So, the model in Eq. (11.8) needs to be modified in order to describe the more realistic market situation better.

If in Eq. (11.8) we assume $0 < a < p < 1$, then a similar analysis as above indicates that the phenomenon of overpricing or underpricing disappears over time. And, if $0 < a = p < 1$ is assumed, then the model in Eq. (11.8) implies that the existing underpricing or overpricing stays fundamentally stable.

If $0 < a < p < 1$ and $a \approx 0$ are assumed, then Eq. (11.8) implies that $\frac{p}{a} \approx +\infty$ so that the fundamental return $\frac{\left(S_{t+1} - Q_{t+1}\right)}{R^q_{t+1}}$ of the asset approaches 0, meaning that the existing bubble gradually disappears with time.

Next, let us focus on the analysis of Eqs. (11.1) and (11.2). In particular, assume that in the $(t + i)$-th period foreign investments are suddenly increased drastically due to expected appearance of activities from the current weak economic state and weak local currency. So for this period, δ (= the physical depreciation rate of capital) would increase due to the increased amount of money supply, which in turn pushes up the inflation. So $(1 - \delta)^i$ would decrease drastically if the influx of foreign investments is large. At the same time, R^q_{t+i} (= the stochastic gross discount rate of the $(t + i)$-th period) would also increase, because of the increased inflation, while the dividends D_{t+i} would generally decrease due to the reason that everybody would like to reinvest much of the available capital back into the maket in order to capture the rising book values, including stocks, real estate, and others with of impressive increasing prices. That is, the present value of the return of the $(t + i)$-th period

$$\frac{(1-\delta)^i D_{t+i}}{R^q_{t+1} \cdots R^q_{t+i}}$$

would drop from the level of expectation. In reality, the investor would hold onto the increased book value by receiving less tangible returns, hoping that the book value would continue to rise drastically.

Due to the wide and conveniently availability of capital, caused by the increased money supply, the local economic activities pick up too in large quantities, while the interest rate also goes up due to the fact that the central bank, in order to control the inflation, revises the interest rate and attempts to limit the money supply.

At this very moment of financially prosperity, assume that a huge amount of foreign investments suddenly leave in the $(t + j)$-th period, where $j > i$, because of the much higher prices in assets, in capital investments, etc., for them to take profit in order to move their capitals to other regions to capture new economic opportunities. So, in the $(t + j)$-th period, when a huge amount of foreign investment leaves, most of the economic activities that got started because of the foreign investments become stalled and/or negatively impacted. Therefore, a good portion of the local investments is forced to be retained with the interrupted economic activities. That is, the investors of the local investments can no longer receive their expected dividends, and at the same time, a large amount of the investments evaporates totally if many of the stalled activities can no longer be continued until their expected completion or are indefinitely delayed. That of course costs additional local capital to do the cleanup of what is left behind, unfinished, and unusable ruins. In particular, in Eqs. (11.1) and (11.2), the dividends D_{t+j} of the $(t + i)$-th period decrease drastically, and the remaining future dividends, if they still come fortunately as expected, would have to be used to bail out (to finish up) some of the other potentially possibly profitable projects.

That is, right before the large amount of foreign investments leaves suddenly and strategically, the local economy is more active than ever before. Hence, the stochastic gross discount rate R^q_{t+i} of the $(t + i)$-th period would be much lower than R^q_{t+j} of the $(t + j)$-th period, because much higher returns on earlier investments are optimistically expected. So, the present ratio:

$$\frac{(1-\delta)^i D_{t+i}}{R^q_{t+1} \cdots R^q_{t+i} \cdots R^q_{t+j}}$$

would in reality be very close to zero.

Summarizing what is just analyzed above, one can see that when a large amount of foreign investments gathers in one place over either a long period or a short period of time and then leaves suddenly and massively, that local economy has to suffer through a positive bubble, caused by the increased money supply as a consequence of the foreign investments, and then a following negative, disastrous bubble, caused by the sudden dry out of the money supply. And due to a large number of economic activities that are either unexpectedly delayed or totally impossible to complete, the local investors are actually unable to continue to collect their originally expected dividends for many periods to come. That is, foreign investments can be employed as a weapon of mass destruction, if they leave strategically and suddenly, no matter whether they come quickly in a short period of time or slowly over a relatively longer period of time.

11.5 Some Final Remarks

Based on the systemic intuition of the yoyo model and the Bernanke-Gertler model of the fundamental value of capital, this chapter demonstrates theoretically how financial crises could be caused and/or created purposefully by certain group(s) of people in order to acquire economic and political gains through the use of movements of money across national borders. Because of the modern-day globalization of the world economy, national and regional economies have been closely intertwined with each other. Hence, when one nation or geographic region suffers from economic and financial crises, the consequent damaging effects and adverse impacts tend to possess international characteristics.

What is obtained specifically in this chapter is that when a large amount of foreign investments gathers in one place over either a long period or a short period of time and then leaves suddenly and massively, that local economy has to suffer through a positive bubble, caused by the increased money supply as a consequence of the foreign investments and then a following negative, disastrous bubble, caused by the sudden dry out of the money supply. And because a large number of economic activities are either unexpectedly delayed or totally impossible to complete, the local investors are actually unable to continue to collect their originally expected dividends for many time periods to come. If we look at such situations differently, this result indicates that foreign investments can be potentially employed as a weapon of mass destruction, if they leave strategically and suddenly, no matter whether they come quickly in a short period of time or slowly over a relatively longer period of time.

Part IV
Strategies of Self Defense

Chapter 12
Self-Defense Through Manipulating Exchange Rate

Contents

Based on the theory of how a currency war could be potentially raged against a nation or a region, this chapter makes use of the results of feedback systems (Lin 1994) to develop a self-defense mechanism that could conceivably protect the nation or region under siege.

12.1 Introduction

When combining the previous theoretical analysis in Chap. 11 or (Forrest et al. 2013a) with the recent cases of speculative attacks in the arena of international finance, we surely see the following predicament. When a nation tries to develop economically, due to its loosening economic and monetary policies, large amounts of foreign investments would be welcomed, and at the same time, a lot of such foreign investments would strategically rush into the nation in order to ride along with the forthcoming economic boom. Now what we have shown earlier is that if a large amount of foreign investments leaves suddenly, then the nation would most likely suffer from a burst of the economic bubble with a large percentage of economic activities interrupted either temporarily or indefinitely. So, a natural question at this junction is: How could we possibly design a measure to counter such sudden leaves of foreign investments in order to avoid the undesirable disastrous consequences?

We will address this problem in the rest of this chapter.

J. Yi-Lin Forrest et al., *Currency Wars*, Contemporary Systems Thinking,
https://doi.org/10.1007/978-3-319-67765-1_12

12.2 A Model for Categorized Purchasing Power

Let us look at the following model that relates the purchasing power of money with the demand and supply of the money of a national economy:

$$\frac{dP}{dt} = k(D - S) \tag{12.1}$$

where D stands for the demand for money, S the money supply, P the purchasing power of money, $k > 0$ is a constant, and t represents time.

What this model says is that the rate of change in purchasing power is directly proportional to the difference between the demand and supply of money. In particular, the model says that with all other variables staying constant, if the money supply S increases by a large amount and satisfies $S > D$, then the purchasing power of the money P decreases so that more money is needed to buy essentials of living and inflation will increase due to the increase in the money supply S.

Now, let us divide the overall national economy into three sectors E_1, E_2, and E_3 as follows: E_1 stands for the goods, services, and relevant production of these goods and services that are needed for maintaining the basic living standard; E_2 the goods, services, and relevant productions that are used to acquire desired living conditions; and E_3 the goods, services, and relevant productions that are used for the enjoyment of luxurious living conditions.

The reason why we divide the economy in such a way is that according to Allen and Goldsmith (1972), the following are four base requirements that allow for a stable society to be achieved and maintained:

1. Minimum disruption of ecological processes
2. Maximum conservation of materials and energy or an economy of stock rather than flow
3. A population in which recruitment equals loss
4. A social system in which individuals can enjoy rather than feel restricted by the first three conditions

So, in terms of economics, to maintain a stable society, a relative stability of the economic sector E_1 has to be achieved first.

Next, let us accordingly divide the overall demand D of money into three corresponding categories as follows:

D_1 = the demand of money for meeting the minimum requirement to maintain the basic living standard;
D_2 = the demand of money for acquiring desired living conditions; and
D_3 = the demand of money for enjoying luxurious living conditions.

Assume that in a stable economy, we have the following allocation of the money demand:

$$D = D_1 + D_2 + D_3 = a_1 D + a_2 D + a_3 D \tag{12.2}$$

where the weights α_i, $i = 1, 2, 3$, stands for the average allocation of the citizens of the economy over the three categories as described above, satisfying $\alpha_1 + \alpha_2 + \alpha_3 = 1$, and $D_i = \alpha_i D$, $i = 1, 2, 3$. For instance, in the stable economy, an average family allocates half of its monthly income on necessities of living, such as food, utilities, etc., four-tenth of the income on acquiring the desired quality of life, and one-tenth of the income on luxurious items, then $\alpha_1 = 0.5$, $\alpha_2 = 0.4$, and $\alpha_3 = 0.1$.

If the money supply S increases drastically, along with the decreasing purchasing power of money, all goods will cost more. If somehow the goods in the category of living necessities rise more rapidly, then a reallocation of household income will appear. For instance, due to rumors about potential interruptions in the supply of food and clean water accompanying a substantial increase in the money supply, the average family has to reallocate its income as follows: $\alpha_1 = 0.625$, $\alpha_2 = 0.3$, and $\alpha_3 = 0.075$.

When such a reallocation of income of the average family is forced to take place, the stability of the economy would very likely be in trouble. So, to stabilize the economy, the purchasing power of money in category D_1 should stay relatively constant, while in D_2 increases somehow slightly, and in D_3 it should be allowed to increase in order to attract and trap the additional money supply away from category D_1. So, let us assume

P_1 = the purchasing power of money in category D_1;
P_2 = the purchasing power of money in category D_2; and
P_3 = the purchasing power of money in category D_3.

Similarly, let us define

S_1 = the money supply that goes into category D_1;
S_2 = the money supply that goes into category D_2; and
S_3 = the money supply that goes into category D_3.

So, Eq. (12.1) would look as follows:

$$\begin{cases} \dfrac{dp_1}{dt} = k_{11}(D_1 - S_1) + k_{12}(D_2 - S_2) + k_{13}(D_3 - S_3) + \sum_{j=1}^{n} q_{1j}x_j \\ \dfrac{dp_2}{dt} = k_{21}(D_1 - S_1) + k_{22}(D_2 - S_2) + k_{23}(D_3 - S_3) + \sum_{j=1}^{n} q_{2j}x_j \\ \dfrac{dp_1}{dt} = k_{31}(D_1 - S_1) + k_{32}(D_2 - S_2) + k_{33}(D_3 - S_3) + \sum_{j=1}^{n} q_{3j}x_j \end{cases} \tag{12.3}$$

where k_{ij} and q_{ij} are constants and x_j stands for monetary policies, $i = 1, 2, 3$, and $j = 1, 2, \ldots, n$. By using matrix notations, Eq. (12.3) can be rewritten as follows:

$$\dot{P} = Kz + Qx \tag{12.4}$$

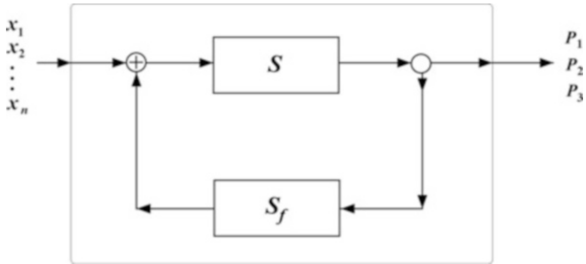

Fig. 12.1 The feedback loop between monetary policies and categorized purchasing powers

where $P = [P_1\ P_2\ P_3]^T$, $\dot{P}$ is Newton's original notation for derivatives such that $\dot{P} = \left[\frac{dP_1}{dt}\ \ \frac{dP_2}{dt}\ \ \frac{dP_3}{dt}\right]^T$, $K = [k_{ij}]_{3\times 3}$ the coefficient matrix of the variables $(D_i - S_i)$, $i = 1, 2, 3$, and $Q = [q_{ij}]_{3\times n}$ the coefficient matrix of the variables x_j, $j = 1, 2, \ldots, n$.

In terms of systems research, the mode in Eq. (12.4) can be seen as a feedback system as depicted in Fig. 12.1, where S represents the initial state of the economy. After the monetary policies x_1, x_2, …, x_n are introduced, the participants of the economy introduce either consciously or unconsciously a feedback component system S_f so that the overall system with the added feedback produces the desired output P_1, P_2, and P_3.

What is shown in Fig. 12.1 is the fact that each and every market economy, where the participants are allowed to design their own methods (without violating the established laws) to achieve their individually defined financial successes, then the economy constitutes a "rotational" field. Here, the word of rotation means that as soon as a monetary policy is introduced, the market participants will find ways to take advantage of the policy so that the policy and the individually designed methods jointly produce the individually desired outputs.

12.3 The Functional Relationship Between *P* and (*D*–*S*)

In this section, we investigate the relationship between the purchasing power vector $[P_1\ P_2\ P_3]^T$ of money and the difference vector $[\boldsymbol{D}_1 - \boldsymbol{S}_1\ \boldsymbol{D}_2 - \boldsymbol{S}_2\ \boldsymbol{D}_3 - \boldsymbol{S}_3]^T$ of the demand and supply of money. In particular, we discuss why the trends found in purchasing power of money could righteously be described by using linear models, although the purchasing power is clearly not linear in terms of the difference of the demand and the supply of money.

To this end, let us introduce the following three models, the first one linear, the second one quadratic, and the third one cubic, to demonstrate the effects of the supply and demand of money on purchasing power of money in each case:

$$P(t) = a(D(t) - S(t)) + \varepsilon \tag{12.5}$$

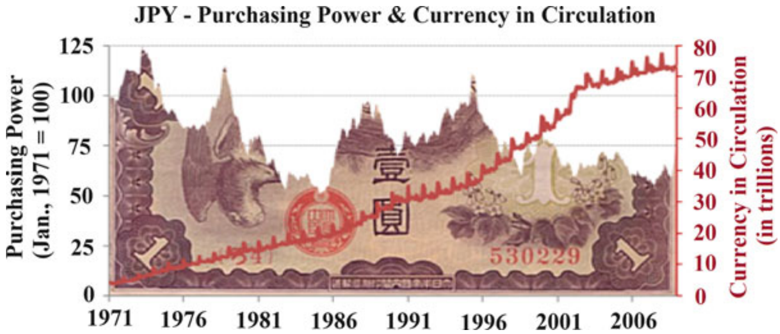

Fig. 12.2 Purchasing power and currency in circulation (From www.dollardaze.com as accessed on April 4, 2012)

$$P(t) = a(D(t) - S(t))^2 + b(D(t) - S(t)) + \varepsilon \tag{12.6}$$

and

$$P(t) = a(D(t) - S(t))^3 + b(D(t) - S(t))^2 + c(D(t) - S(t)) + \varepsilon \tag{12.7}$$

where $P(t)$ stands for the purchasing power of money, $D(t)$ the demand of money, $S(t)$ the supply of money, ε a random variable with mean $C \neq 0$, and *a, b, and c* are constant. More specifically, the random variable ε is the error term in the sense that it compensates for any unpredicted event or factor that could impact the purchasing power and that is not taken into account in the model.

When the nonlinearity in the trend of purchasing power is considered, such as in the case of Japanese yen (Fig. 12.2), the quadratic and cubic models in Eqs. (12.6) and (12.7) seem to model adequate. In particular, the nonlinear graph of the purchasing power of Japanese yen has two distinguishable patterns: one is parabolic and the other cubic. These two types of general patterns are, respectively, depicted by the nonlinear models in Eqs. (12.6) and (12.7).

Figure 12.3 depicts both the purchasing power and the amount of money in circulation of the US dollars over time. Here a clear inverse relationship between the currency in circulation, supply of money, and the purchasing power of money can be seen. That is to say, as the amount of money in circulation increases, the purchasing power of the US dollars decreases. The graph of purchasing power is fairly linear, especially if broken up into two segments: from 1971 to approximately 1981 and from 1981 until the present day. This trend in the purchasing power of US dollars suggests that the linear model in Eq. (12.5) seems to adequately reflect what happened to the purchasing power over time.

In particular, if we employ the linear model in Eq. (12.5) to describe the relationship between the purchasing power of the US dollars and the difference between the demand and supply of the money with respect to time, then this model well explains how the US dollar declines in purchasing power. For instance, the

Fig. 12.3 Purchasing power and currency in circulation of the US dollars (From www.dollardaze.com as accessed on April 4, 2012)

initial high purchasing power was due to the fact that the currency in circulation was fairly low and the value of the US dollar was fixed at $35 an ounce of the gold. However, starting in May 1971, the US dollar suffered from a major crisis and consequently began to depreciate against the gold from the initial $35 an ounce to $38 an ounce on August 15, 1971, then to $42.22 an ounce at the start of 1973, and then to as high as $96 an ounce in March of the same year (Wang and Hu 2005, p. 12). In 1976 a new international agreement was reached in the capital city Kingston of Jamaica; with several rounds of modifications, the international financial system entered the Jamaica system in 1978. Within this new system, gold is no longer considered as a form of money. That is, when the demand for the US dollars is brought into the equation, it can justify why there are more severe or gradual drops in purchasing power as the amount of money in circulation increases. For example, if the change in the supply of money is equal to the increase in the demand of money, then the purchasing power of the money should remain constant. To cause the severe drop in purchasing power as seen from 1971 until approximately 1981, there was an increase in the money supply accompanied by a decrease in the demand for money. This decrease in the demand for money was caused by the transition from the US dollar being backed by gold to that not having gold backing (dollardaze.org). This also makes sense intuitively. If we already know that a rise in the money supply decreases the purchasing power of money, then people wanting the money less would further exacerbate that decrease in purchasing power. From that point on, the demand of money must have increased but still not greater than the supply of money because the decline in the purchasing power flattens out instead of becoming more severely negative. As the graph of the stock prices of the Dow Jones Industrial Average indicates, Fig. 12.4, the stock market began to rise in the early 1980s and had a sharp incline until the start of the twenty-first century. This rise is an indicator that supports the claim that the demand for money increased during this time period and, in conjunction with the supply of money, influenced the purchasing power to decrease less severely than during the time period from 1971 to 1981.

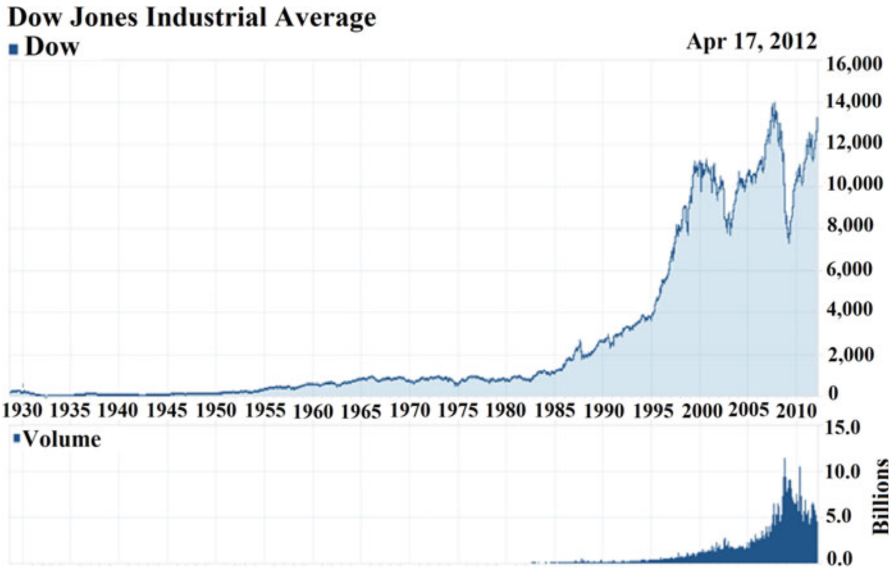

Fig. 12.4 Historical data of DJIA (From Yahoo finance, accessed on April 17, 2012)

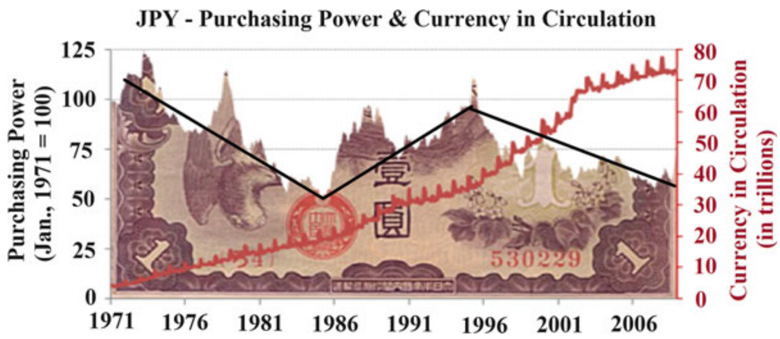

Fig. 12.5 The fluctuation in the purchasing power of Japanese yen

Looking at the same graph created for the Japanese economy, Fig. 12.2, we see a similar but different story. By breaking the graph up into more intervals, Fig. 12.5, we are able to form various linear patterns. From 1971 until around 1986, there was a general decline in the purchasing power of Japanese yen. Then once it came to a peak again in 1996, there again was an overall decline in the purchasing power. These are clearly not linear graphs, but looking at the general motion of the purchasing power in the graph, they are fairly linear in two segments, like the situation with the US dollar. Therefore, it is also reasonable for us to use the linear model in Eq. (12.5) to explain the evolutionary trends in the purchasing power of Japanese yen.

Under the assumption that the supply and purchasing power of money are inversely related when all other factors remain constant, we can see that the purchasing power is a function of the demand and supply with respect to time. By using the linear model in Eq. (12.5) and by breaking up the graph in Fig. 12.5 into two intervals, we see a similar relationship that was discussed with the supply and demand of money in the US dollar. If both the supply and demand increase at the same rate, then the purchasing power will remain constant. If the supply increases with the demand increasing at a faster rate than before but still less than the increase in the supply, then a less severe decline in the purchasing power would be observed. However, if the demand increases at a rate greater than that of the supply of money, then this would lead to an increase in the purchasing power. Furthermore, an increase in the supply matched with a decreasing rate in the demand would result in a more severe decrease in the purchasing power. These explanations help explain varying linear slopes that are reflected in the purchasing power of money in the Japanese economy. For example, notice that for Japan 1986 was the first year of the asset pricing bubble. In the graph of the money supply and the Nikkei 225 stock market (Fig. 12.6) (for details, see Okina et al. 2001), during this time, there was a small increase in the money supply, while the Nikkei 225 increased drastically. With the stock market increasing during this time, the demand for money also increased because people wanted to take advantage of the market rise. As we mentioned earlier, a relatively low increase in the money supply accompanied by a large increase in the demand for money would result in an increase in the purchasing power. This explanation corresponds with the depiction of the purchasing power of Japanese yen until 1990 when it burst reflecting the sharp decline in the purchasing power as reflected in the graph and by our model.

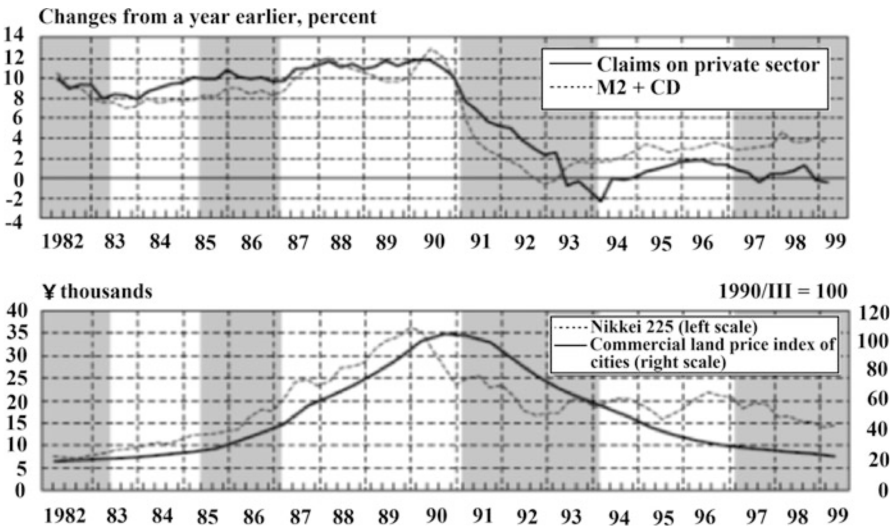

Fig. 12.6 The money supply and the Nikkei 225 stock market (Okina et al. 2001)

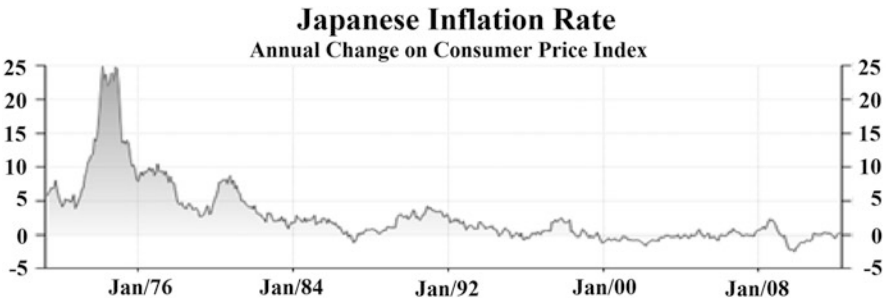

Fig. 12.7 Japanese inflation rate from April 1971 to April 2012 (Source: www.tradingeconomics.com, accessed on April 4, 2012)

The sharp rise in the purchasing power that appeared at around the year of 1973 (Fig. 12.3) could have been due to the oil crisis which caused a shift in Japanese economy toward huge investments in the electronic industries. From Hutchison (1986), we can see that Japan's money supply was fairly constant in the year of 1973, but the demand of money from the oil crisis increased drastically. That made the purchasing power of the money to increase drastically during the early 1970s; this conclusion is further validated by the discussions of (Okina et al. 2001). Figure 12.7 is a graph that reflects the Japanese inflation rate over the time period from April 1971 until April 2012, where we can notice the continuing patterns and similarities with those of the purchasing power.

As a matter of fact, the similarities between the graphic patterns of the purchasing power of money and the inflation rate, as described above, are also seen in the current movements of oil prices. On the Ed Show of the MSNBC at 11:00 p.m., Barny Frank referenced certain people who bought crude oil to drive up the prices only to sell it at a later time for a windfall of profits. The market system unconsciously allows the oil prices to rise and to consequently manipulate the gasoline prices, Fig. 12.8. That situation works in conjunction with the demand and supply of money.

Summarizing what is discussed above, we conclude that it is theoretically reasonable for us to analyze the relationship between the purchasing power of money and the difference of the demand and supply of money by using the linear model in Eq. (12.5), where the random variable ε accounts for all the unexpected factors that are not included in the model.

By combining what is obtained in Sect. 12.3 with the linear model in Eq. (12.5), we have the following relationship between categorized purchasing power $[P_1\ P_2\ P_3]^T$ of money and categorized difference $[\boldsymbol{D}_1 - \boldsymbol{S}_1\ \boldsymbol{D}_2 - \boldsymbol{S}_2\ \boldsymbol{D}_3 - \boldsymbol{S}_3]^T$ of demand and supply of money:

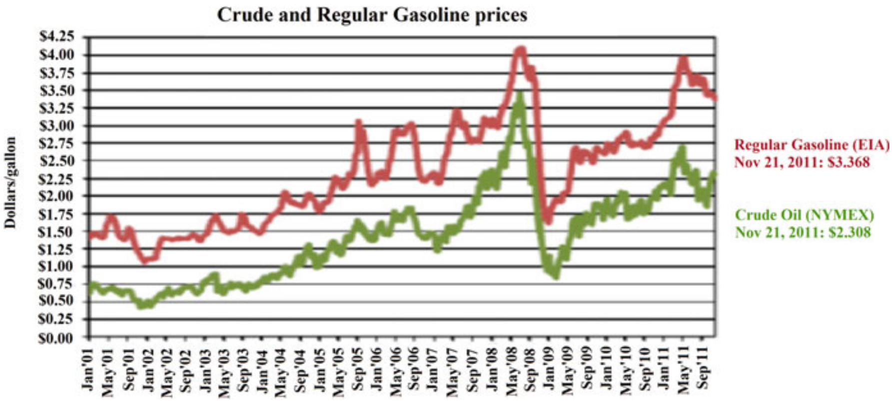

Fig. 12.8 The prices of crude and gasoline move in concert (The original source from the website of the US Department of Energy was accessed on April 17, 2012)

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} = R_{3\times 3} \begin{bmatrix} D_1(t) - S_1(t) \\ D_2(t) - S_2(t) \\ D_3(t) - S_3(t) \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} \tag{12.8}$$

where $R_{3\times 3}$ is a constant square matrix with real entries and $[\varepsilon_1\ \varepsilon_2\ \varepsilon_3]^T$ a random vector with a non-zero mean.

12.4 Separating Economic Categories Using Feedback Component Systems

If we consider the mathematical expectations of the variables in Eq. (12.8), we have

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} = A_{3\times 3} \begin{bmatrix} D_1(t) - S_1(t) \\ D_2(t) - S_2(t) \\ D_3(t) - S_3(t) \end{bmatrix} + \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} \tag{12.9}$$

where $E(\varepsilon_i) = c_i \neq 0$, $i = 1, 2, 3$. By substituting Eq. (12.9) into Eq. (12.4), we have

$$R_{3\times 3}\dot{z} = Kz + Qx \tag{12.10}$$

Without loss of generality, we assume that $R_{3\times 3}$ is invertible. That is, we assume in general the categorized purchasing power of money is completely determined by the categorized differences of the demand and supply of money. Then, Eq. (12.10) can be rewritten as follows:

$$\dot{z} = Az + Bx \tag{12.11}$$

where $A = R^{-1}K$ and $B = R^{-1}Q$. To make the model in Eq. (12.11) technically manageable, we assume without loss of generality that B is a 3×3 matrix, meaning that the monetary policies $x_1, x_2, \ldots, x_n$ are accordingly categorized into three groups:

$X_1 =$ the set of all those monetary policies that deal with the population meeting the minimum need to maintain the basic living standard;
$X_2 =$ the set of all those monetary policies that deal with the population's need for acquiring desired living conditions; and
$X_3 =$ the set of all those monetary policies that deal with the population's need for enjoying luxurious living conditions.

Without loss of generality, we will still use the same symbol x to represent the vector $[X_1 \quad X_2 \quad X_3]^T$ of categorized monetary policies.

Similar to the concept of consumer price index (CPI), let us introduce an economic index vector $y = [y_1 \quad y_2 \quad y_3]^T$ such that y_i measures the state of the economic sector i, $i = 1, 2, 3$. Then from Eq. (12.11), we can establish the following model for the national economy of our concern:

$$\begin{cases} \dot{z} = Az + Bx \\ y = Cz + Dx \\ z(0) = 0 \end{cases} \tag{12.12}$$

where z is the 3×1 matrix $[\boldsymbol{D}_1 - \boldsymbol{S}_1\, \boldsymbol{D}_2 - \boldsymbol{S}_2\, \boldsymbol{D}_3 - \boldsymbol{S}_3]^T$ of the categorized difference of the demand and supply of money, referred to as the state of the economic system; A, B, C, and D are, respectively, constant 3×3 matrices, such that D is non-singular (meaning that each introduction of monetary policies does have direct, either positive or negative, effect on the performance of the economy); and the input space X and output space Y are the following:

$$X = Y = \left\{r : [0, +\infty) \to \boldsymbol{R}^3 : r \text{ is a piecewise continuous function}\right\} \tag{12.13}$$

where $\boldsymbol{R}$ stands for the set of all real numbers and $\boldsymbol{R}^3$ the nth-dimensional Euclidean space.

What is described by Eq. (12.12) is that the state of the national economy is representable through the use of the state variable z that helps the economy to absorb the positive and negative effects of the monetary policies X_1, X_2, and X_3. Then, both the internal mechanism z of the economy and the monetary policies x jointly have a direct effect on the overall performance y of the economy. The condition, as imposed on the input space X and the output space Y, means that monetary policies, which form the input space X, are introduced based on the effects of the previously implemented policies, while the overall performance, indices of which constitute the output space Y, of the economy evolves from

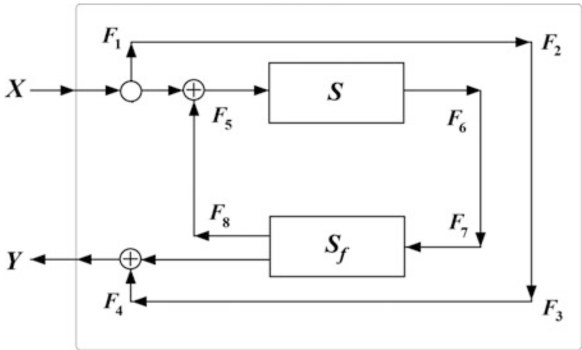

Fig. 12.9 The geometry of the systemic model of the national economy

previous states mostly continuous. Such assumptions historically speaking are not always true, while failures occur rarely in terms of frequencies. For instance, in modern China, the so-called Cultural Revolution occurred abruptly (MacFarquhar and Schoenhals 2008), and several times in the history of Russia, the tsars had introduced rushed social reforms creating a torn country (Huntington 1996).

Geometrically, the systemic model in Eq. (12.12) of the national economy is depicted in Fig. 12.9. The monetary policy input X splits into two portions $F_1F_2F_3F_4$ and $F_5F_6F_7F_8$. The portion labeled $F_1F_2F_3F_4$ directly affects the performance Y of the economy. The other portion, labeled $F_5F_6F_7F_8$, is fed into the initial state of the economy S, leading to the introduction of the feedback component system S_f, which stands for the market reactions to the introduced monetary policies, and the formation of a feedback loop within the economy. This feedback loop in fact constitutes the main body of the economy, while the overall performance vector Y of indices is merely an artificially designed measure. What needs to be noted is that within each of our three economic sectors E_1, E_2, and E_3, the market reactions, which constitute parts of the feedback component system S_f, to monetary policies in general are unique and economic sector specific. That is, the market reactions in one economic sector are different from those of another sector. The inner most loop $F_1F_2F_3F_4$ is the second stage of the economy after the introduction of new monetary policies. They by the joint effect of the market reactions (S_f) and the non-reactionary aspects ($F_5F_6F_7F_8$) of the monetary policies, the final numerical readings Y of the economy are produced.

To see how monetary policy input X could have aspects, one is reactionary and the other non-reactionary, let us assume that X stands for such a monetary policy that allows the inflation to inch higher. Therefore, the price of crude oil is expected to rise accordingly. Now, the reactionary aspects of the policy X make the gradual and calculated increase in the price of crude oil more or less random. On the other hand, the expected outcome of the policy is the theoretical, non-reactionary aspect of the policy. When the actual outcome deviates from the expectation, the difference is caused by the market reactions to the policy.

According to Lin (1994), the three-dimensional system in Eq. (12.12), meaning that both the input x and the output y are elements from $\boldsymbol{R}^3$, can be decoupled into three independent systems of the same kind with one-dimensional input and out. Specifically, if we let

$$\begin{aligned} S = & \ \{(x,y) \in X \times Y : \exists z \in Z \ \text{ such that } \ x,y,z \ \text{ satisfy equ.}(12.12)\} \\ = & \ \text{the system of all the ordered pairs } (x,y) \text{ satisfying equ.}(12.12) \end{aligned}$$

where the state space $Z = \{r : [0, +\infty) \to \boldsymbol{R}^3 : r \textit{ is a piecewise continuous function}\}$, and for each $i = 1, 2, 3$, define a system S_i as follows:

$$\begin{cases} \dot{z} = Az + B_i x_i \\ y_i = C_i z + D_i x_i \\ z(0) = 0 \end{cases} \tag{12.14}$$

where B_i is the ith column of B, C_i the ith raw of C, and D_i a non-zero constant, and the input space X_i and the output space Y_i are given as follows:

$$X_i = Y_i = \ \{r : [0, +\infty) \to \boldsymbol{R} : r \text{ is a piecewise continuous function}\}.$$

In particular, the system S can be decoupled through feedback into the factor systems S_i, $i = 1, 2, 3$, as follows. Let

$$\alpha = \begin{bmatrix} A & 0 & 0 \\ 0 & A & 0 \\ 0 & 0 & A \end{bmatrix}, \beta = \begin{bmatrix} B_1 & 0 & 0 \\ 0 & B_2 & 0 \\ 0 & 0 & B_3 \end{bmatrix}, \gamma = \begin{bmatrix} C_1 & 0 & 0 \\ 0 & C_2 & 0 \\ 0 & 0 & C_3 \end{bmatrix}, \delta = \begin{bmatrix} D_1 & 0 & 0 \\ 0 & D_2 & 0 \\ 0 & 0 & D_3 \end{bmatrix}.$$

Then, the Cartesian product system $S_d = S_1 \times S_2 \times S_3$ is represented by the set of all ordered pairs (x,y) satisfying

$$\begin{cases} \dot{z} = \alpha z + \beta x \\ y = \gamma z + \delta x \\ z(0) = 0 \end{cases} \tag{12.15}$$

Because δ is non-singular, the inverse system S_d^{-1} is obtained as follows:

$$S_d^{-1} = \{(y,x) : (y,x) \ \text{ satisfies } \ \text{eq.}(12.16)\}$$

where Eq. (12.16) is given as follows:

$$\begin{cases} \dot{z} = \left(\alpha - \beta\delta^{-1}\gamma\right)z + \beta\delta^{-1}y \\ x = -\delta^{-1}\gamma z + \delta^{-1}y \\ z(0) = 0 \end{cases} \tag{12.16}$$

The particular feedback component system S_f: $Y \to X$ used in this decoupling is given as follows:

$$\begin{cases} \begin{bmatrix} \dot{z} \\ \dot{z}' \end{bmatrix} = \begin{bmatrix} A - BD^{-1}C & 0 \\ 0 & \alpha - \beta\delta^{-1}\gamma \end{bmatrix} \begin{bmatrix} z \\ z' \end{bmatrix} + \begin{bmatrix} BD^{-1} \\ \beta\delta^{-1} \end{bmatrix} y \\ x = \begin{bmatrix} -D^{-1}C & \delta^{-1}\gamma \end{bmatrix} \begin{bmatrix} z \\ z' \end{bmatrix} + \left(D^{-1} - \delta^{-1} \right) y \\ \begin{bmatrix} z \\ z' \end{bmatrix}(0) = 0 \end{cases} \tag{12.17}$$

In terms of economics, what the concept of decoupling the three-dimensional system S into component systems S_i, $i = 1, 2, 3$, as discussed above, implies is that when monetary policies are established individually and, respectively, for each of the three economic sectors E_1, E_2, and E_3, although these economic sector-specific policies will most definitely have joint effects on the economy, there is at least one way to design a feedback component system S_f so that the overall feedback system $F(S, S_f)$, which represents the whole system as depicted in Fig. 12.1, can be controlled through adjusting individually each of the economic sectors E_1, E_2, and E_3.

12.5 A Strategy for National Defense

The significance of the previous discussion is that we can now propose based on the sound analytical reasoning presented above a strategy for national defense against currency warfare in case that initial “friendly” foreign investments turn out to be an aggressive act of war by suddenly withdrawing all or significant amount of the investments.

In particular, let us assume that at time period t, the total money supply of the specific nation of our concern is \$1000, \$100 of which is from foreign investments. That is, the foreign investments amount to 10% of the total domestic money supply. With the additional money supply (due to the foreign investments), the speed of money circulation increases, signaled by increased spending and elevated levels of economic activities. If these foreign investments leave the nation suddenly, then it is reasonable to expect that more than 10% of the economic activities from around the nation will be more or less affected adversely due to the sudden exhaustion of the money flow, because accompanying the foreign investments there tends to be domestic investments attached too, making the total investments on the related economic activities more than 10% of the national economy.

Now, if before the foreign investments depart while leaving behind disastrous aftermath, the national government has been keeping the exchange rate (to this end not all nations from around the world are currently able to do this successfully) the same while gradually and strategically increasing its money supply, say, to the level of \$10,000, then in the entire monetary circulation around the nation, the proportion of the foreign investments shrinks to about 1% from the original 10%. And if the money supply had been increased to the level of \$1000,000, then the proportion of the foreign investments would have shrunk from the original 10% to about 0.01%, which is nearly zero. So, if at this moment of time the foreign investments are suddenly withdrawn as an aggressive act of war, only around 1% or 0.01% of the consumption and economic activities of the nation will be affected adversely and the overall economic health of the nation will be relatively stable.

On the other hand, along with the drastically increased money supply, all prices in the nation will most certainly go through the roof, placing a large portion of the national population in financial crises due to the runaway inflation. For instance, a certain commodity A, which is a piece of living necessity, used to cost $1.00 a unit; now it requires $10.00 or even $1000 to purchase. Such dramatic increase in prices will surely cause hardships for a good number of citizens of the nation. To this end, the national government needs to work on how to redistribute the additional money supply. In fact, as long as the distribution of the increased money supply does not cause social upheaval, then to this nation, nothing disastrous will really happen, and the potentially damaging impacts of sudden departure of the foreign investments will be under control, too.

However in reality, the distribution of the extra money supply could easily lead to major societal instabilities to the nation due to the increased unevenness in the economic scene: The rich become richer, while the poor become poorer. The situation here is similar to that of the normal inflation, which has been employed to make the economic structure more uneven than before so that the yoyo structure of the economy spins with more strength. In other words, with additional money supply injected into the economy, the redistribution of the wealth that is represented by the increased money supply is surely uneven, where some people receive more than their share, some simply keep pace with the decrease of the purchasing power of their income, while others fall behind or further behind with their financial status. So, if our suggested measure is adopted to counter the damaging effects of sudden departure of foreign investments, the nation needs to develop a practical plan to distribute the extra money supply in order to:

1. Keep societal peace and national stability so that a normal and operational economy can be maintained.
2. Increase the nation's economic prosperity by taking advantage of the foreign investments even though they leave sooner or later either slowly or suddenly.

Specifically, as suggested by the systemic model in the previous section, to help protect the innocent citizens of the nation from suffering from the potential economic turmoil, the national government could purposely divide the economy into three sectors E_1, E_2, and E_3 as described earlier to meet the following goals. In Sector E_1, which consists of living necessities, the sector performance, such as the sector-specific CPI, evolves as normally as possible; in Sector E_2, which consists of such goods, services, and relevant productions that are used by citizens to acquire desired living conditions, the sector performance index, say the particular CPI of E_2, could outpace that of Sector E_1 by a large amount; and critically, the national government needs to manage to trap most of the additional money supply in the economic sector E_3, which consists of such goods, services, and relevant productions that are used by the citizens for their enjoyment of luxurious living. The previous discussion on the systemic model of the national economy indicates that by managing the market reactions correctly, that is the design of the feedback component system S_f, these three economic sectors can be well separated from each other.

When the economic sector E_1 evolves normally as expected based on the history of the nation, the citizens would not need to worry about their basic living and survival. That naturally leads to the desired societal stability and peace. Although the prices in the economic sector E_2 increase drastically when compared to those in E_1, that in general should not affect the mood or the happiness of the population much, because desired living conditions change from time to time and vary from one family to another. In other words, isolated, temporary personally desires, which are not yet satisfied and which are generally inconsistent with each other and even contradictory to each other, could not amalgamate into a political force to cause turmoil. Now, the key is how to keep most of the additional money supply in the economic sector E_3. To address this problem, let us pay attention to our earlier assumption that a large amount of foreign investments entered the nation. That means commercial products and services that are new to the people in the specific nation are expected to and will become available soon. Because these products and services are brand new to the region, high prices can of course be charged for these commercial goods and services. The situation is similar to the scenarios with developed nations, where the focus has been placed on innovations, design, and production of unprecedented products and services. It is these never-seen products and services that generate the most profits.

At this junction, let us address the problem of how to classify a product or a service into one of the three economic sectors E_1, E_2, and E_3. First of all, goods and services that should be classified into E_1 are clear. They represent such commodities that directly relate to the survival of any human being, such as foods, utilities, and shelters of the basic quality. Now, if a family lives in a rented two-bedroom apartment and wants to own a house, then houses to that particular family will be in the economic sector E_2. If the people in a community go to work, shopping, and entertainment mostly on foot, then individually owned transportation tools, such as bicycles, motorcycles, cars, private jets, etc. will belong to the economic sector E_3. That is, as time evolves forward, what belongs to the economic sector E_3 gradually lowers itself into the economic sector E_2, and what used to be in E_2 also gradually moves to E_1. That is, the classification of one particular product or service is a function of time and space. Just by looking around shopping centers, one can see vividly that such classification of commercial goods and services has been successfully done by merchants throughout the world without much trouble.

Now, let us consider the scenario that when the nation purposefully and strategically increases its money supply in order to prevent disastrous aftermaths that could be potentially left behind by sudden withdrawals of foreign investments, additional foreign investments could continue to pour in. In this case, if the nation could not pick up its corresponding speed of economic development, then it will be taken over by the runway high rate of inflation. In this case, if the foreign investments depart strategically, then the nation will be in real major political, societal, and economic crises. To prevent such disastrous consequences, the continued inflow of foreign money has to been managed so that they cannot depart quickly.

Another practical scenario that is different of what has been discussed above is that at a high speed develops the nation itself into a super economic power such that there is no longer such a single amount of foreign investments that can amount to an influencing percentage in the nation's domestic consumption and/or economic activities. In this case, the nation will be safe in the face of any potentially sudden withdrawal of foreign investments.

12.6 A Few Final Words

Similar to how many different methods are there to invest money in life, there should be that many different ways to launch a currency war. What is presented in this chapter of two parts simply considers only one possible way to launch a currency war and one possible way to protect oneself against the disastrous consequences of such an attack. In other words, more scientific efforts should be devoted to the studies of financial attacks (or wars) along the line as outlined in this chapter in the spirit of how conventional warfare is conducted, analyzed, and planned strategically. The purpose of doing so is not to launch financial attacks on the innocent people who simply work hard to make a living; instead, one should always be prepared for the worst that might be imposed upon him by those who always look for ways to take advantage of others. In this regard, we hope that our presentation in this chapter of two parts will play the role of a brick that has been thrown out there to attract beautiful and practically meaningful gemstones.

Chapter 13
Self-Defense Based on Feedback Mechanism

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This chapter studies the problem that when the control-theory model of an economic system is established with the parameters determined, how can one design the corresponding economic policy that is based on feedback of the system so that the performance indicator would approach the pre-determined objective. By identifying the "invisible hand" that adjusts the economic market automatically as the feedback controller that regulates the economy's supply and demand, this chapter focuses on the design of feedback controls that could withstand disturbances of the environment. This chapter establishes a feedback control model for the economic system, provides proofs for how well this proposed control method could perform in practice, and expands this method to design the linear multivariable feedback control and the feedback control of discrete variables.

To show the practical significance of the work in this chapter, an empirical analysis is constructed for the purpose of showing that the established control design can make the regulated economic indicator(s) approach the ideal targets well even when an environmental disturbance exists. This chapter establishes results that are expected to provide practical guidance for developing and adopting appropriate economic policies that could withstand external shocks.

13.1 Introduction

Adam Smith, the initiator of modern quantitative economics, treated economy as a self-regulating (or self-adjusting) system, where "an invisible hand" automatically adjusts the markets so that the system reaches and maintains its equilibrium. As a matter of fact, this so-called "invisible hand" is exactly the feedback controller that bridges the production and the market by regulating the relationship between the system's supply and demand and by making this relationship as balanced as possible through adjusting prices, profits, competition, and other factors. Because of this understanding, the available methods of control theory can be readily associated with many different theories of economics (Chow 1975; Shefrin and Thaler 1981) and provide economists with practically operational procedures for the theoretical research and real-life applications (Kendrick 1981, Seierstad and Sydsaeter 1986). That explains why more and more results of control theory have been employed in the research of economic policies (McKinnon 1993).

For example, Pindyck (1977), a control theorist, resolved the control problem of deterministic secondary tracking of a mathematical model developed for the American economy, where the model contains 28 state variables, by using such control variables as excess tax, government spending, and money supply. This work illustrates the importance of the methods of feedback control in the design of financial and fiscal policies. Moe (1985) presented an empirical analysis of the National Labor Relations Board by the use of the feedback control by focusing on the balance the agency strikes to achieve between the interests of businesses and labors. Kydland and Prescott (1980) presented recursive methods for designing optimal taxation plan. Because most economic systems are nonlinear, the so-called economic model predictive control (MPC) system, which is capable of optimizing closed-loop performance with respect to general economic considerations taken into account in the construction of the cost function, was used to design an estimator for nonlinear economic systems (Rawlings et al. 2012; Diehl et al. 2011; Heidarinejad et al. 2012; Ellis et al. 2014).

Corresponding to the characteristics of the target entities of regional economic policy regulation, such as large inertia, long time delay, etc., we can make use of state feedback to offset the time delay and inertia of the entities, which are to be regulated by policies, so that these entities would have good quality dynamic response characteristics and excellent regulation performance (Hu and Hu 2005). Considering the theoretical continuity and practical discreteness of time in terms of the operation and regulation of economic systems, Wu and Liu (2004) employed the methods of systems theory and control theory to simulate the operational mechanism of macroeconomic systems and developed their replaceable cyclic control model and discrete successive input control decision model for macroeconomic systems. For dynamic input-output economic systems, Chow (1976) investigated a general production strategy based on monitors of consumption, while developing particular strategies for structurally adjusting productions for several specific circumstances of consumption. Based on the methods of control theory, Yang, Zhang, and Zhai (2004) derived an optimal economic adjustment scheme for the optimization control problem of linear quadratic forms of the dynamic input-output model with integral inequality of the state by using the maximization principle. This scheme can be employed to materialize the optimal tracking of the actual output compared to the ideal output.

Because economic systems entail a large amount of nonlinearity and seemingly chaotic phenomena, how to transform the seemingly chaotic dynamics of the systems into orderly matters has become the goal of research on the control and regulation of chaotic economic systems. The control method of prediction feedback, developed by Yao and Sheng (2002), can effectively control discrete chaotic systems and provides a sufficient and necessary condition for the stability of the systems. As a matter of fact, as a dynamic system, each model of the macroscopic economy is incomplete and suffers from errors of parameters' estimation and from signal interference from the environment. In other words, each general physical system inevitably involves uncertainty, and when the uncertainty varies within a pre-determined range, Xiao and Lu (2002) successfully analyzed and optimally controlled a general macroscopic economic system, while guaranteeing that the controlled variables could accurately trace the pre-determined objectives, by simplifying the linear Gauss problem of quadratic form into a general optimization control problem of quadratic form and by obtaining the gain matrix of the Kalman filter. For the control systems of macroscopic economies (Pindyck 1977), they are sometimes not only required to track the expected paths but also desired to have the controlled variables to be as close to the ideal measures as possible. That is the so-called ideal control strategy. By making the quadratic performance index equivalent to observation information of control, Wang and Wang (2006) transformed from the angle of information fusion the original problem on the regulation of the macroscopic economy into one of solving for the optimal estimation of the controlled variable by treating all such information such as the expected trajectory, the system's dynamics, the ideal control strategy, etc., as the observation information of the controlled variable.

For our purpose, let us consider an economic system E, involving three key variables I, P, and S. To make the situation practically imaginable, let us assume that I stands for an economic indicator of the system, P the relevant productivity of the economy, and S the interaction of the economy with the outside world.

To maintain the stability of the economy, our ideal productivity should be u in order to keep the economic indicator I to stay around a projected value Z, that is, P approaches and fluctuates around u over time. Because of the meaning of S, the interaction of the said economy with the outside world, we can think of it as an interference of the outside world. Or, in other words, any interference of the outside world on the said economy is materialized through S.

When S is known, meaning that the relationship between the said economy and the outside world has been observed, the policy makers of the economy would like to accomplish the following goals:

$$P \to u, \text{ and } I \to Z.$$

And if we imagine that the policy output of the economy under macroeconomic management is $y = [P - u \quad I - Z]^T = x_1 + [-1 \quad 0]^T u$, where $x_1 = [P \quad I - Z]^T$, then the goal of the policy makers of the said economy is to design a feedback monetary or fiscal policy $u = K_1 x_1 + K_2 u$ such that the said economy, when seen as a close system, is stable while the output is adjusted so that $y \to 0$.

In particular, what is described above implies the following theoretical problem: When the mathematical model of an economic system is established and the appropriate parameters of the model are determined, can one design the corresponding feedback control strategy (i.e., an economic strategy) so that the variable of control could be made to approach the pre-determined objective? However, the problem is when either the estimates of the parameters of an economic system are not accurate or the true values of the parameters of the economic system have changed with the elapse of time, can one still design good quality feedback control strategies, such as monetary or fiscal policies, so that the variable of control would approach accurately the pre-determined targets? This chapter mainly focuses on the investigation of feedback control strategies that could withstand external disturbances so that the output of the economic system would approach the established goals.

This chapter is organized as follows: Section 13.2 formulates in the language of differential equations the problem that is addressed in this chapter. Section 13.3 studies the design of feedback control with pure gain. Section 13.4 establishes the main result that constitutes the basis for the development of a linear multivariable regulator in Sect. 13.5. Section 13.6 investigates a situation of a particular economic system, a production inventory system, by employing what is established in Sect. 13.5. Then, this chapter is concluded by a general discussion in Sect. 13.7.

13.2 Formulation of the Problem

Assume that x_1 is the state variable of the economy that is to be controlled or regulated, x_2 is the variable that reflects how the environment interferes with the economic system, and u and y represent the control vector and the output vector, respectively. Then the state equation of the economic system that is to be controlled is

$$\frac{dx_1}{dt} = A_1x_1 + A_3x_2 + B_1u \tag{13.1}$$

where the interference variable satisfies the following state equation:

$$\frac{dx_2}{dt} = A_2x_2 \tag{13.2}$$

and the output equation is

$$y = C_1x_1 + C_2x_2. \tag{13.3}$$

When the natural evolution of the state variables of the economic system is affected by the external environment, the people who are charged with the responsibility to overlook the health of the system will often adopt certain strategies or policies to reduce the deviation of the state variables from their targeted values. For example, during a currency war when the currency of the economic system and the target exchange rate are greatly affected, the system tends to adopt the strategy of selling its target currency to lower the rate of change in its currency so that the exchange rate of the system's currency would gradually recover to a certain desired level. As a matter of fact, when the regulator of the economic system adopts counter measures to reduce the influence of the external factors, the action strength of the adopted strategies is roughly directionally proportional to the control deviation of the observable state variables of the economic system. That proportionality constant we will refer to as the pure gain of the adopted strategies. Because the state variables of the original economic system and changes in these variables when the economic system is under influence of some external factors can be readily observed, we can use these observed state variables and the relevant changes as inputs in controlling the action strength of the adopted strategies. Here, the product of the gain of the control strategies and the input value is referred to as the feedback gain; and when the changes in the state variables are used as input, the product is known as pure feedback gain. So, the simplest situation is to use both x_1 and x_2 as feedback to design a feedback controller of pure gains as follows:

$$u = K_1x_1 + K_2x_2 \tag{13.4}$$

so that the resultant closed-loop system is stable while reaching the following goal of regulation of the output:

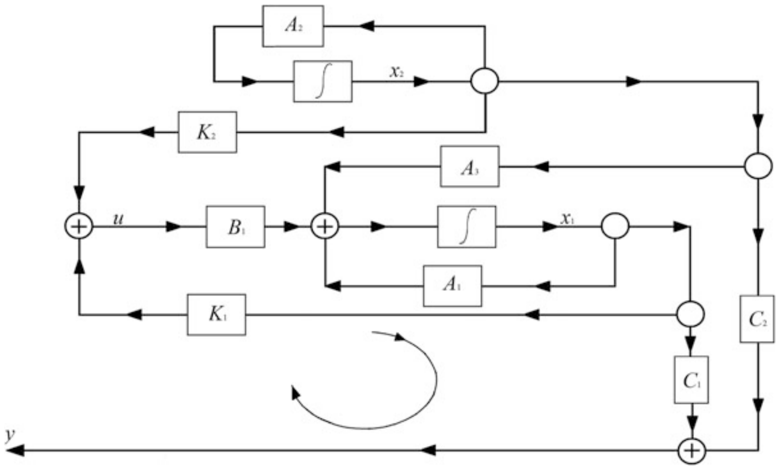

Fig. 13.1 The feedback controller with pure gains

$$\lim_{t \to \infty} y(t) = 0. \tag{13.5}$$

Figure 13.1 shows the block diagram of this closed-loop system. Because we only consider regulating the output and because the solutions that correspond to the eigenvalues with negative real parts do not have any effect on the regulation of the output, without loss of generality, we assume $\sigma(A_2) \subset C^+$, where $\sigma(A_2)$ stands for the set of the extreme points of the interfering system and $\sigma(A_2) \subset C^+$means that the real parts of all the extreme points are positive. As a matter of fact, if none of the extreme points has positive real part, then the interfering system is asymptotically stable. In this case, the interfering system does not affect the stability of the original system. Hence, we only consider the case when the extreme points of the interfering system have positive real parts.

13.3 Design of Feedback Control with Pure Gain

In the following, let us study the problem of how to design a feedback controller with pure gains. By substituting Eq. (13.4) into Eq. (13.1), we obtain the following closed-loop system:

$$\frac{dx_1}{dt} = (A_1 + B_1K_1)x_1 + (A_3 + B_1K_2)x_2. \tag{13.6}$$

For the system in Eq. (13.6) that is to be controlled, as long as we can appropriately choose such a matrix that makes the eigenvalues of the state matrix in Eq. (13.6) all have negative real parts, we then can apply the control strategy as given in Eq. (13.4) to make the controlled variable eventually approach the target value accurately. If some or all of the elements of A, B, and C of the system change, or the interference input x_2 also experiences changes, as long as the real parts of the eigenvalues of the state matrix in Eq. (13.6) stay negative, then the control strategy in Eq. (13.4) can guarantee that the controlled variable will accurately approach the target value. That implies that the control strategy in Eq. (13.4) possesses good quality, is considered "very strong," and is of the robustness.

As a matter of fact, if (A_1, B_1) is controllable, we then can find K_1 such that $A_1 + B_1K_1$ can have any chosen value as its extreme. As long as we place the extreme values at appropriate places on the left-half open plane, we can make the closed-loop system in Eq. (13.6) asymptotically stable. As for how to find K_2 in order to gradually approach the problem of regulation, we will come back to this problem after we first establish the lemma in the next section.

When both x_1 and x_2 can be used as feedback, our problem will be resolved as long as we can find K_1 and K_2. When x_1 and x_2 cannot be all used as feedback, then for the following augmented system

$$\frac{dx}{dt} = \begin{bmatrix} A_1 & A_3 \\ 0 & A_2 \end{bmatrix} x + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} u \equiv Ax + Bu \tag{13.7}$$

$$y = [C_1 \quad C_2]u \equiv Cx \tag{13.8}$$

we need to design the following observer

$$\frac{dz}{dt} = (A + GC)z + Bu - Gy \tag{13.9}$$

and estimate the state $x = \begin{bmatrix} x_1^T & x_1^T \end{bmatrix}$ of the augmented system in Eq. (13.7). If (C, A) is observable, then we can find G such that $A + GC$ has the pre-determined extreme points located on the left-half open place. In this case, we use

$$u = [K_1 \quad K_2]z$$

as the feedback instead of Eq. (13.4). Such a feedback controller with an observer attached is referred to as a linear multivariable regulator.

Additionally, we can use the following general dynamic compensator:

$$\begin{cases} \dfrac{dz}{dt} = Ez + Fy \\ u = Kz + Ly \end{cases}$$

to substitute for the observer. In this case, we obtain the following closed-loop system:

$$\begin{cases} \dfrac{dx_1}{dt} = \begin{bmatrix} A_1 + B_1FC_1 & B_1K \\ FC_1 & E \end{bmatrix} x_1 + \begin{bmatrix} A_3 + B_1FC_2 \\ FC_2 \end{bmatrix} x_2 \equiv A_1x_1 + B_1x_2 \\ \dfrac{dx_2}{dt} = A_2x_2 \\ y = [C_1 \quad 0]x_1 + C_2x_2 \equiv C_1x_1 + C_2x_2 \end{cases}$$

where $x_l = \begin{bmatrix} x_1^T & z^T \end{bmatrix}^T$.

As for whether or not the output of this closed-loop system can still be successfully regulated under the influence of the interference variable, we will address this problem after we first establish the important lemma in the next section.

13.4 The Lemma

Lemma 13.1 For system

$$\frac{dx_l}{dt} = A_lx_l + B_lx_2 \tag{13.10}$$

$$\frac{dx_2}{dt} = A_2x_2 \tag{13.11}$$

$$y = C_lx_l + C_2x_2 \tag{13.12}$$

If $\sigma(A_l) \subset C^-$ and $\sigma(A_2) \subset C^+$, then the following hold true:

(1) The following matrix equation has a unique solution X:

$$A_lX - XA_2 = B_l. \tag{13.13}$$

(2) For any given initial values $x_l(0)$ and $x_2(0)$, a sufficient and necessary condition for $\lim_{t \to \infty} y(t) = 0$ is

$$C_lX = C_2. \tag{13.14}$$

Proof

(1) Because $\sigma(A_l) \subset C^-$ and $\sigma(A_2) \subset C^+$, we have $\sigma(A_l) \cap \sigma(A_2) = \varnothing$. So, from results of algebra, it follows that the matrix equation in Eq. (13.13) has a unique solution.
(2) Let us first prove the sufficiency. If the matrix equation in Eq. (13.13) has solution X such that $C_lX = C_2$, then by direct checking it follows that for any solution x_2 of the interference equation in Eq. (13.11), $-Xx_2$ is a solution of Eq. (13.10). So, we have

$$y = C_l x_l + C_2 x_2 = C_l x_l + C_l X x_2 = C_l[x_l - (-X x_2)]. \tag{13.15}$$

And because both x_l and $-Xx_2$ are solutions of Eq. (13.10), $x_l - (-Xx_2)$ is a solution of the corresponding homogeneous equation:

$$\frac{dx_l}{dt} = A_l x_l. \tag{13.16}$$

From the assumption that A_l is a stable matrix, it follows that when $t \rightarrow \infty$, $[x_l - (-Xx_2)] \rightarrow 0$. That is, we have $\lim_{t\rightarrow\infty} y(t) = 0$.

Next, we show the necessity. If for any initial conditions $x_l(0)$ and $x_2(0)$, $\lim_{t\rightarrow\infty} y(t) = 0$, then assume the solutions that satisfy the initial conditions are $x_l(t)$ and $x_2(t)$. Let $\tilde{x}_l = x_l - (Xx_2)$, and then $\tilde{x}_l$ satisfies the homogeneous equation in Eq. (13.16) and so we have $\lim_{t\rightarrow\infty} \tilde{x}_l(t) = 0$. On the other hand, from Eq. (13.12) and $\lim_{t\rightarrow\infty} y(t) = 0$, it follows that

$$\lim_{t\rightarrow\infty} y(t) = \lim_{t\rightarrow\infty} (C_l x_l + C_2 x_2) = \lim_{t\rightarrow\infty} [C_l \tilde{x}_l + (C_2 - C_l X)x_2] = \lim_{t\rightarrow\infty} [(C_2 - C_l X)x_2] = 0.$$

Because of the arbitrariness of $x_2(0)$, $x_2(t)$ stands for an arbitrary solution of the interference equation. And, because of $\sigma(A_2) \subset C^+$, the previous equation implies $C_2 - C_l X = 0$, that is, $C_l X = C_2$. QED

Under certain specific conditions, such as when large amounts of money suddenly enter into or withdraw from an economic system, the domestic currency system of the economy would have to experience disturbances of the outside world. Some of the state variables of the economic system, which describe the movement of the domestic currency within the economy, would have to undergo drastic changes, causing major impacts on the originally normal operation of the currency system of the economy. More often than not, the impacts bring forward huge economic losses to the domestic currency system. For example, the 1997 financial crisis of Thailand represents a real-life scenario where the control on the economic stability was eventually lost when the domestic currency system of the economy was first disturbed by external factors. To this end, the previous result indicates that even under the influence of an interfering system, if the coefficient matrices of the state variables of the original economic system and of the interfering system satisfy Eqs. (13.13) and (13.14), then the output of the original economic system can still reach a stable state. As a matter of fact, this result also indirectly provides a method on how to stabilize the economic system when the system is interfered by an external environment. That is, if the regulator of the economic system could learn the laws of evolution of the interfering system and the effects of the interfering system on the state variables and the output variables of the original economic system, then he could design an appropriate counter measure of control to keep the original economic system stable. In particular, the counter measure of control only needs to guarantee that under the effect of the adopted strategies (policies) the coefficient matrices of the state variables of the economic system and the interfering system satisfy Eqs. (13.13) and (13.14).

Therefore, in order to introduce appropriate measures in a timely fashion to counter the adverse effects of external interferences on the development of the economic system, the economic decision maker has to promptly acquire the knowledge on how the external interferences affect the state variables and output variables of the economic system. Then he could design his corresponding strategies (policies) according to the previous result in order to keep the economic system within effective control. In the following, we will provide specific method and steps on how to design such counter measures (policies).

13.5 Design of Linear Multivariable Regulator

13.5.1 Design of Pure Gain Feedback Controllers

Assume that the state equation, interference equation, and the output equation of the economic system are given, respectively, by Eqs. (13.1), (13.2), and (13.3) and that (A_1, B_1) is controllable so that $\sigma(A_2) \subset C^{+}$. Let us design the following pure gain feedback controller so that the closed-loop system is stable and accomplishes the desired regulation of the output.

$$u = K_1 x_1 + K_2 x_2.$$

This end can be accomplished in two steps.

Step 1: Use the method of how to replace the extreme points to compute K_1 so that the closed-loop system

$$\frac{dx_1}{dt} = (A_1 + B_1 K_1)x_1 + (A_3 + B_1 K_2)x_2 \tag{13.17}$$

is stable. In order to accomplish this objective, all we need to do is to replace all the extreme points of $A_1 + B_1 K_1$ on the appropriate locations in the left-half open plane.

Step 2: Apply Lemma 13.1 on the system in Eq. (13.14). In order to guarantee that the output is adjustable, solve the matrix equation

$$A_l X - X A_2 = B_l$$
$$C_l X = C_2$$

for its solution X by considering the facts that $A_l = A_1 + B_1 K_1$, $B_l = A_3 + B_1 K_2$, and $C_l = C_1$. The previous two matrix equations can then be simplified into

$$A_1X - XA_2 + B_1U = A_3 \tag{13.18}$$

$$C_1X = C_2 \tag{13.19}$$

where

$$U = K_1X - K_2 \tag{13.20}$$

which leads to

$$K_2 = K_1X - U. \tag{13.21}$$

Because K_2, which is computed out of Eq. (13.21), satisfies Eqs. (13.13) and (13.14), it is guaranteed that the system's output reaches the desired adjustment. Based on this analysis, we obtain the particular steps for designing a pure gain feedback controller as follows.

Step 1: Solve for K_1 so that the extreme points of $A_1 + B_1K_1$ are located at the n predetermined locations in the left-half open plane.

Step 2: Solve the following matrix equation for X and U.

$$A_1X - XA_2 + B_1U = A_3$$
$$C_1X = C_2$$

Step 3: Calculate $K_2 = K_1X - U$ and let $u = K_1x_1 + K_2x_2$, which is the desired pure gain feedback controller.

The pure gain feedback controller, as designed above, consists of two parts: K_1x_1 and K_2x_2. The former is the state feedback, while the latter the feedback of the interference variable. In particular, the state feedback K_1x_1 plays the role of making the closed-loop system stable with good dynamic responses, while the feedback of the interference variable K_2x_2 plays the role of eliminating the effect of the environmental disturbance in order to reach the purpose of adjusting the output.

13.5.2 Design of Linear Multivariable Regulator

The pure gain feedback controller designed by using the previous scheme needs the feedbacks of the state variables and the interference variables. If some of these variables cannot be employed as feedback for various reasons, such as they are not observable, then we have to use the augmented system in Eqs. (13.7) and (13.8) to design the observer in Eq. (13.9). In this case, the resultant closed-loop system is

$$\frac{dx_1}{dt} = A_1x_1 + A_3x_2 + B_1u$$
$$\frac{dx_2}{dt} = A_2x_2$$
$$\frac{dz}{dt} = (A + GC)z + Bu - Gy$$
$$u = [K_1 \quad K_2]z \equiv Kz$$
$$y = C_1x_1 + C_2x_2.$$

By letting $x_l = \begin{bmatrix} x_1^T & z^T \end{bmatrix}^T$, the previous five equations can be rewritten as follows:

$$\begin{cases} \dfrac{dx_l}{dt} = \begin{bmatrix} \dfrac{dx_1}{dt} \\ \dfrac{dz}{dt} \end{bmatrix} = \begin{bmatrix} A_1 & B \\ -GC_1 & A + GC + BK \end{bmatrix} \begin{bmatrix} x_1 \\ z \end{bmatrix} = A_lx_l + B_lx_2 \\ \dfrac{dx_2}{dt} = A_2x_2 \\ y = [C_1 \quad 0]x_l + C_2x_2 = C_1x_l + C_2x_2 \end{cases} \tag{13.22, 13.23, 13.24}$$

By letting

$$A = \begin{bmatrix} A_1 & A_3 \\ 0 & A_2 \end{bmatrix}, B = \begin{bmatrix} B_1 \\ 0 \end{bmatrix}, C = [C_1 \quad C_2], K = [K_1 \quad K_2], G = \begin{bmatrix} G_1 \\ G_2 \end{bmatrix}$$

we obtain

$$A_l = \begin{bmatrix} A_1 & B_1K_1 & B_1K_2 \\ -G_1C_1 & A_1 + G_1C_1 + B_1K_1 & A_3 + G_1C_2 + B_1K_2 \\ -G_2C_1 & G_2C_1 & A_2 + G_2C_2 \end{bmatrix}$$
$$B_l = \begin{bmatrix} A_3 \\ -G_1C_2 \\ -G_2C_2 \end{bmatrix}.$$

So, the characteristic polynomial of the closed-loop system is

$$
\begin{aligned}
|sI - A_l| &= \begin{vmatrix} sI - A_1 & -B_1K_1 & -B_1K_2 \\ G_1C_1 & sI - (A_1 + G_1C_1 + B_1K_1) & -(A_3 + G_1C_2 + B_1K_2) \\ G_2C_1 & -G_2C_1 & sI - (A_2 + G_2C_2) \end{vmatrix} \\
&= \begin{vmatrix} sI - A_1 & -B_1K_1 & -B_1K_2 \\ G_1C_1 & sI - (A_1 + G_1C_1 + B_1K_1) & -(A_3 + G_1C_2 + B_1K_2) \\ G_2C_1 & -G_2C_1 & sI - (A_2 + G_2C_2) \end{vmatrix} \\
&= \begin{vmatrix} sI - (A_1 + B_1K_1) & -B_1K_1 & -B_1K_2 \\ sI - (A_1 + B_1K_1) & sI - (A_1 + G_1C_1 + B_1K_1) & -(A_3 + G_1C_2 + B_1K_2) \\ 0 & -G_2C_1 & sI - (A_2 + G_2C_2) \end{vmatrix} \\
&= \begin{vmatrix} sI - (A_1 + B_1K_1) & -B_1K_1 & -B_1K_2 \\ 0 & sI - (A_1 + G_1C_1) & -(A_3 + G_1C_2) \\ 0 & -G_2C_1 & sI - (A_2 + G_2C_2) \end{vmatrix} \\
&= \begin{vmatrix} sI - (A_1 + B_1K_1) & B_1K \\ 0 & sI - (A + GC) \end{vmatrix}
\end{aligned}
$$

That indicates that the set of all extreme points of the closed-loop system is

$$\sigma(A_1 + B_1K_1) \cup \sigma(A + GC).$$

This end shows that the closed-loop system with an observer in Eq. (13.22) is stable. Now, by using Lemma 13.1 on Eqs. (13.25) and (13.22), (13.23), and (13.24), it follows that the matrix equation

$$A_l\bar{X} + \bar{X}A_2 = B_l \tag{13.25}$$

has a unique solution $\bar{X}$. If we can also prove $C_l\bar{X} = C_2$, then Lemma 13.1 guarantees that $\lim_{t\to\infty} y(t) = 0$.

Before we establish the fact that $C_l\bar{X} = C_2$, let us first check that for any X that satisfies the matrix equations in Eqs. (13.18) and (13.19), the following matrix

$$\bar{X} = \begin{bmatrix} X \\ X \\ -I \end{bmatrix}$$

satisfies matrix equation in Eq. (13.25). By direct substitution, we have

$$
\begin{aligned}
& A_l \begin{bmatrix} X \\ X \\ -I \end{bmatrix} - \begin{bmatrix} X \\ X \\ -I \end{bmatrix} A_2 \\
&= \begin{bmatrix} A_1X + B_1(K_1X - K_2) - XA_2 \\ -G_1C_1X + (A_1 + G_1C_1 + B_1K_1)X - (A_3 + G_1C_2 + B_1K_2) - XA_2 \\ -G_2C_1X + G_2C_1X - (A_2 + G_2C_2) + A_2 \end{bmatrix} = \begin{bmatrix} A_3 \\ -G_1C_2 \\ -G_2C_2 \end{bmatrix} \\
&= B_l.
\end{aligned}
$$

Next, let us check $C_l\bar{X} = C_2$:

$$C_l\bar{X} = [C_1 \quad 0]\begin{bmatrix} X \\ X \\ -I \end{bmatrix} = C_1X = C_2.$$

So, Lemma 13.1 implies that $\lim_{t\to\infty} y(t) = 0$.

Example 1 Assume that the state equation of an economic system is

$$\frac{dx_1}{dt} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}x_1 + \begin{bmatrix} 1 \\ 2 \end{bmatrix}x_2 + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}u$$

with the interference equation and the output equation given, respectively, as follows:

$$\frac{dx_2}{dt} = 0 \text{ and } y = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}x_1.$$

Design a linear multivariable regulator such that the closed-loop system has extreme points -2, -2, -1, -1, and -2.

Solution

Step 1: Calculate K_1 so that $A_1 + B_1K_1$ has extreme points -2 and -2. To this end, we can readily obtain

$$K_1 = \begin{bmatrix} -3 & 0 \\ 0 & -3 \end{bmatrix}.$$

Step 2: Solve the matrix equation

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}X + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}U = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$$
$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}X = 0$$

and obtain the solution

$$X = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}, U = \begin{bmatrix} 1 \\ 2 \end{bmatrix}.$$

Therefore, we obtain

$$K_2 = K_1X - U = -\begin{bmatrix} 1 \\ 2 \end{bmatrix}.$$

So, we obtain the following pure gain feedback controller:

$$u = \begin{bmatrix} -3 & 0 \\ 0 & -3 \end{bmatrix} x_1 - \begin{bmatrix} 1 \\ 2 \end{bmatrix} x_2.$$

Step 3: For the augmented system

$$\frac{dx}{dt} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 2 \\ 0 & 0 & 0 \end{bmatrix} x + \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} u$$
$$y = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x_1,$$

design an observer so that its extreme points are -1, -1, and -2. Hence, the resultant controller with an observer is

$$\begin{cases} \dfrac{dz}{dt} = \begin{bmatrix} -5 & 0 & 1 \\ -24 & 1 & 2 \\ -12 & 1 & 0 \end{bmatrix} z + \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} u + \begin{bmatrix} 6 & 0 \\ 24 & 0 \\ 12 & -1 \end{bmatrix} y \\ u = \begin{bmatrix} -3 & 0 & -1 \\ 0 & -3 & -2 \end{bmatrix} z \end{cases}$$

or

$$\frac{dz}{dt} = \begin{bmatrix} -8 & 0 & 0 \\ -24 & -2 & 0 \\ -12 & 1 & 0 \end{bmatrix} z + \begin{bmatrix} 6 & 0 \\ 24 & 0 \\ 12 & -1 \end{bmatrix} y$$
$$u = \begin{bmatrix} -3 & 0 & -1 \\ 0 & -3 & -2 \end{bmatrix} z.$$

That is the desired regulator.

13.6 Application in the Control of Production Inventory System

13.6.1 The Problem

The basic equation for the production inventory system is

$$\frac{dI}{dt} = P(t) - S(t) \tag{13.26}$$

where $I(t)$ stands for the inventory in the storage of the production at time t, $P(t)$ the productivity of the particular product, and $S(t)$ the speed at which the product is sold. The meaning of Eq. (13.26) is that any change in the inventory is equal to the production minus the sale.

Assume that the desired productivity is $u(t)$. Then the equation that reflects the process for the actual productivity $P(t)$ to reach the necessary level is

$$\frac{dP}{dt} = \theta[u(t) - P(t)]$$

where θ is a positive constant. So, the state equation of the production inventory system is

$$\begin{cases} \dfrac{dP}{dt} = \theta[u(t) - P(t)] \\ \dfrac{dI}{dt} = P(t) - S(t) \end{cases}. \tag{13.27}$$

By introducing the state vector $x_1(t) = [P(t) \quad I(t) - Z]$ and the interference vector $x_2(t) = S(t)$, Eq. (13.27) can be rewritten as the following state equation:

$$\frac{dx_1}{dt} = \begin{bmatrix} -\theta & 0 \\ 1 & 0 \end{bmatrix} x_1(t) + \begin{bmatrix} \theta \\ 1 \end{bmatrix} x_2(t) + \begin{bmatrix} 0 \\ -1 \end{bmatrix} u(t) \tag{13.28}$$

where Z stands for the required level of inventory, which is assumed to be a constant. As a matter of fact, in practical applications, the actual values of both $P(t)$ and $S(t)$ are determined once per unit time period, such as once per day or once per month. So, we can discretize Eq. (13.28) into the following state equation:

$$x_1(k+1) = \begin{bmatrix} q & 0 \\ r & 1 \end{bmatrix} x_1(k) + \begin{bmatrix} 0 \\ -1 \end{bmatrix} x_2(k) + \begin{bmatrix} 1-q \\ 1-r \end{bmatrix} u(k) \tag{13.29}$$

where $q = e^{-\theta}$ and $r = (1 - e^{-\theta})/\theta$. When the speed of sale $S(t)$ is assumed to be a constant, then $x_2(t)$ satisfies the following interference equation:

$$x_2(k+1) = x_2(k). \tag{13.30}$$

And the objective of control $P(k) \rightarrow u(k)$, $I(k) \rightarrow Z$, can be expressed as follows:

$$y(k) = \begin{bmatrix} P(k) - u(k) \\ I(k) - Z \end{bmatrix} = x_1(k) + \begin{bmatrix} -1 \\ 0 \end{bmatrix} u(k) \rightarrow 0$$

so that the output equation can be obtained as follows:

$$y(k) = x_1(k) + \begin{bmatrix} -1 \\ 0 \end{bmatrix} u(k). \tag{13.31}$$

Therefore, the problem of control of the production inventory system becomes: Design a feedback control strategy:

$$u(k) = K_1 x_1(k) + K_2 x_2(k)$$

so that the closed-loop system is stable and its output is controllable. This is a problem of designing a linear multivariable regulator for a discrete control system.

13.6.2 The Solution

Assume that the state equation of the system that is to be controlled is

$$x_1(k+1) = A_1 x_1(k) + A_3 x_2(k) + B_1 u(k) \tag{13.32}$$

with an interference equation and output equation, respectively, being

$$x_2(k+1) = A_2 x_2(k) \tag{13.33}$$

and

$$y(k) = C_1 x_1(k) + C_2 x_2(k) + D u(k). \tag{13.34}$$

Now, the problem of designing a linear multivariable regulator of discrete time is find a pure gain feedback controller

$$u(k) = K_1 x_1(k) + K_2 x_2(k) \tag{13.35}$$

such that the closed-loop system is stable and satisfies the following goal of output adjustment:

$$\lim_{k \to \infty} y(k) = 0.$$

When either $x_1(k)$ or $x_2(k)$ cannot be employed as feedback variables, we need to design an observer to estimate the variable(s) that cannot be employed as feedbacks.

For this problem of designing linear multivariable regulator of discrete time, we have the following result: if in the system as expressed in Eqs. (13.31), (13.32), (13.33) and (13.34) (A_1, B_1) is completely reachable and the eigenvalues of A_2 are not located within the unit circle, then a sufficient and necessary condition for there being a pure gain feedback controller in Eq. (13.35) that makes the closed-loop system stable and the output is controllable is that there are matrices X and U satisfying the following equation:

$$A_1 X - X A_2 + B_1 U = A_3 \tag{13.36}$$

$$C_1X + DU = C_2. \tag{13.37}$$

Therefore, we obtain the following specific steps for designing a pure gain feedback controller:

Step 1: Select a matrix K_1 such that the eigenvalues of $A_1 + B_1K_1$ are located at some appropriate points within the unit circle of the complex plane.
Step 2: Solve the matrix equations in Eqs. (13.36) and (13.37) to obtain matrices X and U.
Step 3: Compute

$$K_2 = K_1X - U \tag{13.38}$$

and so

$$u(k) = K_1x_1 + K_2x_2$$

is the desired pure gain feedback controller.

If necessary, we further design an observer to form a linear multivariable regulator.

13.6.3 Solving the Control Problem of Production Inventory System

Now, let us employ the previous result to solve the problem of the production inventory system control. To this end, let us look at the system given in Eqs. (13.29), (13.30), and (13.31), where

$$A_1 = \begin{bmatrix} q & 0 \\ r & 1 \end{bmatrix}, B_1 = \begin{bmatrix} 1-q \\ 1-r \end{bmatrix}, A_3 = \begin{bmatrix} 0 \\ -1 \end{bmatrix}, A_2 = 1, C_1 = I, C_2 = 0, D = \begin{bmatrix} -1 \\ 0 \end{bmatrix}.$$

Step 1: Select a matrix K_1 so that the eigenvalues of $A_1 + B_1K_1$ are equal to $\lambda_1 = 0$ and $\lambda_2 = 0$. So, we have

$$K_1 = \frac{1}{(1-q)^2}\begin{bmatrix} q^2 - r & q - 1 \end{bmatrix}.$$

Step 2: Solve the following matrix equation

$$\begin{bmatrix} q & 0 \\ r & 1 \end{bmatrix} X - X + \begin{bmatrix} 1-q \\ 1-r \end{bmatrix} U = \begin{bmatrix} 0 \\ -1 \end{bmatrix},$$
$$X + \begin{bmatrix} -1 \\ 0 \end{bmatrix} U = 0$$

and obtain

$$X = \begin{bmatrix} -1 \\ 0 \end{bmatrix} \text{ and } U = -1.$$

Step 3: Compute

$$K_2 = K_1 X - U = \frac{r - q^2}{(1-q)^2} + 1.$$

So, the desired pure gain feedback controller is

$$u(k) = \frac{1}{(1-q)^2}\begin{bmatrix} q^2 - r & q - 1 \end{bmatrix} x_1(k) + \left[\frac{r - q^2}{(1-q)^2} + 1\right] x_2(k).$$

By letting

$$x_1(k) = \begin{bmatrix} P(k) \\ I(k) - Z \end{bmatrix} \text{ and } x_2(k) = S(k)$$

we obtain

$$u(k) = \frac{q^2 - r}{(1-q)^2} P(k) + \frac{1}{q-1}(I(k) - Z) + \left[\frac{r - q^2}{(1-q)^2} + 1\right] S(k). \tag{13.39}$$

When the input is an unknown disturbance, we design a reduced order observer to estimate $S(k)$; say, the estimation is $\hat{S}(k)$. Now, we substitute this estimated value $\hat{S}(k)$ into the previous equation for $S(k)$.

In order to design a reduced order observer, let us consider the following augmented system:

$$\begin{bmatrix} x_2(k+1) \\ \cdots\cdots\cdots \\ x_1(k+1) \end{bmatrix} = \begin{bmatrix} 1 & \vdots & 0 & 0 \\ 0 & \vdots & q & 0 \\ \cdots & \vdots & \cdots & \cdots \\ -1 & \vdots & r & 1 \end{bmatrix} \begin{bmatrix} x_2(k) \\ \cdots\cdots\cdots \\ x_1(k) \end{bmatrix} + \begin{bmatrix} 0 \\ \cdots\cdots\cdots \\ 1 - q \\ 1 - r \end{bmatrix} u(k) \tag{13.40}$$

$$\bar{y}(k) = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_2(k) \\ x_1(k) \end{bmatrix} = x_1(k) \tag{13.41}$$

which takes the identical form of Eq. (13.25). That is, we have

$$A_{11} = 1, A_{12} = \begin{bmatrix} 0 & 0 \end{bmatrix}, A_{21} = \begin{bmatrix} 0 \\ -1 \end{bmatrix}, A_{22} = \begin{bmatrix} q & 0 \\ r & 1 \end{bmatrix}, B_1 = 0, B_2 = \begin{bmatrix} 1 - q \\ 1 - r \end{bmatrix}.$$

We next place the extreme points of the observer at the origin. That is, solve for G such that the extreme values of $A_{11}+GA_{21}$ are equal to 0. That is equivalent to solving $G=[\,g_1 \quad g_2\,]$ such that

$$1+[\,g_1 \quad g_2\,]\begin{bmatrix}0\\-1\end{bmatrix}=1-g_2=0.$$

So, we can simply take $G=[\,0 \quad 1\,]$. Because Eqs. (13.30) and (13.31) are also applicable to discrete time systems, the state equation of the reduced order observer should be

$$\begin{aligned}w(k+1)&=(A_{11}+GA_{21})w(k)+(B_1+GB_2)u(k)\\&\quad+[A_{12}+GA_{22}-(A_{11}+G_{21})G]\bar{y}(k)\\\hat{x}_2&=w(k)-G\bar{y}(k).\end{aligned}$$

So, we obtain the following reduced order observer of the augmented system:

$$\begin{aligned}w(k+1)&=(1-r)u(k)+[\,r \quad 1\,]\bar{y}(k)=rP(k)+(I(k)-Z)+(1-r)u(k)\\\hat{x}_2&=w(k)-[\,0 \quad 1\,]\bar{y}(k)=w(k)-(I(k)-Z).\end{aligned}$$

By substituting $\hat{x}_2(k)$ for $x_2(k)$ as the feedback, the pure gain feedback controller in Eq. (13.39) becomes

$$\begin{aligned}u(k)&=\frac{q^2-r}{(1-q)^2}P(k)+\frac{1}{q-1}(I(k)-Z)+\left[\frac{r-q^2}{(1-q)^2}+1\right]\hat{x}_2(k)\\&=\frac{q^2-r}{(1-q)^2}P(k)+\left[\frac{1}{q-1}-\frac{r-q^2}{(1-q)^2}\right](I(k)-Z)+\left[1+\frac{r-q^2}{(1-q)^2}\right]w(k).\end{aligned}$$

When $q=0.5$, $r=0.72$, $P(0)=10$, $I(0)-Z=0$, $S(k)=11$, the result of the control is depicted in Fig. 13.2.

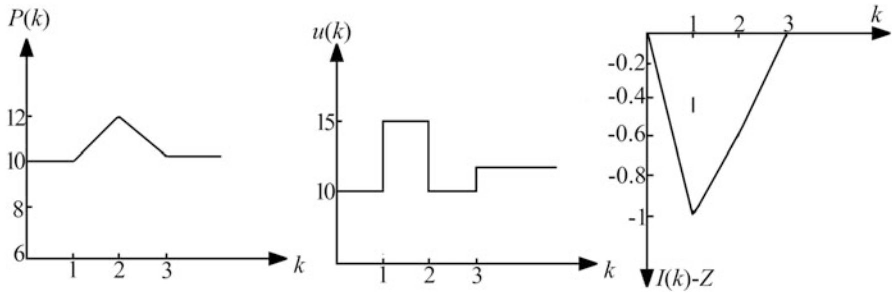

Fig. 13.2 The control and the state trajectory of the production inventory system

13.7 Conclusion

After the control-theory model for an economic system is established with its parameters determined, we can design measures to regulate the economic system by employing the methods of the control theory. Because of the complexity and dynamics of the economic system, the estimates of the model's parameters may well be not accurate or could change without any warning. So, it is necessary under such circumstances to introduce effective control strategies into the economic system so that the controlled variables could approach the target values accurately in order to guarantee the stability of the economic system. Based on this kind of thinking, on the basis of the method of feedback control, this chapter establishes a feedback control model for the economic system, provides proofs for how well this proposed control method could perform in practice, and expands this method to design the linear multivariable feedback control and the feedback control of discrete variables. At the end, this chapter analyzes an empirical case to confirm the feasibility and correctness of the proposed design. The result shows that the proposed control design can make the controlled variable(s) approach the ideal targets quite well even when the economic system is under the influence of environmental disturbance.

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Chapter 14
Another Plan of Self-Protection

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Contents

This chapter, based on (Chen et al. 2017), investigates the following problem: how could a nation possibly design a measure to counter large-scale sudden flight of foreign investments in order to avoid the undesirable disastrous consequences? Continuing what were presented in Chap. 12 (Forrest et al. 2013a), and based on how a currency war could be potentially raged against a nation, all results herein are established by making use of the results of feedback systems. And based on theoretical reasoning and systemic analysis, this chapter develops a self-defense mechanism that could conceivably protect the nation under siege.

When a nation tries to accelerate its economic development, large amounts of foreign investments would generally be welcomed. And at the same time, a lot of such foreign investments would strategically rush into the nation in order to ride along with the forthcoming economic boom. However, recent financial events from around the world indicate that how to avoid the disastrous aftermath when a large-

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scale flight of foreign capital appears suddenly is still not well understood and well planned out. This fact vividly shows the theoretical and practical values of the works presented herein.

14.1 Introduction

14.1.1 Currency War

Since World War II, the form of war has changed. The main battlefield of modern warfare has quietly shifted from direct military operations to the economic maneuvers. Fundamentally, all modern forms of warfare are currency related. Although there is no physical battleground, both the scales and benefits the conflicts eventually generate out of the competition for the financial highlands are no less any those of any war in history.

Each financial crisis can be seen as the signal of a currency war. Our present world on the average experiences about ten massive financial crises per year. The results are that the relevant countries lose their leadership, if there was any, and have to stay in the consequent economic shadows for years to come or, might be worse, they can no longer recover and return to their previous glory, for example, the British sterling crisis, Japan's decade of recession after the Plaza Accord, Southeastern Asia's financial crisis, and so on. These related countries did not experience any military conflict and did not have the time to use any advanced weaponry that had been prepared for use for a long time. Compared to a military warfare, currency wars had made these countries pay a much greater economic cost. The reality is that most nations today have no need, and are unable to resolve conflicts by employing conventional wars, because by using the idea of currency wars, one can achieve his desired goals.

Klein (2003) showed in his empirical analysis that capital account liberalization has different effects on economic growth in different countries. There is a generally inverted U-shaped structure. Middle-income countries benefit from capital account liberalization, while the polar countries (either very rich or very poor) do not significantly benefit from capital account liberalization. Henry (2000), based on event study, discussed the effects of stock market liberalization on the emerging market countries' economic reform and equity market prices. The results showed that the sampled countries obtain the average excess return of 3.3% per month after capital account liberalization within 8 months. Li and Zhang (2008), based on a dynamic model of Aghion, analyzed the impact of capital account liberalization on economic and financial stability. They also used cross-sectional data model involving 57 countries and further studied the economic consequences of opening direct investment for different country samples. Empirical evidence supports their theoretical model predictions. And they proved that in terms of instability, opening direct investment in developing countries or countries with economies in transition will result in a stronger impact than in developed countries.

Zhang (2003) analyzed the conduction of a financial crisis as the breakthrough point, based on the demonstration effect of the conduction, and tried to investigate financial crises from one side. Li (2007) established the currency substitution VEC model and made a dynamic analysis of extent of China's currency substitution and the relationship between its influence factors. The conclusion is that the main factor that has effects on Chinese currency substitution is RMB's nominal effective exchange rate in both long- and short terms. Frequent fluctuations in the nominal effective exchange rate will lead to currency substitution and even cause instability in the demand for money.

After reviewing the previous theoretical analysis with recent cases of speculative attacks in the arena of international finance, we surely see the following predicament. When a nation tries to accelerate the economic development, due to its capital account liberalization and loose monetary policies, large amounts of foreign investments would be welcomed; and at the same time, a lot of such foreign investments would strategically rush into the nation in order to ride along with the forthcoming economic boom. Therefore, a serious question at this junction is how could a nation possibly design a measure to counter such foreign investments to leave suddenly in order to avoid the undesirable disastrous consequences?

In this chapter, based on the studies and discussions of how China's capital account liberalization affects international capital flows and the economy and finance, we study the evolution mechanism of a currency war by using systems theory.

14.1.2 Literature Review

14.1.2.1 Importance of Capital Account Liberalization

Capital account liberalization is an important proposition of the international finance, having long been the focus of attention of economists. As a result of the liberalization in industrialized countries, at present, the issue of capital account liberalization is almost entirely concentrated on developing countries. In the economic globalization today, along with the influence of liberalization of external and induced current accounts, implementation of capital account liberalization in developing countries in fact has become an inevitable choice. But since the 1990s, the world has been prone to financial crises, such as the Mexican financial crisis in 1994, the Asian financial crisis in 1997, and, a few years after that, the outbreak of Brazil's financial crisis, Venezuela's financial crisis, and Argentina's financial crisis. The varying degrees of the crises reflect the negative impacts on economies and finances as caused by international capital flows consequent to the liberalization of capital accounts. For more details and related references, please consult with (Forrest 2014).

14.1.2.2 Currency Superiority of the United States

In order to maintain the central position of power in the world economy, the United States is ready to fight against the threat of any currency system. As of this writing, the United States has deployed three strategic fronts centered on the dollar.

1. Expansion of Global Influence

   In history, the first to the dollar's dominance as the center of the strategic front formed shortly after World War II. On June 5, 1947, George Marshall, the 50th Secretary of State of the United States, who had a long-term strategic mind, delivered a historic speech, declaring that the United States was ready to help with the European recovery to be funded by the United States with the most potentially far-reaching Marshall Plan. This program aimed to make European American. All allies receiving the US economic aids had to be centered on the dollar; and the recovery from the aftermath of World War II made Europe a mixture consisting largely of American interests, values, and informal contact networks. At the same time, European countries also undertook political and economic commitments and obligations. That warranted that the United States would have a good hand in the following contest with the economy of the Soviet Union and greatly curbed the forces of Soviet communist in Europe to advance further from the east to the west. However, the dollar, whose value tumbled in Europe, was used to purchase additional US goods to enter Europe. The consequence was a substantial devaluation of the dollar and led to a confidence crisis in the dollar. European countries then began to hedge the value of the dollars in their hands with gold. In October 1960, the first dollar crisis erupted. On August 15, 1971, Nixon announced a "new economic policy." The United States provisionally stopped the convertibility of the dollar into gold and refused to sell gold to foreign central banks, which not only made the gold-linked dollar in name only but also caused a complete collapse of the Bretton Woods system. However, as the sole oil pricing currency, the dollar gained a qualitative leap and drew for the first time the boundaries, beyond which the United States would employ public actions and deploy military forces. This strategic front of protecting the unique relationship between oil and the dollar, as the time goes on, has become an integral part of American global power. The establishment of cultural, economic, and political networks around oil countries has become a global force for American expansion of global influence. For more details, please consult with (Wang 2012b).
2. Expansion of Its Economic System and Political Will

   The second strategic front of consolidating the center position for the dollar was soon employed after the formation of the first one. Because the liberal economic reforms, as proposed by Chicago school of economics, took place successfully in Latin America, the United States was successful in promoting its capitalist form of economy in terms of geopolitics and in radiating the particular economic form to other socialist countries. The United States subversively tried to make Chile, Bolivia, Mexico, and some other countries to abandon the influence of the Soviet economic model. With the collapse of Soviet Union and economies in Eastern Europe, the United States achieved its important strategic goal to changing the political map of Europe that was formed since World War II and become a dominant force in the global monetary system and acquired its political advantage over others (Wang 2012a). It should be noted that since the start of the new century, with the initial regionalization of the RMB, Sino and US currencies have been in competition for global influence; and because of the marginalization of the dollar by China, the United States has determined to exclude China from the economic power center (Wang 2012b). In 2011, the most important strategic goal of the United States for the next 10 years consisted of: the United States must expand to the west and dramatically increase diplomatic, economic, strategic, and other investments in Asia-Pacific to play a leading role in the entire twenty-first century, because the Pacific region will serve as the center of nation's prosperity and global leadership (Wang 2012b).

3. Global Comprehensive Containment Capability

   This third strategic front was formed much later in time. The previous two strategic fronts made the United States maintain a multifaceted, crosscutting, integrated containment capability. Even if there were one such a country that could surpass the United States in terms of military, that country would still be hampered by its economic capacity, technological innovation, and social development so that it would no longer be a potentially threatening rival. More importantly, the advantage of technological innovations of the United States led to strategic advantages in many areas, such as the deployment of conventional forces around the world, competition in energy production, climate warming, space network, computer technology, and so on. Military force becomes less critical in terms of defending national interests, while its importance only lies in helping the United States to establish a decisive advantage in the world. Weak dollar monetary policy was used to hinder economic influence of developing countries. However, unexpectedly, such monetary policies that might shift the US debt crisis also made the economic strengths of these developing countries both constrained and strengthened at the same time. In other words, America's massive QE monetary policy was introduced at the expense of its national political influence, while its long-term strategic goals are immeasurable.

   The inconsistency between the monetary dominance of the dollar and the health of the world economy will continue to evolve. In order to reduce the risk of foreign exchanges, various countries will put aside the dollar and settle their international trades with its own currency. A new currency pattern will be formed. For more in-depth discussion along this line, please consult with (Wang 2012a).

14.1.2.3 Increasing Influence of Chinese Currency

To reduce the pain created by large-scale quantitative easing in the United States, and to maintain its currency sovereignty, China has adopted a strategy to marginalize the dollar while expanding the influence of its RMB (Wang 2012b).

1. The Center Front of Marginalizing the Dollar Strategy

   In the center front, to support and strengthen the RMB's global influence, China in recent years mainly relied on signing RMB's bilateral currency swap agreements, expanding the regionalization of trade settlement in the RMB and selectively deepening multilateral cooperation (e.g., FTA). In order to ensure the safety of all its assets that are priced in the dollar, China exercises strategic relations with other developing countries in order to promote its RMB's global ambition and to restrict the effect of the dollar. Due to the increasing global influence of the RMB, China indeed poses a potential and visible threat to the United States through extensive global-scale deployments of its RMB while providing a new currency alternative to the world. China's activities have resulted in such a directional trend in the international arena that many governments, including some in Europe, tend to "marginalize the dollar" rather than oppose to the expanding global influence of the RMB. In addition, because China's overall economic level has been below that of the United States, the trend has positively contributed to the implementation and expansion of China's strategy of marginalizing the dollar (Wang 2012b).
2. The International Front of Marginalizing the Dollar Strategy

   In the international front, China relies more heavily on the political and diplomatic methods. Some countries have recognized the fact that heavy dependency on the United States is not appropriate in terms of international trades and currencies (Wang 2012a, b). This is the political foundation for China to implement the RMB trade settlement and bilateral currency swap agreements in the world. And, it represents a time to establish a broad, united front of currency union in politics, which would include mainly developing currencies and emerging countries in the currency markets and secondly all of the capitalist countries that are seriously and adversely affected by the dollar hegemony. The union would establish a multilateral currency swap fund for its member countries in order for them to resolve all crises as caused by the instability of the current international currencies and the world financial system due to the instability of the dollar.
3. The Outside Front of Marginalizing the Dollar Strategy

   In the outside front, the United States is clearly aware of the growing, worldwide movement of marginalizing the dollar. This will certainly encourage the United States to exploit any existing weaknesses or economic friction in order to slow down China's economic growth and its expanding global currency influence. As a currency policy tool, the exchange rate of the dollar has shown its dual effect. On one hand, depreciation of the dollar leads to a sharp rise in the trading price of the dollar-denominated commodities, such as oil and gold, forces countries from around the world to increase their demand for the dollar, triggers global inflation, and exploits people including the American people themselves. On the other hand, in order to avoid the dollar exchange rate to rise from the increased demand for the dollar, the US government increased the supply of the dollar through massive QEs, which not only reduce the fiscal deficit and valuation of foreign debts but also enables the government to devalue the dollar to achieve the relative appreciation of other currencies so as to realize comparative advantage of the weak currency in exports. To counter such uncertainties, China has maintained the stability of its exchange rate with the dollar and appropriate trade scale. For more details, please consult with (Wang 2012a, b).

Lemma For any positive definite symmetric matrix W and any constant $y > 0$, the following inequality holds true:

$$-y \int_{-y}^{0} \dot{x}^T(t+\xi) W \dot{x}(t+\xi) d\xi \leq \left(x^T(t) - x^T(t-y)\right) W (x(t) - x(t-y)) \quad (14.1)$$

Proof Because W is a positive definite symmetric matrix, there is $D > 0$ such that $W = D^T D$. Let $G = (\mathrm{g}_1, \ldots, \mathrm{g}_n) \in \mathrm{R}^n$, $\|G\| = 1$ be a constant vector G of length one. Then in the light of Cauchy inequality, we have

$$\begin{aligned} &\int_{-y}^{0} D\dot{x}(t+\xi)^T D\dot{x}(t+\xi) d\xi \int_{-y}^{0} G^T G d\xi \geq \left(\int_{-y}^{0} G^T D\dot{x}(t+\xi) d\xi\right) \\ &\left(\int_{-y}^{0} D\dot{x}(t+\xi)^T G d\xi\right) \end{aligned} \quad (14.2)$$

Therefore, we have

$$\begin{aligned} \int_{-y}^{0} \dot{x}^T(t+\xi) W \dot{x}(t+\xi) d\xi &\geq \frac{1}{y}\left(\int_{-y}^{0} G^T D\dot{x}(t+\xi) d\xi\right)\left(\int_{-y}^{0} D\dot{x}(t+\xi)^T G d\xi\right) \\ &= \frac{1}{y}\left(x^T(t) - x^T(t-y)\right)\left(D^T G \cdot G^T D\right)\left(x(t) - x(t-y)\right) \\ &= \frac{1}{y}\left(x^T(t) - x^T(t-y)\right) W (x(t) - x(t-y)). \end{aligned}$$

The Lemma is proven.

14.2 The Main Result

Considering the following situation with a general polynomial lag:

$$\begin{cases} \dot{x} = Ax(t) + \sum_{i=1}^{n} A_i x(t-h_i) + Bw(t) + B_1 u(t) & 3(\mathrm{a}) \\ z = Cx(t) + \sum_{i=1}^{n} C_i x(t-h_i) + Dw(t) + D_1 u(t) & 3(\mathrm{b}) \\ \quad x(t) = \varphi(t), t \in \left[-\bar{h}, 0\right] \end{cases} \tag{14.3}$$

Choose a V function as follows:

$$V = x^T P x + \sum_{i=1}^{m} \int_{t-h_i}^{t} x^T Q_i x dt + \sum_{i=1}^{m} \int_{t-h_i}^{t} (h_i - t + \xi)\dot{x}^T (hR_i)\dot{x}\, dt \tag{14.4}$$

Then we have the following result:

Theorem 14.1 If the decision matrix $M = M_1 + M_2 + M_3$ of system (14.3) satisfies $M_1 + M_2 + M_3 < 0$, then system (14.3) is stable.

Proof A stability condition of system (3) is that the eigenvalues of M are negative numbers. This condition of equivalence means that the decision matrix M must be negative definite, that is, $M = M_1 + M_2 + M_3 < 0$.

In fact, we can do the following symbolic calculation:

$$\begin{aligned} \dot{V}(t) = {} & \dot{x}^T(t)Px(t) + x^T(t)P\dot{x}(t) + \sum_{i=1}^{m} x^T(t)Q_i x(t) - \sum_{i=1}^{m} x^T(t-k_i)Q_i x(t-k_i) \\ & + \sum_{i=1}^{m} \dot{x}^T(t)\left(k_i^2 R_i\right)\dot{x}(t) - \sum_{i=1}^{m} \int_{t-k_i}^{t} \dot{x}^T(\xi)(k_i Q_i)\dot{x}(\xi)d\xi \end{aligned} \tag{14.5}$$

$$\begin{aligned} = {} & 2x^T(t)A^T P x(t) + 2\sum_{i=1}^{m} x^T(t-k_i)A_i^T P x(t) + 2W^T B^T P\dot{x}(t) + \sum_{i=1}^{m} x^T(t)Q_i x(t) \\ & - \sum_{i=1}^{m} x^T(t-k_i)Q_i(xt-k_i) + \sum_{i=1}^{m} \dot{x}^T(t)\left(k_i^2 R_i\right)\dot{x}(t) - \sum_{i=1}^{m} \int_{t-k_i}^{t} \dot{x}^T(\xi)(k_i Q_i)\dot{x}(\xi)d\xi \end{aligned}$$

Notice that

(a) $$\sum_{i=1}^{m} \dot{x}^T(t)\left(k_i^2 R_i\right)\dot{x}(t)$$

$$= \begin{pmatrix} x^T(t) & x^T(t-k_1) & \cdots & x^T(t-k_m) & W^T \end{pmatrix} \begin{pmatrix} A \\ A_2 \\ \vdots \\ A_m \\ B \end{pmatrix}$$

$$\left(\sum_{i=1}^{m} k_i^2 R_i\right) \begin{pmatrix} A^T & A_1^T & \cdots & A_m^T & W^T \end{pmatrix} \begin{pmatrix} x \\ x(t-h_1) \\ \vdots \\ x(t-h_m) \\ W \end{pmatrix}$$

$$= \begin{pmatrix} x^T(t) & x^T(t-k_1) & \cdots & x^T(t-k_m) & W^T \end{pmatrix} M_1 \begin{pmatrix} x \\ x(t-h_1) \\ \vdots \\ x(t-h_m) \\ W \end{pmatrix}$$

where

$$M_1 = \begin{pmatrix} A\left(\sum_{i=1}^{m} k_i^2 R_i\right)A^T & A\left(\sum_{i=1}^{m} k_i^2 R_i\right)A_1^T & \cdots & A\left(\sum_{i=1}^{m} k_i^2 R_i\right)A_m^T & A\left(\sum_{i=1}^{m} k_i^2 R_i\right)W^T \\ A_1\left(\sum_{i=1}^{m} k_i^2 R_i\right)A^T & A_1\left(\sum_{i=1}^{m} k_i^2 R_i\right)A_1^T & \cdots & A_1\left(\sum_{i=1}^{m} k_i^2 R_i\right)A_m^T & A_1\left(\sum_{i=1}^{m} k_i^2 R_i\right)W^T \\ \vdots & & \ddots & & \vdots \\ B\left(\sum_{i=1}^{m} k_i^2 R_i\right)A^T & B\left(\sum_{i=1}^{m} k_i^2 R_i\right)A_1^T & \cdots & B\left(\sum_{i=1}^{m} k_i^2 R_i\right)A_m^T & B\left(\sum_{i=1}^{m} k_i^2 R_i\right)W^T \end{pmatrix} \tag{14.6}$$

(b) $$\int_{t-k_i}^{t} \dot{x}^T(\xi)(k_i R_i)\dot{x}(\xi)d\xi \leq (x(t)-x(t-k_i))^T (k_i R_i)(x(t)-x(t-k_i))$$

$$-\sum_{i=1}^{m} \int_{t-k_i}^{t} \dot{x}^T(\xi)(k_i R_i)\dot{x}(\xi)d\xi \leq \begin{pmatrix} x^T(t) & x^T(t-k_1) & \cdots & x^T(t-k_m) & W^T \end{pmatrix} M_2 \begin{pmatrix} x(t) \\ x(t-h_1) \\ \vdots \\ x(t-h_m) \\ W \end{pmatrix}$$

where

$$M_2 = \begin{pmatrix} -R_1 & R_1 & \cdots & R_m & 0 \\ R_1 & -R_1 & \cdots & R_m & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R_m & R_m & R_m & -R_m & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{14.7}$$

By plugging Eqs. (14.6) and (14.7) into Eq. (14.5), we have

$$\dot{V}(t) = \begin{pmatrix} x^T(t) & x^T(t-k_1) & \cdots & x^T(t-k_m) & W^T \end{pmatrix} M \begin{pmatrix} x(t) \\ x(t-h_1) \\ \vdots \\ x(t-h_m) \\ W \end{pmatrix}$$

Because $M = M_1 + M_2 + M_3$,

$$M_3 = \begin{pmatrix} A^TP + PA + \sum_{i=1}^{m} Q_i & PA_1 & PA_2 & \cdots & PA_m & PB \\ A_1^TP & -Q_1 & 0 & \cdots & 0 & 0 \\ A_2^TP & & -Q_2 & \cdots & \vdots & \vdots \\ \vdots & 0 & & \ddots & \vdots & \vdots \\ A_m^TP & 0 & 0 & \cdots & -Q_m & 0 \\ B^TP & 0 & 0 & \cdots & 0 & 0 \end{pmatrix} \tag{14.8}$$

Now, the stability condition of the general system with polynomial lag is

$$M_1 + M_2 + M_3 < 0 \tag{14.9}$$

This ends the proof of Theorem 14.1.

14.3 A Case Analysis

As in Forrest et al. (2013a), we will continue to use the same symbol w to represent the vector $\begin{bmatrix} W_1 & W_2 & W_3 \end{bmatrix}^{\mathrm{T}}$ of categorized monetary policies $w_1, w_2 \ldots, w_n$, which are accordingly grouped into three categories as follows:

W_1 = the set of all those monetary policies that deal with the population meeting the minimum need to maintain the basic living standard

W_2 = the set of all those monetary policies that deal with the population's need for acquiring desired living conditions
W_3 = the set of all those monetary policies that deal with the population's need for enjoying luxurious living conditions

Similar to the concept of overall balance of international payments, we introduce an economic index vector $z = \begin{bmatrix} z_1 & z_2 & z_3 \end{bmatrix}^T$ such that z_i measures the state of the economic sector i, i = 1, 2, 3. When the purchasing power increases, people will purchase more assets and products from foreign countries, and the overall balance of international payments will decrease (foreign exchange expenditure increases); when the purchasing power decreases, people will sell more assets and products from the domestic country, and the overall balance of international payments will increase (foreign exchange revenue increases).

We established the systemic model (Eq. 14.3) with polynomial lag variables. In this systemic model, we will use the symbol Z to represent the state of the national economy and w_1, w_2, and w_3 to represent the positive and negative effects of the monetary policies on the performance of the economy directly or on the currency demand and supply to have an impact on the economy indirectly. Here $u(t)$ is a random vector with a none-zero mean. Due to the fact that economic development can be seen as a continuous process, the current change in the money stock is determined by the current monetary policies, money stock, and the previous money stock. And the current performance of the economy is also determined by the current monetary policies, money stock, and the previous money stock.

Here x is the 3×1 matrix $[D_1 - S_1\, D_2 - S_2\, D_3 - S_3]^T$ of the categorized difference of demand and supply of money, referred to as the three parts of the state of the economic system. Specifically, our systemic model divides the economy into three sectors, E_1, E_2, and E_3. Compared to sector E_2, which consists of such goods, services that are used by citizens to acquire desired living conditions, sector E_1 consists of living necessities. Sector E_3 consists of such goods, services that are used by the citizens for their enjoyment of luxurious living. Our systemic model of the national economy indicates that our separation of the economy into these three sectors can help properly manage the market reaction to the monetary policies. When the monetary policies have positive effect on the performance of the economy, people in every economic sector will purchase more assets and products with the increase of the purchasing power of their income (foreign exchange expenditure increases); when monetary policies have negative effect on the performance of the economy, people in every economic sector will sell more assets and products with the decrease of the purchasing power of their income (foreign exchange revenue increases).

We obtained the stability criterion $M_1 + M_2 + M_3 < 0$ (Eq. 14.9) for the general time-delay system based on the systemic model structure with the first-order lag. Let

$$A_i = \begin{bmatrix} A_1 & 0 & 0 \\ 0 & A_2 & 0 \\ 0 & 0 & A_3 \end{bmatrix}, B_i = \begin{bmatrix} B_1 & 0 & 0 \\ 0 & B_2 & 0 \\ 0 & 0 & B_3 \end{bmatrix},$$

$$C_i = \begin{bmatrix} C_1 & 0 & 0 \\ 0 & C_2 & 0 \\ 0 & 0 & C_3 \end{bmatrix}, D_i = \begin{bmatrix} D_1 & 0 & 0 \\ 0 & D_2 & 0 \\ 0 & 0 & D_3 \end{bmatrix}.$$

Because $A_iR_i = k_i$, $B_iR_i = Q_i$, and W are positive definite matrix, from Eqs. (14.6), (14.7), and (14.8), we have

$$M_1 = \begin{pmatrix} A\left(\sum_{i=1}^{3} k_i^2 R_i\right)A^T & A\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_1^T & A\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_2^T & A\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_3^T & A\left(\sum_{i=1}^{3} k_i^2 R_i\right)W^T \\ A_1\left(\sum_{i=1}^{3} k_i^2 R_i\right)A^T & A_1\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_1^T & A_1\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_2^T & A_1\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_3^T & A_1\left(\sum_{i=1}^{3} k_i^2 R_i\right)W^T \\ A_2\left(\sum_{i=1}^{3} k_i^2 R_i\right)A^T & A_2\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_1^T & A_2\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_2^T & A_2\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_3^T & A_2\left(\sum_{i=1}^{3} k_i^2 R_i\right)W^T \\ A_3\left(\sum_{i=1}^{3} k_i^2 R_i\right)A^T & A_3\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_1^T & A_3\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_2^T & A_3\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_3^T & A_3\left(\sum_{i=1}^{3} k_i^2 R_i\right)W^T \\ B\left(\sum_{i=1}^{3} k_i^2 R_i\right)A^T & B\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_1^T & B\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_2^T & B\left(\sum_{i=1}^{3} k_i^2 R_i\right)A_3^T & B\left(\sum_{i=1}^{3} k_i^2 R_i\right)W^T \end{pmatrix}$$

$$M_2 = \begin{pmatrix} -R_1 & R_1 & R_2 & R_3 & 0 \\ R_1 & -R_1 & R_2 & R_3 & 0 \\ R_2 & R_1 & -R_2 & R_3 & 0 \\ R_3 & R_3 & R_3 & -R_3 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$M_3 = \begin{pmatrix} A^TP + PA + \sum_{i=1}^{3} Q_i & PA_1 & PA_2 & PA_3 & PB \\ A_1^TP & -Q_1 & 0 & 0 & 0 \\ A_2^TP & 0 & -Q_2 & 0 & 0 \\ A_3^TP & 0 & 0 & -Q_3 & 0 \\ B^TP & 0 & 0 & 0 & 0 \end{pmatrix}.$$

So we can obtain an expression for $M_1 + M_2 + M_3$ explicitly. If the value of the sum is negative, then the systemic model above is stable.

To facilitate the detailed calculation, we only select a one-dimensional case for explanation so that the three sectors in (Forrest et al. 2013a) become one sector. By substituting the demand and supply of money, x is defined as an exchange rate. We will still use the same symbol w to represent the vector $[w_1\ w_2\ w_3]^T$ of categorized monetary policies. Equation (3a) in Eq. (14.3) indicates that the current exchange rate is not only determined by the current monetary policies but also by the previous monetary policies. In this chapter, our model established by empirical studies

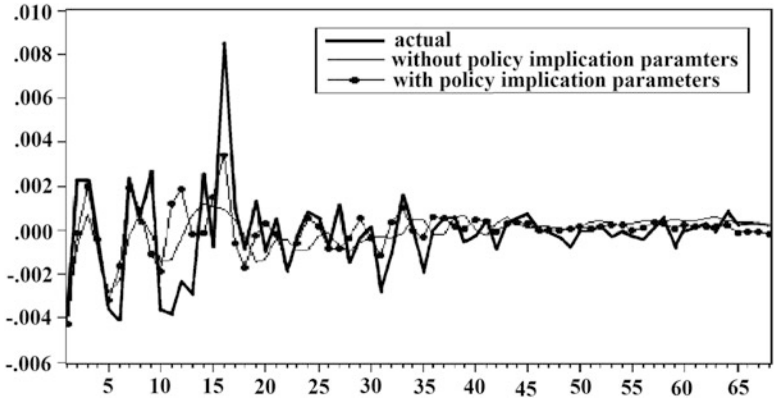

Fig. 14.1 Delayed effects of monetary policies (fitting after the second-order difference in 68 weeks from 2008 to 2010)

shows that when the financial crisis occurred (from 2008 to 2010), the government made the exchange rate of the RMB against the US dollar remaining at around 6.8 through the implementation of a series of effective policies and instruments. Based on the systemic model structure for the second-order lag, the fitting degree of the model that contains parameters for policy implications increases 16.8% from that of the model without any parameters for policy implications (for details, see Fig. 14.1). This result means the effectiveness of the policy parameters.

When we define Z as the overall balance of international payments, Equation (3b) in Eq. (14.3) indicates that the overall balance of international payments is determined by the current exchange rate and the previous exchange rates. The result also shows the fitting degree of model that contains parameters for policy implications is better than that of the model without any parameter for policy implications. The policy parameters are useful and necessary in the fitting process. We also know that Z is determined by the current exchange rate and the previous exchange rates directly and determined by the current monetary policies and the previous monetary policies indirectly. So the nature of the changing Z is determined by quantitative continuous-deferred monetary policies.

14.4 Implications of the Established Theory

In the internationalization process of a currency, the government policy becomes an extremely important factor. To this end, let us consider the policy implication process of some major currencies from around the world.

GBP: Britain was the first country in the history to build modern financial institutions that grew the fastest and developed with the most perfection. British national order passed a bill to establish a Bank of England in 1694 so that Britain became the first country in the world to have a central bank. From 1816 to 1819, the British government issued a series of regulations and policies about mint and exchange and implemented a true gold standard, which also made Britain the world's first to implement such a standard. From the Middle Ages to the nineteenth century when Britain became the "sun" empire, the British had dominated the world's finance. After World War I, in which the "dollar bloc" and "franc bloc" supplant, pound was no longer used as an international currency. After World War II, with the establishment of the Bretton Woods system, pound was degraded to a national currency. See Yu and Xie (2011) for relevant discussions.

USD: After a century of dormancy, with the establishment of the Bretton Woods system, the dollar rose as the world currency by replacing the throne of British pound in the world of finance. However, as of 1971, a deficit in the overall balance of payments of the United States, which had not been seen since 1893, emerged, and the gold reserve of the United States amounted to less than one-fifth of the foreign short-term liabilities. In order to potentially prevent various countries to exchange their holdings of the dollar into gold, President Nixon announced the New Economic Policy on August 15, 1971. Subsequently, the Nixon administration issued a series of policies and laws in order to save the crumbling of the Bretton Woods system; and the Group of Ten reached the Smithsonian Agreement in December 1971. However, all these efforts still failed to curb the selling wave of the dollar and the buying of gold and other currencies of the world. The Bretton Woods system completely collapsed in 1973. Since then, the German mark, French franc, Britain pound, and other currencies began to enter the international currency system. Even since, the dollar began to embark on its long downward spiral. See (Yu and Xie 2011) for more details.

JPY: After the Meiji Restoration, Japan established the Bank of Japan, the central bank of the country, in October 1882. Diverted to the gold standard in 1897, Japan became the Asian financial pacesetter. After World War I, Japan became the second only to the United States to dominate the Far East and the Pacific region. After the defeat in World War II, Japan was taken over by America's "Allied Command." Since then, Japan implemented a series of democratization reform measures, such as the formulation of a new constitution, the dissolution of the feudal zaibatsu, and land reform. As a result of the war on the Korean Peninsula as well as the Dodge Plan in June 1950, Japanese economy quickly recovered to prewar levels. In 1952, Japan recovered its sovereignty and joined the International Monetary Fund and the World Bank. However, the nationalization and free convertibility of the yen is not synchronized. Since the early 1970s, the yen has become an international currency, but Japan did not issued a decree to allow foreigners to issue bond in Japan until the mid-1970s. In the meanwhile, Japanese investment in foreign securities began to liberalize. During the time of 2013–2014, the proportion of Japanese yen traded in New York foreign exchange market was hovering around 23%. See (Lu and Zhu 2011) for more details.

Mark: After World War I, Germany became the country in the world that suffered the most from inflation; the record was 42 trillion German marks per dollar. Since the defeat in World War II, Germany has always stressed the independence of its central bank; and the German territories occupied by the Western followed the United States and established a two-stage system in order to avoid the government from manipulating the central bank. On July 26, 1957, the Federal German Parliament enacted the Bundesbank Act, making Bundesbank a unified central bank. As of this writing, Bundesbank has been the world's most independent central bank. After the 1973 collapse of the Bretton Woods system, the German decree introduced a floating exchange rate system. Since then, the German mark became the second largest international currency in the world only after the dollar of the United States. Before the euro was introduced, the German mark among all the countries of SDRs was ranked second in the constitution, and its share was stable at around 1/5. See (Yu and Xie 2011) for more details.

EUR: At the beginning, the euro was controversial. Based on the Eurozone's GDP, import and export volume when comparable to that of the United States, many European scholars held their widespread optimism that the euro will challenge the dollar with weight tilting on the side of the euro. But scholars of the United States held bearish view on the euro. For example, Paul A. Samuelson, a Nobel laureate in economics, thought that the European single currency is "stupid" and the solution is irrelevant for Europe (Samuelson 2000). Another Nobel laureate Paul R. Krugman also stressed that "the creation of (euro) currency is primarily a political project rather than an economic plan" (Frankel 2015). American speculator George Soros believed that after the implementation, the euro will soon disappear (Soros 2010). On January 4, 1999, the euro came into the world. Since then, the history seems to suggest that although the European Union has introduced a series of policies and regulations, the effectiveness of the policies has impacted the international community (Lu and Zhu 2011).

China is now the second largest economy and the largest exporter in the world. With its growing economy and deepening financial reform, its RMB has the ambition to become an international currency. However, the relevant internationalization will have to be a long process due to mainly the following three reasons:

The Chinese government deems Free Trade Agreements (FTAs) as a new platform to further open up the country to the outside world and speed up domestic reforms, an effective approach to integrate the country into the global economy and to strengthen economic cooperation with other economies, as well as particularly an important supplement to the multilateral trading system. Currently, China has 20 FTAs under construction, among which 12 agreements have already been signed and implemented. In the perceived, unified market, the RMB is aimed to eventually become a regional financial settlement instrument and commodity with the ongoing development of the multilateral economic cooperation. It is seen as a natural and regional monetary integration which will eliminate the cost of currency trading and the risk of exchange rate fluctuations and gradually expand the trading network and promote the economic cycle. Secondly, the internationalization of the RMB will provide favorable conditions for the development and implementation of China's economic policies. This factor has a strong appeal to the Chinese government. The internationalization of the RMB will enhance the autonomy of monetary policy in China and help China to get rid of problems that exist in developed countries, such as the "Mead dilemma" that to maintain external balance developing countries will have to sacrifice internal balance. This end will help China reduce the risk of economic instability and safeguard the national economic security, which is particularly important in the course of economic globalization. Finally, the internationalization of the RMB will help China to guard against financial crises (Xu 2014).

There are many institutional deficiencies in today's dollar-dominated international monetary system. For instance, the United States can freely print money. In the existing monetary system, the non-principal issuers of the global reserve currencies often face a large liquidity risk and the risk of fluctuations in prices. The regionalization and internationalization of the RMB will improve China's capacity of finance. When financial assets are priced (at least partially) in the RMB in the world markets, China would be able to decide prices and control risk to some extent. In the process of internationalization of the RMB, China must face two types of risks:

First, the liquidity risk. Because of the integration of the global finance, when the assets China holds are priced in a foreign currency, the government will have no means of control to provide liquidity as lender of the last resort. This risk is difficult to manage once the market becomes volatile. The assets and liabilities held by either the government or the citizens in the current account will lead a basic process of money creation. We believe that a contraction of the money supply indicates a greater liquidity problem. Even for those countries that have enough foreign exchange reserves, like China, trying to provide adequate liquidity within a brief moment of time will cause a huge impact on the asset markets and create a vicious cycle.

Secondly, the risk of price fluctuations under currency mismatch. Under the floating exchange rate regime, one has to face the risk of price fluctuations. However, if assets are denominated in the local currency, the risk of price fluctuations will to certain extent be reduced. The fact that the assets held by China are denominated in foreign currencies means that China has surrendered part of its power to regulate its financial market to some foreign governments. So, whether it is for the purpose for China to maintain the stability of its economy and the security of its financial assets or for the purpose for it to balance the stability of its international trades, it is important for China to accelerate the internationalization of its currency, the RMB.

The recent rise of emerging market economies provides a special opportunity for the internationalization of the RMB, because diversified international currency represents the interests of the majority of countries. Because of these particular circumstances, China enjoys many favorable conditions to promote the internationalization of its RMB.

First, China's comprehensive national strength has increased significantly. Its fast growing economy in the past decades has laid a firm foundation for people from around the world to use the RMB. Due to the introduction of prudent monetary policies, China has enjoyed favorable social reputation. For example, China has maintained the value of its RMB by curbing its domestic inflation. The RMB has played a notable role in combating the recent global financial crisis. The relatively stable exchange rate has also laid a solid, reliable foundation for promoting the internationalization of the RMB.

Secondly, it is the relatively liberal regime environment in China and improvement of the convertibility of the RMB. In China's neighboring countries and regions, the RMB has been employed in similar fashions as the dollar and other hard currencies that are relatively easy to acquire. In order to promote the RMB in cross-border trade settlements, some border provinces have developed innovative institutions. ASEAN Free Trade Area for overseas circulation of the RMB has provided a broad space for promoting the RMB. Under the premise of stable exchange rate with the RMB, some countries and regions, which trade and invest frequently or with large amounts with China, have been willing to accept the RMB as the denominated settlement currency. For example, in trades with Vietnam, Thailand, Myanmar, and other countries, the RMB has in fact become one of the monetary instruments for settlements (Wang 2012b).

Thirdly, Hong Kong, a recognized center of international finance, represents a unique advantage for China. In the process of internationalizing the RMB, Hong Kong can play and has played an important role. The city has a complete and mature legal system and perfect market infrastructure, and the HKMA (Hong Kong Monetary Authority) operates independently from the government. So Hong Kong can help with the implementation of the RMB's regionalization and provide useful experience for the Chinese central government. Before the Chinese financial market could become mature enough to handle the excessive volatility of the international financial market, the offshore RMB market in Hong Kong will play the role of "firewall" for the mainland. And, the financial supervisory system in Hong Kong can help the mainland government and currency authority to grasp market trends and to detect potential threats.

Although many favorable conditions exist, the regionalization of the RMB is still plagued with various internal and external difficulties.

First, the degree of regional economic integration affects the scale of the RMB's regionalization. In areas where trades and personnel exchanges happen frequently, especially in border areas, the RMB has seen greater liquidity and even enjoyed more popularity than the relevant national currencies. However, if a neighboring country did not reach any institutional arrangement with China, then the existing economic integration measures along the border between the two countries would not in general be extended to the whole region, where the regionalization of the RMB could only be confined to the border areas. In such areas, financial services are generally in short supply, and there would be no unified basis for the exchange rate of the RMB.

In some areas of Southeastern Asia that have liberalized trades and traded heavily with China, including CAFTA (China and ASEAN Free Trade Area), many countries suffer from their underdeveloped banking systems so that these countries have few financial institutions that handle the business of the RMB exchange. In addition, many of these countries do not have their official exchange rates for direct conversion of their local currencies into the RMB other than the black market. Also, the current security issues and conflicts in Northeastern and Southeastern Asia might very well place a damp on the internationalization of the RMB and affect the confidence for the RMB to be widely used in trade settlements and investments in the region.

Because of the constraints of these listed factors, the internationalization of the RMB will be a gradual and long-drawn-out process. That surely posts challenges for China's authorities to formulate and to implement wise currency policies. With the increase in capital liquidity and overseas business of Chinese commercial banks, the authorities better have an ability to predict, to manage, and to control risks.

14.5 Some Final Remarks

Each currency war represents a battle without involving gunpowder. During the fight, countries try to compete for acquiring biggest economic benefits mainly by adjusting the supply and value of their domestic money. Today, more than 100 countries have been actively or passively involved in currency wars. Although some countries can benefit from currency competitions in the short term, it is doubtful whether this benefit is sustainable. And one thing is for sure: most countries, especially those involuntarily involved in the wars, will suffer great economic and social unrest.

By taking the impact of capital account liberalization of China on international capital flow and economic and financial system as an entry point, this paper establishes a dynamic systemic model with lag variables and the stability condition of the dynamical system. Then, a one-dimensional case is developed to explain the significance of this work. Through the model we can know: Firstly, stability condition of the dynamical system shows monetary policy, and its subsequent effects can play an important role in the economic stability of the country under the free flow of capital, and this condition has certain warning effect; secondly, how monetary policy regulates the economy in the system; thirdly, the impact of monetary policy and its subsequent effects will play a decisive role in regulating economic equilibrium.

Based on what has been accomplished in this paper, we have the following important suggestions on defense solutions toward currency wars:

Firstly, it is comparatively limited in theory to study simply the dynamic systems model between two countries. Such study should be expanded to a much bigger dynamic system involving many mutually reciprocal feedback countries so that more convincing results with real policy effects can be established.

Secondly, the following is truly a quite complex problem: how can one improve the accuracy of assessing and quantifying the impact of different monetary policies on the economy? This problem and related issues need to be further investigated.

Part V
Clean Up Disastrous Aftermath Through Policies and Reforms

Chapter 15
Design Economic Policies Based on Various Performance Indicators

Jeffrey Yi-Lin Forrest, Yirong Ying, Zaiwu Gong, Huan Guo, Jinli Guo, and Stephen Larson

Contents

This chapter investigates when a large amount of capital flows suddenly to or away from a particular economy and how the consequent economic shocks can be minimized by employing feedback controls while the desirable economic growth can still be on track. By employing the method of the state and/or output feedbacks of control theory, this chapter explores how to practically design mechanisms based

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on the concepts of state and/or output feedbacks. In particular, this chapter presents a method of designing economically stabilizing strategies when the economic system suffers from external shocks by employing output feedback and Lyapunov feedback control.

Speaking socially, what is presented in this chapter implies that a disturbed economic system by outside forces could be stabilized if appropriate economic policies were designed and adopted. The value of this chapter lies on the fact, shown herein, that the disturbed economic system could be successfully stabilized if the policy maker could make the real parts of the eigenvalues of the unstable system all negative.

15.1 Introduction

When a large amount of money enters or withdraws from an economic system within a short period of time, various state variables of the economic system will experience drastic changes, causing significant shocks to the originally orderly operation of the economic system (Forrest et al. 2013a; Forrest 2014). These shocks create uncertainties in the previously established relationship between the state vector and the output vector of the economic system and pose major challenges for how all the participants of the economy could potentially handle the difficult aftermath. If we use $\varphi(t)$ to represent the interference or the shock, then for policy makers, a key question is, under the effect of the interference $\varphi(t)$, what kind of decision input $u(t)$ should be adopted so that the changes in the output $y(t)$ of the economic system would satisfy a certain pre-determined objective? For example, if a large amount of foreign capital enters or leaves an economic system within a short period of time, that is, the interference $\varphi(t)$ is known, then what kind of fiscal policy and/or monetary policy (i.e., the decision input $u(t)$) should be adopted by the government to accomplish the following objectives: maintain a stable price level and the gross domestic production still grows as originally expected, which are the economic system's output $y(t)$.

To materialize these objectives, it is a must to measure continuously the state vector and the output vector of the economic system in order to determine whether or not the actual values deviate from the target values. If a deviation does exist, the decision-makers will then need to adjust the control vector to make the deviation approach zero. It is like the situation that a ship sails in the ocean; no matter how the helmsman constantly adjusts the compass, there most likely is the phenomenon that the ship is deviating from the desired route (the control objective). Even for the best helmsman, he still cannot be assured that he would stay perfectly on the pre-determined course at any given moment of time. That is, because in its sailing, the ship experiences various interferences from the external environment, while the random disturbances constantly interfere with the result of control (applied on the ship) to approach the objective of the control.

An effective method for realizing these objectives is to make adjustments based on feedback (Granger 1963; Infante and Stein 1973; Norman 1974; Moe 1985; Hui 1991; Chong and Calderon 2000; Kiekintveld et al. 2004, Kirk 2012; Zhang et al. 2014). That is, by using the method of feedback to make necessary adjustments, we will be able to feed the deviation between the result of control, such as the "actual state" of the output of the system (e.g., the actual route of the ship), and the pre-determined objective of control, such as the "ideal state" (e.g., the pre-determined route), back into the input of the controlled system as the basis for applying the next level of adjustment. Such a system with feedback is referred to as a closed control system. This kind of thinking is known as feedback control. To this end, Chong and Calderon (2000) is a good example on how a similar idea has been successfully employed in the study of economic systems.

In the feedback process, because not all of the state variables are observable, such as most of the activities in the underground economy (Tanzi 1999; Schneider and Klinglmair 2004; Schneider and Enste 2013; Schneider et al. 2015), that is, it is often the case that the state vector is only partially observable, some of the state variables due to their unknown values cannot be used in feedback control. Because of this problem, a natural question arises: can we construct a system so that the state vector of this constructed system is (roughly) equal to that of the actual system and that the state vector of the constructed system is completely observable? If such a system can be constructed, we can use the output vector of the constructed system as estimate of the state vector of the actual system so that the estimate can be employed as the input of the feedback control. In other words, can we construct based on the input and output of the actual system an observer whose output can restructure the state of the original system? We will consider how to construct such a system as an approximation of the actual system so that we can provide a needed input for the state feedback control.

In the process of controlling a system, sometimes it is not enough for us to just require the output $y(t)$ to approach the target value. Beyond this requirement, it also often requires the process of approaching the target value experience fewer ups and downs and less fluctuation. That is, the control strategy that is designed for adoption must have relatively good characteristics. In other words, we might like to define various different objectives for the system control. As a matter of fact, no matter whether it is about maintaining the stability (Shen and Zheng 2015) of the economy, as seen as a system, performing at a certain desirable level, or the tracking control (Nguyen and Krylov 2015) that tracks a certain mobile and dynamic target of the actual system, the essence is about how to resist the interference of various factors of the external environment and how to reduce or eliminate the occasional deviation between the actual output of the controlled system and desired pre-determined targets so that the performance of the system reaches the expected objective of control. Hence, this chapter will mainly discuss the feedback control and method of adjustment of economic systems in order to develop practically operational methods to effectively counter the shocks on the economic system as caused by external interferences.

As a continuation of Chap. 3, this chapter is organized as follows: Sect. 15.2 studies two kinds of feedback mechanisms: the state feedback and the output feedback. Section 15.3 looks at how one can specifically design feedback controls. Section 15.4 shows that all the results obtained for continuous variables are also held true for discrete time series data. Then, Sect. 15.5 concludes the presentation.

15.2 Economic Indicator Feedback and Performance Feedback

15.2.1 Formulation of the Feedback Problem

In the healthy development of economy, industrial production and daily lives require certain physical quantities to be maintained with some range or to be equal to some fixed values. For example, in the economic development, we require the inflation to be appropriate, the unemployment rate to stay at a certain level, and the exchange rates of the exchange market to be in par with the domestic interest rate. For the cases of a chemical plant and a power plant, we tend to require the set-point control for pressures, temperatures, and flows. For homes, we tend to require the indoor temperature and humidity to be constant.

For some other circumstances, we may very well require the behavior of the controlled economic system to adjust itself according to the changes that appear in the input. For example, when the main currencies of the world depreciate against the US dollar on the foreign exchange markets, a nation may very well need to react in a certain way in order to keep its domestic economy healthy; when the economy overheats, new monetary policies may very well need to be adopted, etc. In fact, the feedback of the information of either how the state of the controlled system changes or how the output varies is the key for realizing the afore-described control problem.

However, the control process of any economic system cannot be seen as a simple process of delivering information from the controlling system (the manipulating entity or the policy maker) to the controlled economic system (the implementing entity). It is because the controlled system, on one hand, has to be manipulated by the informational input from the controlling system and, on the other hand, constantly experiences various random disturbances from the outside world (Lin 2008). The effect of the random disturbances relentlessly interrupts the transfer of commands from the controlling system and constantly interferes with the results of control of the controlled system from approaching the target objectives.

By applying the method of feedback adjustments, we can effectively handle various interfering factors of the environment. Utilizing this method to make adjustment can feed the deviation between the result of control, the "actual state" of the controlled system's output, such as the unemployment rate, inflation, etc., of the economic system, and the expected objective of control, the "ideal state," such as the targeted unemployment rate, the desired rate of inflation, etc., back into the controlled system as input and as the basis to design and to modify the control strategy of the next step. Such feedback mechanism represents a kind of closed-loop control over economic systems.

15.2.2 Classification of Feedbacks

When applying a feedback control, there are different ways to choose, as reference, the feedback input information. For example, we can employ the information of the state vector of the economic system as our feedback input, while we can also select the information of the system's output vector as our feedback input. Hence, a natural question that arises at this junction is how can we select the information for feedback input based on the characteristics of the economic system? Additionally, because both observability and controllability are important characteristics of the controlled system, would applying a feedback control alter the system's observability and controllability? In this chapter, we will focus on the discussion of these problems.

Let us consider the following constant coefficient linear representation of an economic system:

$$\begin{cases} \dfrac{dx}{dt} = Ax + Bu \\ y = Cx \end{cases} \tag{15.1}$$

Theoretically, the state of an economic system at time t is completely describable by all relevant economic factor variables (Zhang and Zhang 1981), where the totality of the variables is referred to as the state of the system with the state space determined by the permissible values of the variables. The literature in economics and finance indicates that this state is finite dimensional (Forrest et al. 2013a, b; Myoken 1979), although the dimensionality could potentially be very high. Additionally, the state of the economic system is affected constantly by human decisions, such as monetary and fiscal policies, which shape the state of the economy of the next time moment (Westcott 1977) so that in theory, these policies can be treated as input variables that regulate the economic system. In general, the development of the economic system can be described as in Eq. (15.1) except that the right-hand sides of the equations are, respectively, $f(x, u, t)$ and $g(x, u, t)$, where f and g can be either linear or nonlinear; for details, see Chap. 3.

Because currently there is no general method that can universally deal with nonlinear systems, such systems still cannot be handled with satisfaction. However, through using nonlinear state transformations and nonlinear state feedbacks, a nonlinear control system can be likely transformed into one with linear state equation and linear output equation (Shilnikov et al. 1998) so that a linear differential relationship between the output $y(t)$ and the input $u(t)$ is established. Then, methods of linear control can be employed to construct regulation schemes to adjust the performance of the economic system (Westcott 1977). Practically, monetary and fiscal policies are generally introduced for short-term purposes. So, any

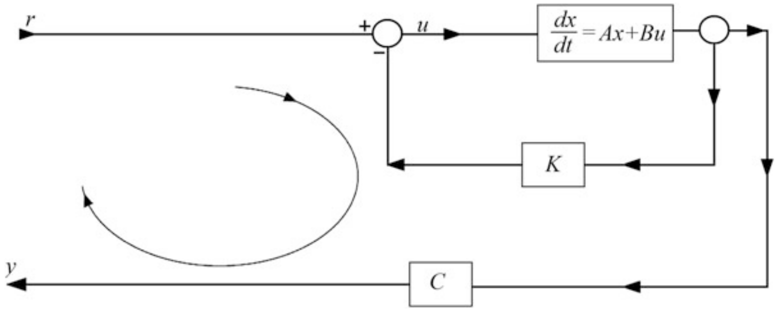

Fig. 15.1 The control system of state feedback

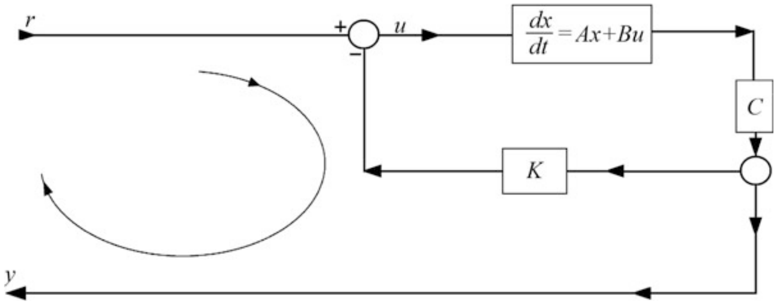

Fig. 15.2 The control system of output feedback

nonlinear control representation of the economic system can be adequately approximated by linear models for the short time window of concern through using series expansion of mathematics, where the omitted nonlinear terms can be summed up into a random error with mean 0. That is, the linear system in Eq. (15.1) can approximately represent the state of the economic system at time t when mathematical expectations are concerned. As for how such a linear approximation of the economic system can be identified, we will leave it to a future report to address in order not to make this chapter too long.

When the input is

$$u(t) = r(t) - Kx(t), \tag{15.2}$$

we obtain a state feedback control, which is depicted in Fig. 15.1. Intuitively speaking, within the overall spin field of the economy, there is a localized whirlpool, which first forms a regional system and then contributes to the operation of the overall system.

When the input is

$$u(t) = r(t) - Ky(t), \tag{15.3}$$

we obtain an output feedback control, which is depicted in Fig. 15.2, where the function $r(t)$ is the reference input of the system and K is known as the gain matrix of the feedback. In this case, the system's overall output is simultaneously used by regional whirlpools within the economic system.

The main reason why we might have to consider using output feedback is because it is very possible that many aspects of the state of the economic system are not observable to the policy maker. In this case, instead of using a state feedback mechanism, we might look at using an output feedback mechanism. To this end, let us look at the following illustration, where what is shown is how some well-known indices might contain aspects of the economy that are not observable.

The consumer price index (CPI) has been designed and employed to reflect within a period of time the trend and degree of change of the price levels of consumer goods and services. It is an index calculated based on the changing prices of some products and labor that are closely related to daily living of the residents. The rate of change in CPI more or less represents the level of inflation or deflation. It is generally employed as an important indicator of inflation. The relationship between the CPI index and inflation can be described roughly as follows: when CPI increases more than 3%, there is a recognizable inflation; when CPI rises more than 5%, the economy is referred to as being in a serious inflation. So, CPI is an important index considered not only for introducing and adopting major economic and financial policies but also for investment decisions and adjustment decision for deposit and lending rates. It is also an important indicator on whether or not a national macroeconomic policy is effective. For example, when a nation thinks about whether to adopt tightening or expansionary fiscal and monetary policies, it first looks at the magnitude of CPI. At the same time, the magnitude of CPI directly influences the issuance and strength of the nation's macroeconomic control measures, such as those of whether or not the bank rates should be adjusted, whether or not the rate of reserves needs to be varied, etc. Additionally, the level of the CPI also indirectly affects the financial markets, such as the stock market, commodity market, capital market, etc.

Generally, the CPI is calculated as follows: firstly, select the representative products; secondly, determine the geographic survey locations; thirdly, directly collect the necessary prices; and lastly, determine the weights for all the surveyed consumer products and services and compute the final CPI value with some possible adjustments.

As an important index critically employed to examine the state of the domestic economy and heavily relied on for making macroeconomic adjustment policies, if the CPI deviates greatly from the actual figure, it would then inevitably cause great impacts on the national macroeconomic control while adversely interferes the operation of the domestic economy. However, such important variables for investment returns as the expected deviation in the CPI, the expected economic growth, etc. represent some of the macroeconomic factors that are not observable. In fact, the compilation of the CPI uses a fixed basket of products as the basis for price collection. However, the consumer goods of our modern time evolve rapidly; the consumption shares of the goods in the basket accordingly change with time, which weakens the representation power of the basket. Additionally, there have naturally been great differences in the consumption habits and structures between different classes of incomes and different geographic regions. So, using a fixed basket of goods can hardly represent the common consumption characteristics of all income levels and geographic areas. In other words, it is inevitable for the CPI to contain various deviations from the reality it intends to represent. On the other hand, any adjustment in the weight composite used in the calculation of the CPI can affect the result of the relevant computations. Along with the changes in income, the consumption structure evolves rapidly. For example, increasing incomes, changes in consumption preferences, and even adjustments in income allocations can affect the spending structure so that the weights of different goods change constantly in people's consumptions. It is often the case that these changes are not instantaneously reflected in the calculation of the CPI.

However, as a leading indicator of the macroscopic economy, the CPI has played the role of early warming in practical production and economic activities and is known as the barometer of macroeconomic activities. Other than the aforementioned non-observabilities of the expected deviation of the CPI, the expected economic growth, etc., such economic indices as the scale of the shadow economy, the scale of the shadow banking system, etc. are also not observable. Therefore, we need to employ certain methods to materialize the prediction and estimation of these non-observable macroeconomic variables so that the parameters of the consequent economic systems models can more accurately reflect the true state of development of the economy. To this end, the output feedback is one of those methods that can be relatively readily employed.

When the state feedback in Eq. (15.2) is employed, the state equation of the closed-loop system is

$$\frac{dx}{dt} = (A - BK)x + Br \tag{15.4}$$

Here, we should note particularly that CPI can at most be a part of the state x, because many economic variables affect the predictive power and control of CPI. For example, Altimari (2001) finds that the total amount of money and credit can effectively predict the future inflation; Rüffer and Stracca (2006) make use of the scale of international liquidity surplus as an effective indicator for inflation pressure; Furlong and Ingenito (1996) recognize that the factory price of industrial products is a leading indicator for inflation; Kyrtsou and Labys (2006) find that changes in producer price index (PPI) lead to changes in CPI and affect the entire domestic economy. Stock returns, changes in the difference between short- and long-term interest rates, fluctuations of the food and energy commodity markets, etc. can all influence CPI (Qi and Li 2013). On the other hand, the amount of credit, industrial prices, PPI, energy prices, and other factors are impacted by government interventions. The consequence of such interventions will be reflected in the values of CPI. So, when Eq. (15.1) is employed to model an economic system, the state x represents all variables that affect either parts of CPI or different aspects of the economy, r the control measures that could exert effects on these variables through using whatever means, such as fiscal/monetary policies, and y the output of the system. Such a model establishes an association between the state and the performance of the economy and the policies employed. So, studies of such a model can be potentially employed to estimate and forecast the movement of CPI; for example, Ghysels et al. (2006) model the dynamics of CPI by using monthly macro variables and daily financial market indices, and Monteforte and Moretti (2013) predict the Eurozone inflation by employing mixed frequency data sampling models.

As a matter of fact, for an arbitrarily chosen economic system, if some of its state variables cannot be observed constantly, we cannot use the state feedback. In this case, we can consider employing the output of the system as the feedback information, that is, we employ the output feedback. Applying the output feedback in Eq. (15.3) provides the following state equation of the resultant closed-loop system:

$$\frac{dx}{dt} = (A - BKC)x + Br \tag{15.5}$$

If we know the state $x(t_0)$ of the economic system at the initial time moment t_0, and we can select an appropriate control variable (input) within a bounded time interval $[t_0, t_f]$, such as certain monetary or fiscal policies, to make the economic system to reach the expected state $x(t_f)$ at time t_f, then we say that the economic system is controllable at time moment t_0. For the linear constant coefficient system in Eq. (15.1), if any of its state is controllable, then we say that the economic system is completely controllable or $(A\,, B)$ controllable for short. For this situation, we have the following established result (Perko 2013). To make this presentation self-contained, a version of the proof is also given.

Theorem 15.1 Applying any state feedback does not affect the controllability of the system. That is, (A, B) controllability is equivalent to $(A - BK, B)$ controllability.

Proof Employing the following relationship

$$[\lambda I - (A - BK) \vdots B] = [\lambda I - A \vdots B]\begin{bmatrix} I_n & 0 \\ K & I_m \end{bmatrix}$$

and the fact that for any matrix K with m rows and n columns, the matrix

$$\begin{bmatrix} I_n & 0 \\ K & I_m \end{bmatrix}$$

is always of full rank, and because the multiplication of a matrix with a full rank matrix does not change of the rank of the former matrix, we have the following equation:

$$\operatorname{rank}[\lambda I - (A - BK) \vdots B] = \operatorname{rank}[\lambda I - A \vdots B]$$

for any λ. Therefore, we conclude that (A, B) controllability is equivalent to $(A - BK, B)$ controllability. QED

Assume that the input of the system in Eq. (15.1) is zero. If for any given initial state x_0, there is a finite time moment $t_1 > t_0$ such that the output $y(t)$ on the time interval $[t_0, t_1]$ can be used to determine the initial state x_0, then we say that this economic system is completely observable or (C, A) observable for short. Then similar to the previous result, the following (Perko 2013) holds:

Theorem 15.2 Applying output feedback does not affect the economic system's observability.

What Theorems 15.1 and 15.2 say is that no matter what kind of feedback mechanism exists in the economic system, the controllability and observability of the system are not affected. In other words, these results guarantee that as long as monetary or fiscal policies are internally introduced to the economy to counter various interfering factors, the over-arching properties of the economy are not altered.

Example 15.1 Assume that the control-theory representation of an economic system is given as follows:

$$\begin{cases} \dfrac{dx}{dt} = \begin{bmatrix} 0 & 1 \\ -3 & -4 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u \\ y = [1 \quad -1]x \end{cases}$$

Then it is ready to show that this economic system is controllable and observable. By applying the following state feedback to this economic system

$$x = r - [k_1 \quad k_2]x$$

we obtain the following closed-loop system:

$$\begin{cases} \dfrac{dx}{dt} = \begin{bmatrix} 0 & 1 \\ -3 - k_1 & -4 - k_2 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} r \\ y = [1 \quad -1]x \end{cases}$$

For this new system, the controllability matrix U and the observability matrix V are, respectively,

$$U = \begin{bmatrix} 0 & 1 \\ 1 & -4 - k_2 \end{bmatrix} \text{ and } V = \begin{bmatrix} 1 & -1 \\ 3 + k_1 & 5 + k_2 \end{bmatrix}.$$

Evidently, for any k_1 and k_2, the closed-loop system is completely controllable. And only when $k_1 + k_2 \neq -8$, the rank of V is 2 and the closed-loop system is completely observable. This fact implies that state feedback affects the observability of the system.

15.3 Design Feedback Control by Using Lyapunov Method

The purpose of employing feedback control is to make the economic system of concern reach our pre-determined target. For example, based on employment and inflation data, appropriate monetary policies are introduced so that the growth of the economy can be kept at a certain desirable level (Orphanides 2001, 2004; Dosi et al. 2015; Reifschneider et al. 2015; Li et al. 2015a). However, different mechanisms of feedback control can make the output of the economy take different forms. In some cases, the outputs gradually approach the expected output values, while in some other cases, the outputs fluctuate around the expected values or move further and further away from the expected values without materializing the purpose of control (Arnason et al. 2004; Colander et al. 2009; Helbing 2012). So, some natural questions that appear at this junction are: Why do we have these different results? What determines the characteristics of feedback control of the economy? What kind of feedback control should be employed to materialize our pre-determined objective of control? As a matter fact, the 1997 financial crisis that originated in Thailand is a real-life example of how a particular feedback control could cause large swings of the economic system and make the controlled system eventually move further and further away from the expected objective, controlling the crisis (Lauridsen 1998; Phongpaichit and Baker 2000; Laird 2000).

During the time period from 1971 to 1991, the Thai economy on the average grew 7.9% annually. And during the time period from 1991 to 1996, the average annual growth rate reached 8%. Such sustained growth rates that were higher than the average growth rate of the world economy made Thailand be recognized as the "fifth tiger" after the "four tigers" of Asia. Additionally, because the inflation of Thailand was effectively controlled within the range of 3–6% for a long period of time, the nation's domestic economic development and accomplishment had been widely acknowledged.

However, in the year of 1997, a financial crisis broke out in Thailand. In early February 1997, international speculators started to massively sell Thai baht, causing the exchange rate of Thai baht to fluctuate majorly. They began by borrowing several month distant Thai baht contracts for as much as around US$15 billion from Thai banks and then massively sold out the contracts in the spot market, placing the exchange rate of Thai baht under greater pressure to fluctuate and causing earthquakes in the financial market of Thailand. To defend Thai baht, the central bank of Thailand mobilized as much as US$2 billion in the month of February to calm the market. On March 4, the central bank of Thailand required the nine financial companies and one housing loan corporation that suffered from problems of cash flow to increase their capital by the amount of 8.25 billion Thai baht (= US$0.317 billion) and demanded banks and other financial institutions to increase their rate of reserves for bad loans 100% to somewhere between 115% and 120%. This latter requirement made the financial system increase its reserves by the amount of 50 billion Thai baht (= US$1.94 billion). The purpose of these new requirements from the central bank of Thailand was to strengthen the stability of the financial system and to boost the confidence of the financial market. However, unfortunately, these requirements not only did not play out their stabilizing role but also helped to drop the confidence of the public on the financial institutions, leading to bank runs. On the 2 days of the fifth and the sixth, investors transferred nearly 15 billion Thai baht (roughly US$0.577 billion) out of ten financial companies that were experiencing difficulties. At the same time, investors massively sold out the stocks of banks and financial companies, causing the Thai stock market to fall continuously and increasing pressure on the foreign exchanges. With the vigorous intervention of the central bank of Thailand, the Thai stock and foreign exchange markets were stabilized temporarily.

Entering the month of May, on May 7, currency speculators quietly established positions between the foreign exchange contracts of the spot month and distant months through oversea banks that handled offshore businesses. Starting on May 8, creating difficulties in the financial markets by borrowing Thai baht from local banks in Thailand, that is, selling short large amounts of spot month and distant month contracts on the futures market, that caused the spot month exchange rate of Thai baht to drop drastically and broke through the fluctuation limit of the exchange rate multiple times, established by the central bank of Thailand. That led to a panic in the financial markets, causing domestic banks and business enterprises and foreign banks to sell short spot month Thai baht and buy long the US dollars or distant months Thai baht vs US dollar hedge trades. That made the financial markets of Thailand further deteriorated, once depreciating Thai baht against the US dollar to the level of 26.94:1.

Facing this round of shocks, the central bank of Thailand interfered its financial markets with increasing strength by mobilizing around US$5 billion of its foreign reserves, which gained various kinds of supports from the central banks of Japan, Singapore, Hong Kong, Malaysia, Philippines, Indonesia, and others. At the same time, the central bank of Thailand also raised the interest rate of offshore borrowing to 1000% in order to make the cost of speculating Thai baht extremely high, while placing a ban for Thai banks to lend out Thai baht. With the interference of a series of intervention measures, the exchange rate of Thai baht was stabilized and the central bank of Thailand regained the control of the situation temporarily. In late June, the Thai treasurer resigned, which once again caused financial markets to expect a forthcoming depreciation of Thai baht. That led to a major fall of the exchange rate of Thai baht to the level of about 28 Thai baht for each 1 US dollar. The Thai stock market also fell to 461.32, the lowest in the past 8 years, from 1200 reached at the beginning of the year. The financial market of Thailand was in chaos. On July 2, the central bank of Thailand suddenly announced its decision to give up the 14-year-old exchange rate policy of pegging Thai baht to the US dollar. Instead, it would start using a managed floating exchange rate system. At the same time, the central bank also announced that it would increase the interest rate from 10.5% to 12.5%. With the announcement of the news, Thai baht fell another 17%, reaching a new low. So, the financial crisis of Thailand broke out officially.

The financial crisis caused by the depreciation of Thai baht severely damaged the Thai economic development, causing the prices of goods to rise constantly, the interest rate to stay at a high level, the debts of businesses increased, capital flows tightened, business environment extremely difficult, the stock market fell majorly, and the economy dwindled. The Thai GDP growth rate in 1997 dropped to about 2% from the previous 7% in 1996.

As a matter of fact, in the feedback control of the economy, the output result approaches the target value only conditionally. If the mechanism of the feedback suffers from problem(s), such phenomena as imbalance or fluctuation in the development of the economic system could occur. The so-called imbalance here generally appears when the feedback is insufficient, where no matter how the system is adjusted, the performance of the system still stays in an erroneous state that is far away from the expected target of control. As for the financial crisis in Thailand, the failure of preventing the worst from happening was closely related to not only how the policies were implemented but also the relevant problems existing in the economic development of Thailand. That is, that financial crisis stands for a systemic imbalance of the economic system itself. The so-called fluctuation generally means the phenomenon that the output of the economic system fluctuates around the target value as the feedback is employed excessively or with a delay. Such phenomena are commonly experienced in our ordinarily lives. For example, when we just begin learning how to ride a bicycle, we have to go through a period of swinging left and right. What is causing the problem? It is not because as the beginner, we did not apply feedback control. Instead, our feedback control either comes a little too late or is applied with too much force. Anybody who has an experience with taking a shower would know that if at the beginning of the shower the cold water is too cold, he would then turn on the hot water supply (that is a negative feedback). However, because there is always a time delay between when the hot water is turned on to when the mixture of cold and hot water reaches a new equilibrium, there often appears the situation that the hot water supply is turned on too much so that the shower is too hot, then the consequent adjustment of the hot water supply makes the shower too cold again. That is, the temperature of the shower fluctuates up and down for a while until it reaches the desired level. In other words, the previous problem is also the stability problem of feedback control of the economy, especially the output feedback.

The purpose of output feedback is first to make the closed loop of the economy to become a stable system and then to further improve the performance of the closed-loop economy. In other words, if the economic system used to be situated in a state of equilibrium and then it is forced to deviate from the state by an external interference from the environment, can the system eliminate the interference and return to its state of equilibrium? That is the so-called problem of system's stability.

15.3.1 Lyapunov Stability

The concept of stability of the control systems of differential equations has been well studied in the relevant textbooks of differential equations (Coddington and Levinson 1955; Perko 2013). For constant coefficient linear system

$$\frac{dx}{dt} = Ax, x(0) = x_0 \tag{15.6}$$

let us use $\phi(t; x_0, 0)$ to represent the state trajectory of the system whose initial state is $x(0) = x_0$ at the initial time moment 0. If

$$\lim_{t \to \infty} \| \phi(t; x_0, 0) \| = \infty,$$

then we say that the initial state x_0 is not stable or unstable. When the system in Eq. (15.6) does not have any unstable initial state, then we say the system is stable. In particular, when

$$\lim_{t \to \infty} \| \phi(t; x_0, 0) \| = 0$$

holds true for any $x_0 \in R^n$, then we say that the system in Eq. (15.6) is asymptotically stable. Because for the real-life economic system of our concern what is important is the concept of asymptotical stability, we will refer the economy's asymptotical stability as economic stability, or we will simply say that A is a stable matrix.

For constant coefficient linear systems, we have the following well-known result (Perko 2013):

Theorem 15.3 For the constant coefficient linear system in Eq. (15.6), the following results hold true:

1. If all eigenvalue of A have negative real parts, then the system is asymptotically stable.
2. If A has an eigenvalue such that its real part is positive, then the system is unstable.
3. If the real parts of all eigenvalues of A are nonpositive and all the eigenvalues with real part 0 are not roots of the minimal polynomial of A of multiplicity >1, then the system is stable while not asymptotically stable.
4. If A does have such an eigenvalue whose real part is 0 and it is a root of A's minimal polynomial of multiplicity k, $k > 1$, then the system is unstable.

As for the stability of nonlinear systems, we can employ the concept of Lyaponov stability. Assume that $x(t)$ stands for the trajectory of the system. If there is a function $V(x)$ such that it has continuous first-order derivative with respect to x, satisfying $V(0) = 0$, for all $x \neq 0$, $V(x) > 0$, and $\frac{dV}{dt} \leq 0$, then the function $V(x)$ is known as a Lyapunov function of the system.

The so-called Lyapunov second method of analyzing a system's stability is to employ Lyapunov functions to investigate the stability of the system. This method is applicable to the study of general systems. For our purpose, we will only list several relevant results. Their proofs can be found in most of the textbooks on differential equations.

Theorem 15.4 Assume that $x = 0$ is a state of equilibrium of the system. If the system has a Lyapunov function, then the state of equilibrium $x = 0$ is stable.

Theorem 15.5 Assume that $x = 0$ is a state of equilibrium of the system. If the system has a Lyapunov function $V(x)$, satisfying $\frac{dV}{dt} \leq 0$, then the state of equilibrium $x = 0$ is asymptotically stable.

Theorem 15.6 Assume that $x = 0$ is a state of equilibrium of the system. If the system has a continuously differentiable Lyapunov function $V(x)$ such that $V(0) = 0$ and for any neighborhood of $x = 0$ there is $x^* \neq 0$ such that $V(x^*) < 0$ and $\frac{dV}{dt} \leq 0$, then the state of equilibrium $x = 0$ of the system is not asymptotically stable. If $\frac{dV}{dt} < 0$, then the state of equilibrium is not stable.

If we apply the Lyapunov second method to the linear system in Eq. (15.6), we have the following (Perko 2013). Once again, to make this presentation self-contained, a version of the proof is given.

Theorem 15.7 A sufficient and necessary condition for the constant coefficient linear system in Eq. (15.6) to be asymptotically stable is that for any chosen symmetrical positive definite matrix Q, the following matrix equation

$$A^T P + PA = -Q \tag{15.7}$$

has a unique solution and P is also positive definite. Eq. (15.7) is known as the Lyapunov equation.

Proof Sufficiency. Assume that for any chosen symmetrical positive definite matrix Q, Eq. (15.7) has a unique positive definite solution P. Let $V(x) = x^T P x$. Then it is ready to see that $V(x)$ is a positive definite function and satisfies

$$\begin{aligned}\frac{dV}{dt} &= \frac{dx^T}{dt} Px + x^T P \frac{dx}{dt} \\ &= x^T A^T P x + x^T P A x \\ &= x^T \left(A^T P + PA\right) x \\ &= x^T (-Q) x < 0\end{aligned}$$

From Theorem 15.5, it follows that the state of equilibrium $x = 0$ of the system in Eq. (15.6) is asymptotically stable. That is, the system in Eq. (15.6) is asymptotically stable.

Necessity. Assume that the system in Eq. (15.6) is asymptotically stable. Then all the eigenvalues of A have negative real parts, and for any two eigenvalues λ_i and λ_j of A, we have $\lambda_i + \lambda_j \neq 0$. That is exactly one of the sufficient and necessary conditions for the matrix equation in Eq. (15.7) to have a unique solution. Additionally, because

$$A^T P^T + P^T A = (PA)^T + \left(A^T P\right)^T = \left(PA + A^T P\right)^T = -Q^T = -Q$$

P^T is also a solution of Eq. (15.7). So, the uniqueness of solutions guarantees that $P^T = P$. That is, Eq. (15.7) has a unique symmetrical matrix solution P. In the following we show that for any $Q > 0$, P has to be a positive definite matrix.

Let $V(x) = x^T P x$. Then we have

$$\frac{dV}{dt} = x^T \left(A^T P + PA\right) x = -x^T Q x < 0$$

Let us first prove that P is semi-positive definite. By contradiction, if P is not semi-positive definite, that is, $V(x)$ is not semi-positive definite, then there is $x^* \neq 0$ such that $V(x^*) = x*^T P x^* < 0$. So, from Theorem 15.6 it follows that the system in Eq. (15.6) is not asymptotically stable. That is a contradiction. Therefore, P has to be semi-positive definite.

Next, we further show that P is positive definite. If P is not positive definite, that is, $V(x)$ is not positive definite, then for any neighborhood of $x = 0$, there must be $x^* \neq 0$ such that $V(x^*) = x*^T P x^* = 0$.

Assume that the trajectory of the system in Eq. (15.6) with x^* as the initial state is $x(t)$. Then there is t' such that $0 \leq t \leq t'$ and $x(t) \neq 0$. So, we have

$$\frac{dV(x(t))}{dt} = -x^T Q x < 0.$$

Therefore, $V(x) < V(x^*) = 0$. That contradicts with the fact that $V(x)$ is semi-positive definite. So, we have shown that P is positive definite. By combining what has been shown, we have proved that the Lyapunov equation in Eq. (15.7) has a unique positive definite solution. QED

Sometimes, we require not only that the economic system of our concern be stable but also that the real parts of all the eigenvalues of the matrix A be smaller than $-\sigma$, where σ is a fixed positive number. By applying Theorem 15.7 directly, we have Perko (2013).

Theorem 15.8 A sufficient and necessary condition for the real parts of all the poles of the constant coefficient linear system in (15.6) to be less than $-\sigma$, for a fixed positive number σ, is that there is a positive definite matrix Q such that the following matrix equation

$$A^T P + PA + 2\sigma P = -Q \tag{15.8}$$

has a unique positive definite solution.

The statement that the real parts of all the eigenvalues of matrix A are less than $-\sigma$ is equivalent to the statement that the real parts of all the eigenvalues of the matrix $A + \sigma I$ are negative. That is why Theorem 15.8 is a direct consequence of Theorem 15.7.

15.3.2 Feedback Design Based on Lyapunov Second Method

Let us consider the following constant coefficient linear system

$$\frac{dx}{dt} = Ax + Bu$$

and design a feedback control

$$u = r - Kx$$

so that the resultant closed-loop system is asymptotically stable.

When considering stability, we can let the reference output be $r = 0$ while ignoring the negative sign. So, we have the following feedback control

$$u = Kx$$

In this case, the closed-loop system is

$$\frac{dx}{dt} = (A + BK)x$$

One of the sufficient and necessary conditions for this system to be asymptotically stable is for any Q, the Lyapunov equation has a unique positive definite solution. If we let $Q = P = I$, then the Lyapunov equation is simplified into

$$(A + BK)^T + (A + BK) = -I,$$

The matrix K we obtain by solving this equation is the desired feedback gain matrix.

Example 15.2 Assume that the control-theory model of a simply economic system is given as follows:

$$\frac{dx}{dt} = \begin{bmatrix} 0 & 1 \\ 2 & 2 \end{bmatrix} x + \begin{bmatrix} 1 & 1 \\ -2 & 1 \end{bmatrix} u$$

Find a feedback $u = Kx$, such that the resultant closed-loop system is stable.

Solution Let $P = Q = I$. Then the Lyapunov equation becomes

$$\begin{bmatrix} k_{11} + k_{21} & 1 + k_{12} + k_{22} \\ 2 - 2k_{11} + k_{21} & 2 - 2k_{12} + k_{22} \end{bmatrix}^T + \begin{bmatrix} k_{11} + k_{21} & 1 + k_{12} + k_{22} \\ 2 - 2k_{11} + k_{21} & 2 - 2k_{12} + k_{22} \end{bmatrix}$$
$$= -\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

So, we have

$$\begin{cases} 2k_{11} + 2k_{21} = -1 \\ 3 - 2k_{11} + k_{12} + k_{21} + k_{22} = 0 \\ 4 - 4k_{12} + 2k_{22} = -1 \end{cases}$$

By letting $k_{11} = 1$, we obtain $k_{21} = -\frac{3}{2}$, $k_{12} = 1$, $k_{22} = -\frac{1}{2}$, and the feedback gain matrix

$$K = \begin{bmatrix} 1 & 1 \\ -\dfrac{3}{2} & -\dfrac{1}{2} \end{bmatrix}$$

It can be readily checked that when this matrix K is used as the feedback gain, the pole of the resultant closed-loop system (that is the eigenvalue of the matrix $A + BK$) has -0.5 as the real part, and the closed-loop system is asymptotically stable.

If we choose $P = \frac{1}{10}I$ and $Q = I$, then solving the Lyapunov equation gives us another feedback gain matrix. In this case, the pole of the resultant closed-loop system has been moved leftward with -5 as the real part.

In order to guarantee the response speed of the closed-loop system, we generally need to design a feedback $u = Kx$ such that the real parts of poles on the closed loop are less than $-\sigma$, where σ is a positive number. In this case, we can employ Theorem 15.8. For this end let us use the following example to illustrate the specific steps.

Example 15.3 For the economic system in Example 15.2, design a feedback $u = Kx$ such that the poles of the closed loop have real parts less than -3.

Solution Let $P = Q = I$ and $\sigma = 3$. So, the closed-loop system in Eq. (15.8) becomes

$$(A + BK)^T + (A + BK) + 6I = -I$$

For the matrices A, B, and $K = \begin{bmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{bmatrix}$, as given in this example, the previous equation becomes

$$\begin{bmatrix} k_{11} + k_{21} & 1 + k_{12} + k_{22} \\ 2 - 2k_{11} + k_{21} & 2 - 2k_{12} + k_{22} \end{bmatrix}^T + \begin{bmatrix} k_{11} + k_{21} & 1 + k_{12} + k_{22} \\ 2 - 2k_{11} + k_{21} & 2 - 2k_{12} + k_{22} \end{bmatrix}$$
$$+ \begin{bmatrix} 6 & 0 \\ 0 & 6 \end{bmatrix} = -\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

So, we have

$$\begin{cases} 2k_{11} + 2k_{21} = -7 \\ -2k_{11} + k_{12} + k_{21} + k_{22} = -3 \\ -4k_{12} + 2k_{22} = -11 \end{cases}$$

Letting $k_{11} = 1$ leads to $k_{21} = -\frac{9}{2}$, $k_{12} = 3$, $k_{22} = \frac{1}{2}$, and the following feedback gain matrix:

$$K = \begin{bmatrix} 1 & 3 \\ -\dfrac{9}{2} & \dfrac{1}{2} \end{bmatrix}$$

It can be readily checked that the pole of the resultant closed-loop system has -3.5 as its real part.

The essential operation behind designing feedback by using Lyapunov equation is solving systems of algebraic equations. That can be done reasonably conveniently. Even so, of course, there are constant coefficient linear systems such that no feedback mechanism exists to make their resultant closed-loop systems stable.

15.3.3 An Iterative Method for Solving Lyapunov Equations

When the order of the economic system is relatively high, we can solve the Lyapunov equation in Eq. (15.7) by using the Davison-Man method and by following the iteration steps below (for more details on the Davison-Man method, please consult with (Hached 2015) and references listed there):

Step 1: Choose $h = 10^{-4}/(2||A||)$ and let $P_0 = hQ$.
Step 2: Compute the matrix: $E = (I - hA/2 + h^2A^2/12)^{-1}(I + hA/2 + h^2A^2/12)$.
Step 3: Calculate $P_{i+1} = (E^T)^{2i}P_iE^{2i} + P_i$.
Step 4: Check the error. If $(E^T)^{2i}||\Delta P|| = ||P_{i+1} - P_i|| < \varepsilon$, then stop; otherwise, go back to Step 3, where ε stands for the requirement of precision.

This computational scheme converges only when the eigenvalues of A all have negative real parts, that is, only when A is a stable matrix. And, empirical tests indicate that with merely ten iterations, this scheme could produce results within the precision of 10^{-6}.

15.4 Corresponding Results for Economies Measured with Discrete Time

The afore-described Lyapunov method can also be employed to investigate discrete economic system. In particular, for the following given constant coefficient linear system of discrete time

$$x(k+1) = Ax(k) \tag{15.9}$$

Theorem 15.3 can be rewritten as follows (Perko 2013):

Theorem 15.8a For the constant coefficient linear system in Eq. (15.9) with discrete time, the following hold true:

1. If the norms of all the eigenvalues of A are less than 1, then the system is asymptotically stable.
2. If one of the eigenvalues of A has norm greater than 1, then the system is not stable.
3. If the norms of all the eigenvalues of A are less than or equal to 1 and the eigenvalues with norm = 1 are roots of the minimal polynomial of A of multiplicity 1, then the system is stable but not asymptotically stable.
4. If one of the eigenvalues with norm = 1 is a root of the minimal polynomial of A of multiplicity >1, then the system is not stable.

For discrete economic systems, we can also introduce the concept of Lyapunov functions. In this case, the condition $\frac{dV}{dt} < 0$ is replaced by $\Delta V(x) = V(x(k+1)) - V(x(k)) < 0$. And correspondingly, the statement of Theorem 15.7 needs to be slightly modified as follows (Perko 2013).

Theorem 15.9 A sufficient and necessary condition for the discrete constant coefficient system in Eq. (15.9) to be asymptotically stable is that for any positive definite matrix Q, the following matrix equation

$$A^T PA - P = -Q \tag{15.10}$$

has a unique positive definite solution.

Eq. (15.10) is known as the Lyapunov equation of the discrete system in Eq. (15.9). Similarly, we can employ this result to design closed-loop, stable feedback systems.

Now let us revisit the case of Thai crisis in the 1990s.

When the Thai financial crisis started to break out, the nation's foreign exchange reserves were far less than the demand for exchange rate intervention. So, it was theoretically important to address how to minimize adverse effects of the forthcoming financial crisis on the credit environment in order for the normal operation of the economy to be maintained, the tension in the financial markets eased, and the financial system stabilized.

In fact, at the onset of a financial crisis, because of the transmission mechanism of self-fulfilling panic, investors, both domestic and foreign, tend to convert their assets into cash in foreign currencies; that quickly exhausts the limited availability of the nation's foreign exchange reserves. In such a case, the mechanism of monetary policy, such as raising interest rate to attract inflow of capital, reducing demand for money, depreciating the domestic currency, etc. alone will not do much in terms of controlling capital flight and eliminating foreign exchange reserve shortages. Therefore, decision-makers commonly select exchange rates among all crisis response measures as an intermediate target of monetary policy operations with open market operation as the most important monetary policy instrument. To reach the monetary policy target of stabilizing the exchange rate and avoiding inflation, the Thai government, on one hand, used open market operations to affect the interest rate of the money market through the central bank's bills and repurchase agreements and, on the other hand, cleanly intervened the fluctuation of exchange rate in the foreign exchange market by selling a certain amount of foreign currencies daily to ease the pressure on that market.

Based on the feedback mechanism of control theory, this chapter illustrates the applicability of control methods, such as interest rate regulation, foreign exchange rate intervention, tightening fiscal policies, structuring of the financial sector, etc., employed during the Thai financial crisis, in the study of economic systems. Based on the discussions above, our theoretical suggestion for handling the Thai crisis would include the following additional to what had been done:

- Stabilizing the exchange rate and interest rate needs to be accomplished simultaneously.
- The investors' confidence in the stock market needs to be supported.
- The cost of speculating currencies needs to lifted higher.
- Measures need to be introduced to limit short selling.

And due to the lack of relevant financial data before the breakout of the Thai financial crisis and the related records of what control measures and policies were employed during the crisis, our suggestion could not be made more specific than what is given above.

15.5 Conclusion

When the parameters of the control-theory model of the economic system experience sudden changes within a short period of time, it often causes the economic system to deviate from its expected trajectory of development. Such deviations tend to bring about severe damages to the otherwise well-performing economic system and are clearly indicated by massive loss of the societal wealth. Therefore, it is very important for us to investigate whether or not one can effectively introduce control strategies to bring the economic system back to its normal, stable state of operation when the system experiences external interferences. In other words, when the parameters of the control-theory model of the economic system suffer from sudden shocks within a short period of time, it is practically extremely important to know whether or not one can effectively shield the economy from the adverse effect of the environment. In this chapter, we establish a method on how to design stabilizing strategies when the economic system experiences external impacts by employing the concept of output feedback and the method of Lyapunov feedback control. By applying output feedback control strategies on the unstable subsystem of the economic system, the proposed method in this chapter is able to stabilize the disturbed system through making the real parts of the eigenvalues of the unstable system all negative. Although this method could stabilize a disturbed system in theory, in practice, the process of approaching the desired target might experience relatively major fluctuations and might take a long time. So, it is necessary as a future topic of research to investigate how to make a disturbed economic system to become stable again in a timely fashion by developing high quality control strategies and methods.

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Chapter 16
Design Economic Policies that Do Not Create Bumpy Recovery

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Contents

This chapter studies how to make sure when the economic performance indicators approach some pre-determined target values due to the effect of adopted policies, the economy also develops reasonably well without experiencing much severe up-and-down fluctuations. This problem of concern is resolved by addressing the corresponding problem of pole placement of the general control-theory model of the economic system. This chapter (1) discusses conditions under which the poles of a constant coefficient linear economic system can be arbitrarily placed,

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(2) provides a way to calculate the matrix of feedback gain that is useful in placing the poles by using the feedback control mechanism so that the resultant constant coefficient linear economic system possesses a good quality stability and fast response speed, and (3) investigates the problem of how to design state or output feedbacks (economic policies) so that the resultant closed-loop economic system will have the pre-determined poles. At the end, some open problems of great importance are posed for future research. This chapter relates the issue of economic policy making and the pole placement of the general control-theory model of the economic system. The results are expected to provide practically useful guidelines.

16.1 Introduction

Since the 1990s, with the economic integration and the financial market globalization, the frequency and contagion of financial crises have increased tremendously (Table 16.1). That has had profoundly impacts on the globalization and captured the attention of many governments and scholars from around the world. In particular, the global financial crisis, triggered by the US subprime mortgage crisis in 2007, had shown a new feature that not only has a more complex transmission channel and effect but also makes it possible for a non-systemic risk of a single country or local region to become a global financial systemic risk along the path of financial globalization and economic integration. This feature created far more severe aftermath consequences than any of the previous financial crises and brings forward new challenges to the existing theories of financial crises and regulations. Therefore, it is necessary to reexamine the contagion problem of global financial crises and to consider building a supervision system for the outbreak of crises and consequent contagion. To this end, it is important for us to look for sufficient conditions of dynamic path controllability of economic systems, while this effort

Table 16.1 Several major financial crises since the 1990s

Time	Crisis name	Country	Type of country
1990	Bank of Scandinavia crisis	Finland, Sweden, and Norway	Developed economy
1992	Japan's asset price bubble crisis	Japan	Developed economy
1994	Mexico economic crisis	Mexico	Emerging economy
1997	Asian financial crisis	Thailand	Emerging economy
1998	Russian financial crisis	Russia	Emerging economy
1999	Brazil financial crisis	Brazil	Emerging economy
2001	Argentina financial crisis	Argentina	Emerging economy
2001	Dotcom bubble crisis	America	Developed economy
2007	Subprime crisis	America	Developed economy

Resources: Chen and Ying (2012)

surely has great theoretical value for follow-up studies on the prevention of financial crises (Chen and Ying 2012, 2014).

In practical studies of the economy, we require to a certain degree not only the economic system to be controllable so that the controlled variable, such as the GDP, the inflation, etc., approaches the target value but also the economic system to perform reasonably well in its process of approaching the target value. To achieve this end, it involves addressing the problem of pole placement of general systems (Cobb 1981; Kaczorek 1985; Ogata 1995; Ram et al. 2011; Kirk 2012; Zubov et al. 2013).

From Chap. 15, it follows that when the real parts of the eigenvalues of matrix A are all negative, the economic system is asymptotically stable. Although the feedback control strategy that is designed by using the Lyapunov method can help to materialize the goal of regulating the economy, the process for the performance of the economic system to approach the targeted values might still experience major fluctuations and might take a long time to actually reach the targets. This end has a lot to do with the eigenvalues of A which are in fact the poles of the economic system. In particular, if the poles of the economic system, or the eigenvalues of matrix A, are located on the left half plane but near the imaginary axis, then in its process of approaching the targeted values, the performance of the economy will suffer from severe up-and-down fluctuations. Such severe up-and-down fluctuations had been experienced during the process of dealing with the 1998 Russian financial crisis.

In October 1997, a financial crisis broke out in Southeast Asia. And in the following 10 months, Russia made unremitting efforts to survive. During the time period, Russia issued large amounts of national debts and sacrificed a lot of foreign exchange in the market, which drastically reduced Russian foreign exchange and gold reserves. Therefore, Russian government faced a dilemma: either continue to maintain the floating exchange rate policy of the "currency corridor" or support the bond market. Eventually Russian government decided to go with the former choice. However, the financial situation did not turn for the better; and ruble started to depreciate drastically.

Facing the continuous occurrence of new turmoil in the financial market, Russian government introduced an economic program to stabilize the financial situation. However, the program did not gain enough investor confidence. On August 13, 1998, George Soros, a renowned international speculator, publically suggested for Russian government to depreciate ruble in the scale of 15–25%. On that day, the price index of 100 industrial company stocks, as calculated by Interfax, lost over 70% of its value and fell sharply to the level of about 26% of the value at the start of the year. At the same time, the tax collected during the month of July was only about 12 billion ruble, while the operational budget for each month was no less than 20 billion ruble, showing a huge gap between the income and expense. Under the pressure of the internal and external difficulties, on August 17, the government launched three tough emergency measures:

- The first was to expand the floating range for the exchange rate of ruble while lowering the upper limit of the ruble's exchange rate against the dollar to 9.5:1. That in fact declared the depreciation of ruble against the dollar from 6.295 to 9.5, more than 50% depreciation. So, the market predicted based on this emergency measure that the exchange rate of ruble would continue to drop drastically. And indeed, in the next 10 days, ruble fell to 20–21:1, which busted the stable exchange rate of the past 3 plus years.
- The second was to delay the payments, which were due, of foreign debts, which were estimated to be around US$15 billion, for 90 days.
- The third was to lengthen the repayment periods of domestic debts, making all national debts, totaling about US$20 billion, that would mature by December 31, 2099, become midterm debts that would mature in the next 3, 4, or 5 years. And before finishing the change of maturities, the national debt market was closed for trading.

As soon as these three measures were announced, they immediately caused public outcry, the stock market crashed and closed for trading, and the exchange rate of ruble plunged. Afterward, the central bank altogether declared that it would allow ruble to float freely. That caused the public to either run for ruble in order to exchange for the US dollar or buy anxiously consumer goods. Along with the fall of ruble's exchange rate, the stock market plummeted much further. As of the end of August 28, the price index of the 100 industrial company stocks, as calculated by Interfax, fell to US$15.92 billion, which represented a fall of 85% when compared to the level of US$103.356 billion reached at the start of the year. And then the market simply closed down, making the price index become worthless.

Although all the responses adopted by Russian government helped to reduce the economic loss of the nation, they also created major obstacles for the recovery of the domestic economy.

Firstly, half of the deposits of the domestic residents were lost. The prices of imported goods rose 2–3 times, which also made the prices of domestic goods go up drastically. In September, the consumer prices went up 40%, which was more than the 36% rise that occurred in February 1992, the highest since the start of the economic reform. People's actual wages went down 13.8%, making nearly one-third of all the residents live under the poverty line. The overall economy dropped 5%, industry 5.2%, agriculture 10%, and foreign trade 16.1%.

Secondly, a large number of commercial banks, especial those big banks, suffered heavy losses. The SBS agriculture bank, one of the seven financial giants, at the time held short-term national debts in the equivalent amount of US$1 billion, which became worthless instantly. It was estimated that about one-half of the commercial banks were on the verge of bankruptcy.

Thirdly, this Russian financial crisis spread over its national border and affected Europe, the United States, and Latin America, becoming a global effect. Foreign investors lost about US$33 billion in this huge financial storm, where American long-term capital management firms (or hedge funds) lost about US$2.5 billion, George Soros' Quantum Fund lost around US$2 billion, and American Bankers

Trust lost somewhere near US$0.49 billion. Germany was the largest creditor of Russia, which owed Germany 75 billion marks (about US$44.4 billion), most of which were government-guaranteed bank loans. So, any trouble that appeared on the Russian financial market affected the safety of German creditors, creating shocks on the German market. Then the shock waves were spread over to the entire European financial market. For example, the Frankfurt DAX index once fell over 3%, the CAC 40 index of Paris stock market dropped 1.76%, the Amsterdam stock market lowered 2%, the Zurich stock market lost 1.6%, etc. For related details, please consult with Dabrowski (2012); Kenourgios and Padhi (2012); Kenourgios et al. (2011); Bisignano et al. (2012); Gluschenko (2015); and Razin and Rosefielde (2011).

Therefore, in the process of actually controlling the conflict of currencies, we need the adopted feedback control strategies to show desirable good qualities in order to reduce as much as possible the severe systemic fluctuations caused by the employed control strategies, such as the excessive chaos of the market caused by the measures adopted by Russian government to control the exchange rate. Additionally, when not all of the eigenvalues of matrix A are located on the left half of the complex plane, the economic system is not asymptotically stable, and the feedback strategies designed by using the Lyapunov method cannot make the performance of the economy approach the pre-determined targets. Hence, it is necessary for us to establish new methods not only to guarantee that the process for the performance of the economy (or the output of the economic system) to approach the pre-determined targets exhibits desirable qualities but also to make the performance of the economy actually approach the pre-determined targets by designing relatively good feedback control strategies, even if the economic system itself is not asymptotically stable. To this end, the design of such feedback control strategies is closely related to the poles of the economic system, which is known as a method for pole placement.

Additionally, from the discussion in Chap. 15, it follows that state feedback affects the poles of any closed-loop system and that for certain open-loop unstable economic systems, we can design a feedback control so that the resultant closed-loop system is stable.

Results in Chap. 15 indicate that the poles of the economic system determine the stability of the system. Additionally, some other properties of the economic system are also determined by the location of the poles. For example, the dynamic characteristics of the system are greatly influenced by the location of the poles of the closed-loop system. This chapter discusses the problem of how to design feedback so that the resultant closed-loop economic system will have the pre-determined poles, known as the problem of pole placement. In other words, the so-called pole placement is to place the poles of the closed-loop system at desirable locations by using either state feedback or the output feedback. Because the performance of the economic system is closely related to the location of the system's poles, it makes the problem of pole placement occupy an important position in the study of feedback economic policy design. Here, we need to solve two problems. First, we need to establish the conditions under which the poles can be relocated; and second, we need to determine the feedback gain matrix that plays an important role in the poles relocation.

This chapter is organized as follows: Sect. 16.2 discusses the problem of how to place the poles of the economic system by using either state feedback or output feedback, and the problem of how to determine the desirable locations for the poles. Section 16.3 outlines the need to study the placement of eigenvectors and so the problem of eigenstructure assignment. Then, the presentation of this chapter is concluded in Sect. 16.4.

16.2 Pole Placement

16.2.1 Pole Placement by Using State Feedback

First of all, let us look at the following problem: For what kind of economic system can we arbitrarily place its poles? Because the locations of the poles determine some of the very important properties of the economic system, the ability to arbitrarily relocate these points means the capability to alter at one's will some of these important characteristics of the economy through using feedback. Hence, the ability to relocate the poles should be closely related to the controllability of the economic system. Based on this reasoning, we will address this problem by using the form of controllable systemic structures.

Assume that an economy can be written as a constant coefficient linear system, which takes the following structural form and is (A_1, B_1) controllable:

$$\begin{bmatrix} \frac{dx_c}{dt} \\ \frac{dx_{Nc}}{dt} \end{bmatrix} = \begin{bmatrix} A_1 & A_{12} \\ 0 & A_2 \end{bmatrix} \begin{bmatrix} x_c \\ x_{Nc} \end{bmatrix} + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} u \tag{16.1}$$

$$y = \begin{bmatrix} C_1{}^1 & C_2 \end{bmatrix} \begin{bmatrix} x_c \\ x_{Nc} \end{bmatrix}. \tag{16.2}$$

Evidently, the set of poles of this system is $\sigma(A_1) \cup \sigma(A_2)$. By using the following feedback

$$u = r - Kx = r + [K_c \quad K_{Nc}] \begin{bmatrix} x_c \\ x_{Nc} \end{bmatrix}$$

where $-K = [K_c \quad K_{Nc}]$, we obtain the following closed-loop system:

$$\begin{bmatrix} \frac{dx_c}{dt} \\ \frac{dx_{Nc}}{dt} \end{bmatrix} = \begin{bmatrix} A_1 + B_1K_c & A_{12} + B_1K_{Nc} \\ 0 & A_2 \end{bmatrix} \begin{bmatrix} x_c \\ x_{Nc} \end{bmatrix} + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} r$$

whose set of poles is $\sigma(A_1 + B_1K_c) \cup \sigma(A_2)$.

From the discussion in Chap. 15, it follows that $\sigma(A_2)$ should stay the same with the applied feedback. Therefore, it means that if the economic system in Eq. (16.1) is not completely controllable, then we cannot arbitrarily relocate the system's poles by using feedback. Because linear transformations do not change a system's controllability and poles, this conclusion holds true generally for general constant coefficient linear systems. On the other hand, if a constant coefficient linear system is completely controllable, can the system's poles be arbitrarily placed? The answer is yes. So, we have the following important result.

Theorem 16.1 A sufficient and necessary condition for an economic system $(A\,,B)$ to arbitrarily place its poles is that the system is completely $(A\,,B)$ controllable.

Assume that A is not a stable matrix. If there is K such that the matrix $A+BK$ of the resultant closed-loop system as obtained from using the feedback $u=r+Kx$ is a stable matrix, then we say that the original economy is capable of being stable.

Theorem 16.2 A sufficient and necessary condition for an economic system to be capable of being stable is that all elements in $\sigma(A_2)$ are of negative real parts.

This result is also a natural consequence of the previous discussions. The problem of finding K such that $A+BK$is stable is referred to as the problem of stabilization.

In the following, let us look at the specific details of how to place the poles of a controllable economic system. First, let us look at the case of economy which involves only a single performance index and a single indicator.

Assume that the systemic representation of the economy is

$$\frac{dx}{dt} = Ax + bu \tag{16.3}$$

which is controllable and written in the canonical form so that we have

$$A = \begin{bmatrix} 0 & 1 & 0 & \cdots & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \\ \dots & \cdots & & & & \\ 0 & & & & 0 & 1 \\ -a_0 & -a_1 & \cdots & \cdots & \cdots & -a_{n-1} \end{bmatrix}, b = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{bmatrix}.$$

The characteristic polynomial of this system is

$$\mid sI - A \mid = s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0$$

Under the effect of the feedback $u=kx+r=[k_1,\ \cdots, k_n]x+r$, we obtain the following closed-loop system:

$$\frac{dx}{dt} = (A + bk)x + br$$

where

$$A+bk=\begin{bmatrix} 0 & 1 & 0 & \cdots & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \\ \cdots & \cdots & & & & \\ 0 & & & & 0 & 1 \\ -a_0+k_1 & -a_1+k_2 & \cdots & \cdots & \cdots & -a_{n-1}+k_n \end{bmatrix}.$$

The characteristic polynomial of the resultant closed-loop system is

$$\mid sI-(A+bk)\mid = s^n+(a_{n-1}-k_n)s^{n-1}+\cdots+(a_1-k_2)s+(a_0-k_1). \quad (16.4)$$

Assume that we like to place the poles of the system at n given locations on the complex plane: $\lambda_1, \lambda_2, \cdots, \lambda_n$. From these n points, we can calculate the characteristic polynomial

$$(s-\lambda_1)(s-\lambda_2)\cdots(s-\lambda_n)=s^n+\alpha_{n-1}s^{n-1}+\cdots+\alpha_1 s+\alpha_0. \quad (16.5)$$

If we assume that when there is one complex number in the list of the pre-determined poles $\lambda_1, \lambda_2, \cdots, \lambda_n$, its conjugate needs also to appear in the list, and then all the coefficients α_i in the previous equation are real numbers. By comparing Eqs. (16.4 and 16.5), we know that in order to materialize the required poles for the closed loop, we only need to select appropriate $k_1, k_2, \cdots, k_n$ such that

$$\begin{cases} \alpha_0 = a_0 - k_1 \\ \alpha_1 = a_1 - k_2 \\ \vdots \\ \alpha_{n-1} = a_{n-1} - k_n \end{cases}.$$

That is, the following vector will satisfy our need:

$$k=[a_0-\alpha_0, a_1-\alpha_1, \cdots, a_{n-1}-\alpha_{n-1}]. \quad (16.6)$$

For the general controllable economic system in Eq. (16.3) with a single performance indicator, we first transform it into the canonical form and then place its poles. To this end, we use the following transformation:

$$x = Tx'$$

$$T=\begin{bmatrix} q \\ qA \\ \vdots \\ qA^{n-1} \end{bmatrix}^{-1}$$

where $q = [0, 0, \cdots, 1]U^{-1}$ and $U = [b, Ab, \cdots, A^{n-1}b]^{-1}$. This transformation changes the original system in Eq. (16.3) into

$$\frac{dx'}{dt} = T^{-1}ATx' + T^{-1}bu.$$

Because $qU = [0, 0, \cdots, 1] = [qb, qAb, \cdots, qA^{n-1}b]$, we have

$$qb = 0, qAb = 0, \cdots, qA^{n-2}b = 0, qA^{n-1}b = 1.$$

That implies

$$T^{-1}b = \begin{bmatrix} qb \\ qAb \\ \vdots \\ qA^{n-1}b \end{bmatrix} = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix}.$$

Next we show that $T^{-1}AT$ is of our desired form. That is, we show

$$T^{-1}AT = \begin{bmatrix} 0 & 1 & 0 & \cdots & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \\ \cdots & \cdots & & & & \\ 0 & & & & 0 & 1 \\ -a_0 & -a_1 & \cdots & \cdots & \cdots & -a_{n-1} \end{bmatrix} \tag{16.7}$$

Because the characteristic polynomial of A is

$$|\, sI - A \,| = s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0$$

we have

$$\begin{bmatrix} 0 & 1 & 0 & \cdots & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \\ \cdots & \cdots & & & & \\ 0 & & & & 0 & 1 \\ -a_0 & -a_1 & \cdots & \cdots & \cdots & -a_{n-1} \end{bmatrix} T^{-1} = \begin{bmatrix} 0 & 1 & 0 & \cdots & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \\ \cdots & \cdots & & & & \\ 0 & & & & 0 & 1 \\ -a_0 & -a_1 & \cdots & \cdots & \cdots & -a_{n-1} \end{bmatrix} \begin{bmatrix} q \\ qA \\ \vdots \\ qA^{n-1} \end{bmatrix}$$

$$= \begin{bmatrix} qA \\ qA^2 \\ \vdots \\ qA^{n-1} \\ q\left(-a_0 I - a_1 A - \cdots - a_{n-1}A^{n-1}\right) \end{bmatrix} = \begin{bmatrix} qA \\ qA^2 \\ \vdots \\ qA^{n-1} \\ qA^n \end{bmatrix} = T^{-1}A.$$

So, Eq. (16.7) is proven.

Therefore, we have transformed the original single-input controllable system in Eq. (16.3) into the canonical form, and we can now arbitrarily place the poles according to Eq. (16.6). In the previous equations, we have used the following:

$$A^n = -a_0 I - a_1 A - \cdots - a_{n-1} A^{n-1}.$$

So, based on Eq. (16.6), we obtain the feedback $u = kx' + r$. By returning back to the original coordinate system x, we produce

$$u = kT^{-1}x + r = Kx + r \tag{16.8}$$

That is what we wanted, where $K = kT^{-1}$.

Example 16.1 Assume that the control-theory model of an economic system is given as follows:

$$\frac{dx}{dt} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & -1 & 0 \\ 0 & 1 & 3 \end{bmatrix} x + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} u$$

Find a state feedback such that the resultant closed-loop system has the following poles: -1, $-2 + 3i$, and $-2-3i$.

Solution Step 1: Let us compute the characteristic polynomial of the given model:

$$| sI - A | = s^3 - 3s^2 - 2s + 6.$$

Step 2: Calculate the required characteristic polynomial:

$$(s + 1)(s + 2 - 3i)(s + 2 + 3i) = s^3 + 5s^2 + 17s + 13.$$

From Eq. (16.6), it follows that

$$k = [a_0 - \alpha_0, a_1 - \alpha_1, a_2 - \alpha_2] = [-7, -19, -8].$$

For returning to the original coordinate system, we compute

$$U = \begin{bmatrix} 1 & 1 & 2 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, q = [0\ \ 0\ \ 1]U^{-1} = [0\ \ 0\ \ 1], T^{-1} = \begin{bmatrix} q \\ qA \\ qA^2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 3 \\ 1 & 2 & 9 \end{bmatrix}$$

So, we have the follow desired feedback:

$$u = kT^{-1}x + r = [-8 \quad -35 \quad -136]x + r.$$

Because when we represent an economy by using a control-theory model, the model most likely contains many variables. That is, such a control-theory model would generally be high dimensional. So, in the following, let us investigate the problem of pole placement for an economy with multiple economic policy factors as the system's input.

Assume that the multiple-input control-theory model of the economy is

$$\frac{dx}{dt} = Ax + Bu. \tag{16.9}$$

We will provide a method to first solve for a state feedback to convert a multiple-input controllable system into a single-input controllable system and then to employ the developed method to place the poles of the single-input system of the original multiple-input system. In particular, we have the following details.

Assume that $B = \begin{bmatrix} b_1 & b_2 & \cdots & b_m \end{bmatrix}$. Because the system in Eq. (16.9) is (A, B) controllable, the rank of $U = \begin{bmatrix} B \vdots & AB \vdots & \cdots & \vdots A^{n-1}B \end{bmatrix}$ is n. Next, we rearrange column vectors of U as follows:

$$\left\{b_1 \;\; Ab_1 \;\; \cdots \;\; A^{n-1}b_1; \;\; b_2 \;\; Ab_2 \;\; \cdots \;\; A^{n-1}b_2; \;\; \cdots; \;\; b_m \;\; Ab_m \;\; \cdots \;\; A^{n-1}b_m\right\}.$$

From these $n \times m$ columns, we select from left to right all the linearly independent vectors and obtain the following matrix:

$$Q = \left[b_1 \;\; Ab_1 \;\; \cdots \;\; A^{\mu_1-1}b_1; \;\; b_2 \;\; Ab_2 \;\; \cdots \;\; A^{\mu_2-1}b_2; \;\; \cdots; \;\; b_m \;\; Ab_m \;\; \cdots \;\; A^{\mu_m-1}b_m\right]. \tag{16.10}$$

Let

$$S = \begin{array}{cccccccc} [0\cdots 0 & e_2 & ;0\cdots 0 & e_3 & ;\cdots;0\cdots 0 & e_m & ;0\cdots 0 & 0;] \\ & \uparrow & & \uparrow & & \uparrow & & \uparrow \\ & \mu_1 th\ column & & (\mu_1+\mu_2)th\ column & & (\mu_1+\cdots+\mu_{m-1})\ th\ column & & nthcolumn \end{array} \tag{16.11}$$

where matrix S has n columns, and e_i is the ith column of the $m \times m$ identity matrix and the $(\mu_1+\mu_2+...+\mu_{i-1})$th column.

It can be shown that the matrix $\hat{K} = SQ^{-1}$ constructed by employing these previous matrices Q and S can help convert the original system into a single-input controllable system.

Lemma 16.1 Assume that $b_1 \neq 0$. Then under the effect of the feedback $u = \hat{K}x + v = SQ^{-1}x + v$, the closed-loop system

$$\frac{dx}{dt} = \left(A + B\hat{K}\right)x + b_1 v_1$$

is controllable, where v_1 stands for the first component of v.

Proof From the definition of $\hat{K}$, we have $\hat{K}Q = S$. That is,

$$\begin{aligned}&\hat{K}\left[b_1\ \ Ab_1\ \ \cdots\ \ A^{\mu_1-1}b_1;\ \ b_2\ \ Ab_2\ \ \cdots\ \ A^{\mu_2-1}b_2;\ \ \cdots;\ \ b_m\ \ Ab_m\ \ \cdots\ \ A^{\mu_m-1}b_m\right]\\&=[0\ \ \cdots\ \ 0\ \ e_2;\ \ 0\ \ \cdots\ \ 0\ \ e_3;\ \ \cdots\ \ e_m;\ \ 0\ \ \ \cdots 0\ \ 0].\end{aligned}$$

So, we obtain the following series of equations:

$$\begin{aligned}&\hat{K}b_1 = 0, \hat{K}Ab_1 = 0,\ \ \cdots\ \ , \hat{K}A^{\mu_1-2}b_1 = 0, \hat{K}A^{\mu_1-1}b_1 = e_2;\\&\hat{K}b_2 = 0, \hat{K}Ab_2 = 0,\ \ \cdots, \hat{K}A^{\mu_2-2}b_2 = 0,\ \ \hat{K}A^{\mu_2-1}b_2 = e_3;\\&\ \vdots\\&\hat{K}b_{m-1} = 0, \hat{K}Ab_{m-1} = 0,\ \ \cdots\ \ , \hat{K}A^{\mu_{m-1}-2}b_{m-1} = 0, \hat{K}A^{\mu_{m-1}-1}b_{m-1} = e_m;\\&\hat{K}b_m = 0\ \ , \hat{K}Ab_m = 0\ \ , \cdots\ \ , \hat{K}A^{\mu_m-2}b_m = 0, \hat{K}A^{\mu_m-1}b_m = 0].\end{aligned}$$

Let $\bar{A} = A + B\hat{K}$. In the following, we show the $(\bar{A}, b_1)$ controllability. We successively compute the matrix series of the $(\bar{A}, b_1)$ controllability:

$$\begin{aligned}&\bar{A}b_1 = (A + B\hat{K})b_1 = Ab_1 + B\hat{K}b_1 = Ab_1,\\&\cdots,\\&\bar{A}^{\mu_1-1}b_1 = \bar{A}(A^{\mu_1-2}b_1) = (A + B\hat{K})A^{\mu_1-2}b_1 = A^{\mu_1-1}b_1,\\&\bar{A}^{\mu_1}b_1 = \bar{A}(A^{\mu_1-1}b_1) = (A + B\hat{K})A^{\mu_1-1}b_1 = A^{\mu_1}b_1 + B\hat{K}A^{\mu_1-1}b_1.\end{aligned}$$

Based on how Q is constructed, we know that $A^{\mu_1}b_1$ is a linear combination of all the columns of Q that are located to the left b_2. Let $\tilde{b}_2 = A^{\mu_1}b_1$.Then we have

$$\begin{aligned}\bar{A}^{\mu_1}b_1 &= \tilde{b}_2 + Be_2 = \tilde{b}_2 + b_2\\\bar{A}^{\mu_1+1}b_1 &= (A + B\hat{K})(\tilde{b}_2 + b_2) = Ab_2 + B\hat{K}\tilde{b}_2 + A\tilde{b}_2 + B\hat{K}b_2\end{aligned}$$

where $B\hat{K}b_2 = 0$. Through detailed analysis, it is not difficult to see that both $B\hat{K}\tilde{b}_2$ and $A\tilde{b}_2$ are linear combinations of the columns of Q that are located to the left of Ab_2. Let $\widehat{Ab_2} = B\hat{K}\tilde{b}_2 + A\tilde{b}_2$. Then we have

$$\bar{A}^{\mu_1+1}b_1 = Ab_2 + \widehat{Ab_2}$$

Similarly, we obtain

$$\begin{aligned}&\bar{A}^{\mu_1+\mu_2}b_1 = b_3 + \tilde{b}_3\\&\ \vdots\\&\bar{A}^{n-1}b_1 = A^{\mu_m-1}b_m + \widehat{A^{\mu_m-1}b_m}\end{aligned}$$

Therefore,

$$\begin{aligned}
&\operatorname{rank}\left[b_1\ \bar{A}b_1\cdots\bar{A}^{n-1}b_1\right]\\
&=\operatorname{rank}\left[b_1\ Ab_1\cdots A^{\mu_1-1}b_1b_2+\widehat{b_2}\ Ab_2+\widehat{Ab_2}\cdots A^{\mu_2-1}b_2+\widehat{A^{\mu_2-1}}b_2\cdots b_m\right.\\
&\left.+\widehat{b_m}\cdots A^{\mu_m-1}b_m+\widehat{A^{\mu_m-1}}b_m\right]\\
&=\operatorname{rank}\left[b_1\ Ab_1\cdots A^{\mu_1-1}b_1;b_2\ Ab_2\cdots A^{\mu_2-1}b_2;\cdots;b_m\ Ab_m\cdots A^{\mu_m-1}b_m\right]=n.
\end{aligned}$$

Therefore, we have obtained the $(\bar{A}, b_1)$ controllability. QED

By applying the result in Lemma 16.1, we can first compute $\hat{K}$ in order to simplify the control-theory model of the economic system into a single-input controllable system and then place the poles by using the method of pole placement established for single-input controllable systems.

Assume that $\hat{k}$ is the calculated matrix of feedback gain and makes the resultant single-input system $(\bar{A}, b_1)$ have the desirable poles. That is, $\bar{A}+b_1\hat{k}$ has the following pre-determined poles: $\lambda_1, \lambda_2, \cdots, \lambda_n$. Then, we can show that

$$\hat{K}+\bar{K}=\hat{K}+\begin{bmatrix}\hat{k}\\0\end{bmatrix}$$

will also help to place the poles of the system (A, B)onto $\lambda_1, \lambda_2, \cdots, \lambda_n$. In fact, it is ready to see that

$$A+B\left(\hat{K}+\bar{K}\right)=A+B\hat{K}+b_1\hat{k}=\bar{A}+b_1\hat{k}$$

has $\lambda_1, \lambda_2, \cdots, \lambda_n$ as poles. So, $\hat{K}+\bar{K}$ is the desired matrix of feedback gain.

Summarizing what has been discussed above, we have the following particular computational steps for placing the poles of a multiple-input controllable system:

Step 1: Construct matrices Q and S according to Eqs. (16.10 and 16.11) and then compute $\hat{K}=SQ^{-1}$.

Step 2: Calculate $\bar{A}=A+B\hat{K}$ and its characteristic polynomial

$$\mid sI-\bar{A}\mid = s^n+a_{n-1}s^{n-1}+\cdots+a_1s+a_0.$$

Step 3: For given n poles $\lambda_1, \lambda_2, \cdots, \lambda_n$, calculate the following polynomial:

$$(s-\lambda_1)(s-\lambda_2)\cdots(s-\lambda_n)=s^n+a_{n-1}s^{n-1}+\cdots+a_1s+a_0$$

and

$$k=[a_0-\alpha_0, a_1-\alpha_1,\cdots,a_{n-1}-\alpha_{n-1}].$$

Step 4: Compute $\tilde{k} = kT^{-1}$, where

$$T^{-1} = \begin{bmatrix} q \\ q\bar{A} \\ \vdots \\ q\bar{A}^{n-1} \end{bmatrix}$$

where q is the last row of the inverse matrix of the controllability matrix U of $(\bar{A}, b_1)$.

Step 5: Calculate

$$K = \hat{K} + \begin{bmatrix} \hat{k} \\ 0 \end{bmatrix}$$

which is the desired matrix of feedback gain.

Example 16.2 Assume that a given economy is written in the following analytic form:

$$\frac{dx}{dt} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} x + \begin{bmatrix} 1 & 2 \\ 1 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} u.$$

Find the matrix K of feedback gain so that the resultant closed-loop system has poles $\lambda_1 = -1, \lambda_2 = -1, \lambda_3 = -2, \lambda_4 = -2$.

Solution Step 1: Let us construct the following matrix:

$$Q = \begin{bmatrix} 1 & 2 & 2 & 2 \\ 1 & 2 & 0 & 0 \\ 0 & 1 & 0 & 2 \\ 0 & 1 & 0 & 0 \end{bmatrix} \text{ and } S = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

and the feedback matrix:

$$\hat{K} = SQ^{-1} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & -2 \\ 0 & 0 & 0 & 1 \\ \frac{1}{2} & -\frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ 0 & 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Step 2: Calculate

$$\bar{A} = A + B\hat{K} = \begin{bmatrix} 1 & 1 & 0 & 2 \\ 0 & 2 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

and its characteristic polynomial

$$\mid sI - \bar{A} \mid = s^4 - 3s^3 + 2s^2.$$

Step 3: Calculate the desired polynomial

$$(s+1)(s+1)(s+2)(s+2) = s^4 + 6s^3 + 13s^2 + 12s + 4$$

so that we have $k = [-4, -12, -11, -9]$.
Step 4: Calculate

$$q = [0 \ \cdots \ 0 \ \ 1]\left[b_1 \ \ \bar{A}b_1 \ \ \cdots \ \ \ \bar{A}^{n-1}b_1\right]^{-1} = \begin{bmatrix} 0 & 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix},$$

$$T^{-1} = \begin{bmatrix} q \\ q\bar{A} \\ \vdots \\ q\bar{A}^{n-1} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{1}{2} & -\frac{1}{2} \\ \frac{1}{2} & -\frac{1}{2} & 0 & 0 \\ \frac{1}{2} & -\frac{1}{2} & 0 & 1 \\ \frac{1}{2} & \frac{1}{2} & 0 & 1 \end{bmatrix},$$

and $\tilde{k} = kT^{-1} = [-16, 7, -2, -18]$.

Step 5: Calculate

$$K = \hat{K} + \begin{bmatrix} \hat{k} \\ 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} -16 & 7 & -2 & -18 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$
$$= \begin{bmatrix} -16 & 7 & -2 & -18 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

As of this point in our presentation, we have concluded our discussion on the complete controllability of economic systems that can be modeled by using constant coefficient linear control systems. We provided a method to arbitrarily place all the poles of a closed-loop system by using state feedback so that the proof of Theorem 16.1 is finished.

In the discussions above, among the conditions of controllability, we mainly employed that the rank of the matrix $U = [B\ AB\ \cdots\ A^{n-1}B]$ is n. As for the following constant coefficient linear economic system of discrete time

$$x(k+1) = Ax(k) + Bu(k),$$

this particular condition is equivalent to that of complete reachability. So, for discrete economic systems, we have the following result:

Theorem 16.3 A sufficient and necessary condition for a constant coefficient linear economic system (A, B) of discrete time to arbitrarily place its poles through using state feedback is that it is completely reachable.

For economic systems of discrete time, Theorem 16.2 also holds true. And the afore-described computational scheme for placing poles is also applicable to constant coefficient linear economic systems of discrete time. All the relevant details are omitted here. In the following, let us look at a much simplified method for placing poles, which can greatly reduce the amount of computations.

16.2.2 An Improvement on How to Place Poles

In step 4 of placing the poles, we needed to calculate the last row q of the inverse of the controllability matrix of $(\bar{A}, b_1)$. In Example 16.2, we found that q is equal to the last row of Q^{-1}. This discovery is not a coincidence. In fact, it is a common phenomenon. To this end, we have the following result.

Lemma 16.2 The last row of the inverse of the controllability matrix U of the system $(\bar{A}, b_1)$ is equal to the last row of the inverse of the matrix Q as constructed according to Eq. (16.10).

To show this result, we only need to prove that the determinants of U and Q are the same and the corresponding cofactors of the ith row and nth column are also the same. All the details are omitted here.

By applying this lemma and the derivations in Wang (1985), we have the following simplified scheme for placing poles.

Step 1: Construct matrices Q and S according to Eqs. (16.10 and 16.11) and then calculate $\hat{K} = SQ^{-1}$ and denote the last row of Q^{-1} as q.

Step 2: Assume that the desired poles are $\lambda_1, \lambda_2, \cdots, \lambda_h$, $a_1 \pm b_1 i, a_2 \pm b_2 i, \cdots,$ $a_l \pm b_l i$, and $h + 2l = n$. Calculate

$$\hat{k} = -q(\bar{A} - \lambda_1 I)\cdots(\bar{A} - \lambda_h I)\left[\bar{A}^2 - 2a_1\bar{A} + \left(a_1^2 + b_1^2\right)\right]\cdots\left[\bar{A}^2 - 2a_l\bar{A} + \left(a_l^2 + b_l^2\right)\right].$$

Step 3: The following is what is desired:

$$K = \hat{K} + \begin{bmatrix} \hat{k} \\ 0 \end{bmatrix}.$$

This simplified scheme omits many of the operational steps, such as computing the inverse of the controllability matrix, the characteristic polynomial of $\bar{A}$, and the desired characteristic polynomial, when compared to the previous scheme. When the magnitude of n is large, the amount of reduced computation becomes noticeable.

Example 16.3 Let us still look at the same problem of pole placement as discussed in Example 16.2.

Solution Step 1, which is the same as before, produces

$$\hat{K} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

and

$$q = \begin{bmatrix} 0 & 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix}.$$

Step 2:

$$\begin{aligned} \hat{k} &= -\begin{bmatrix} 0 & 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix}(A+I)(A+I)(A+2I)(A+2I) \\ &= [-16 \quad 7 \quad -2 \quad -18]. \end{aligned}$$

Step 3:

$$K = \hat{K} + \begin{bmatrix} \hat{k} \\ 0 \end{bmatrix} = \begin{bmatrix} -16 & 7 & -2 & -18 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

16.2.3 Pole Placement Through Output Feedback

When some of the states of the economic system cannot be used as feedback, such as the performance of the underground economy, we can consider using output feedback to place the poles. From comparing Eqs. (15.4 and 15.5) in Chap. 15, it follows that this is equivalent to replacing K_0 by KC within the closed-loop system. Let K_s stand for the gain matrix of state feedback and K_0 the gain matrix of output feedback. When $K_s = K_0C$, that is, when we solve for K_0 from $K_s = K_0C$, we can use the output feedback to arbitrarily place the poles of the controllable economic system. From the knowledge of algebra, it follows that that end is only possible when K_S^T belongs to span(C^T). So, generally speaking, it means that not all poles can be arbitrarily placed; and how many poles of a closed-loop system can be arbitrarily placed through output feedback becomes an important question. Zheng (1990) has surveyed the results obtained along this research line and provided two computational schemes on how to place $m+r-1$ poles through using output feedback, where m is the dimension of the control vector and r is the dimension of the output vector. So, it can be seen that when $m+r-1 \geq n$, the economic system of concern can arbitrarily place all of its poles through using output feedback.

In the following, let us look at a computational scheme on how to arbitrarily place $m+r-1$ poles of a controllable economic system (C,A,B) by applying output feedback. For all the technical details of the reasoning behind this scheme, please consult with (Zheng (1990).

Step 1: The particular way to place $m-1$ poles $\lambda_1, \cdots, \lambda_{m-1}$ by solving for the matrix $K_1 = q_1 k_1 = \begin{bmatrix} q_1^1 & \cdots & q_m^1 \end{bmatrix}^T \begin{bmatrix} k_1^1 & \cdots & k_r^1 \end{bmatrix}$ is given below.

Determine k_1 such that $(A, k_1 C)$ is observable. And arbitrarily select one element of q_1, and the other $m-1$ elements of q_1 are determined based on $\lambda_1, \cdots, \lambda_{m-1}$ as follows:

$$p_1(s) = p_0(s) - k_1 W_0(s) q_1$$

where $p_1(s)$ stands for the characteristic polynomial of the closed-loop economic system that is obtained from the output feedback with K_1 as the matrix of feedback gain. That is, we have

$$p_1(s) = \det(sI - A - BK_1C) = \det(sI - A - Bq_1k_1C)$$
$$p_0(s) = \det(sI - A)$$
$$W_0(s) = C\mathrm{Adj}(sI - A)B.$$

In particular, by solving the system of equations

$$p_1(\lambda_i) = p_0(\lambda_i) - k_1 W_0(\lambda_i) q_1, i = 1, \cdots, m-1,$$

we obtain the other $m-1$ elements of q_1.

Step 2: Solve for matrix $K_2 = q_2 k^2 = \begin{bmatrix} q_1^2 & \cdots & q_m^2 \end{bmatrix}^T \begin{bmatrix} k_1^2 & \cdots & k_r^2 \end{bmatrix}$ so that under the effect of the output feedback with K_2 as the matrix of feedback gain, the already placed $m-1$ poles will be maintained. And then we place the additional r poles $\lambda_m, \lambda_{m+1}, \cdots, \lambda_{m+r-1}$. The particular details are given below.

Maintaining the already placed $m-1$ poles is materialized by appropriately selecting q_2, while placing the additional r poles is done through selecting k_2. The specific method is to apply the following equation:

$$p_2(s) = p_1(s) - k_2 W_1(s) q_2,$$

where $p_2(s) = \det(sI - A - BK_1C - BK_2C)$ and $W_1(s) = C\mathrm{Adj}(sI - A - BK_1C)B$.

In order to maintain $\lambda_1, \cdots, \lambda_{m-1}$, we need $p_2(\lambda_i) = 0 (i = 1, \cdots, m-1)$, which can be satisfied by $w_i q_2 = 0 (i = 1, \cdots, m-1)$, where w_i is the only linearly independent row of $W_1(s)$. After having determined an arbitrary element of q_2, all other elements of q_2 are solved out of the equations $w_i q_2 = 0 (i = 1, \cdots, m-1)$. After q_2 is determined, we obtain k_2 from solving the following system of equations:

$$p_2(\lambda_i) = p_1(\lambda_i) - k_2 W_1(\lambda_i) q_2 = 0, i = m, m+1, \cdots, m+r-1.$$

Step 3: Let $K = K_1 + K_2$, which is exactly the matrix of output feedback gain useful for placing the $m + r - 1$ additional poles $\lambda_1, \cdots, \lambda_{m+r-1}$.

As a matter of fact, other than its advantages, using the method of placing poles to design macroeconomic policies also suffers from some weaknesses. One advantage of the method is that the feedback mechanism is of good qualities, such as involving less fluctuations, etc. However, the method suffers from the following major weaknesses:

Weakness #1: When it is desirable for the performance of the economy to approach its target rapidly, where the fast speed could be reached in theory when all the eigenvalues are zero after placing the poles, the needed strength of policy interference might be very high. For example, during the time when the Russian government needed to react to the crisis in order to avoid its currency to depreciate quickly, they needed the support of a huge amount of US dollars within a short moment of time. However, at that particular moment, the government did not have a means to satisfy that demand.

Weakness #2: Each theoretical model for the economic system is only an approximate description of the reality. So, as long as the estimate of the parameters of the model is not accurate, there is always an expected deviation between the model and the reality. When the parameters are not accurate or when the parameters change with time, the method of pole placement will not be able to guarantee that the regulated economic variables can still accurately track the pre-determined targets.

To overcome Weakness #1, we can design feedback control strategies by using different methods of pole placement after we first select the poles of desired qualities or other appropriate methods. To overcome Weakness #2, we can employ the design method of robust regulators.

16.2.4 Determination of Pole Locations

In the previous sections, we have studied the computational schemes on how to place poles. In the following, let us look at the problem of how to determine the expected poles of the closed loop. In other words, we like to know how to convert the expected performance indicators of the closed-loop economic system into desired locations of the poles.

One method is established on the premises that the pair of dominant poles determines the properties of the economic system, while other poles bear little influence on the system. To this end, assume that the transfer function of the second-order economic system with dominant poles λ_1, λ_2 is given as follows:

$$G(s) = \frac{w_n^2}{s^2 + 2\xi w_n s + w_n^2}$$

where w_n stands for the natural frequency of economic cycles without any artificial interference and ξ the artificial interference ratio. Then, λ_1, λ_2, ξ, and w_n satisfy the following relationship:

$$| \lambda_1 | = | \lambda_2 | = w_n, \quad \theta = \cos^{-1}\xi.$$

To continue our discussion, let us look at the concept of overshoot or the maximum overshoot of systems. The so-called overshoot is defined as the difference between the maximum response of the system when it receives a step signal input and the system's steady-state value divided by the steady-state value. The magnitude of the overshoot of a system represents the system's ability to adjust itself and to react to occasional and sudden changes in the input. It indicates how much the system's operation could withstand extraordinary shocks.

Most systems should have its overshoot capability. However, if a system does not have its appropriate overshoot, it is equivalent to say that the system does not have any ability to bear workload beyond its load. It is relatively easy for such a system to crash. Therefore, allowing the existence of a certain level overshoot in reality corresponds to some capability for the system to adjust itself along with the up-and-down waves and cycles of oscillation. Other than including the concept of overloading, the concept of overshoot also contains the requirement of returning to the steady state: within the allowed ratio of the overshoot, even if an overload appears, it will not lead to unexpected crashes or interruption of the system's operation.

The global financial crisis, triggered by the US subprime mortgage crisis in 2008, is a very good example on how the overshoot of the then-current financial system could not handle the severe volatility of the market. Because of the levering manipulation and excessive trading of the highly efficient and greatly leveraged financial derivatives with significant price effects of the US credit market, the consequent risks were transferred and spread over into the rest of the world by the innovative credit risk tools. So, the initial risk of the US capital market became a risk of the entire financial market of the world. At the same time, with the ever expansion of influence over the global market, the volatility of the risk got bigger and eventually made it difficult for the overshoot of the financial system to absorb and to meet the abnormal large-scale fluctuating demand. That eventually made the initial US subprime mortgage crisis a global financial crisis.

As a matter of fact, within the socioeconomic development, the evolution of most systems has their naturally attached allowance of overshoot. Because temporary deviations from the normality exist commonly in socioeconomic systems, appropriately setting overshoots is practically meaningful. A basic requirement for socioeconomic systems is to set their individual overshoots at the right levels. Hence, for the general economic operation, if one wishes to set the overshoot to a small value, it means that he/she expects relatively small fluctuations and relatively low levels of risk for the process of development. In realistic economic operations, the economic system with slow response speed generally has small overshoot necessary for dealing with minor fluctuations; while for economic systems of high financial efficiency, the encountered overshoots are generally very large.

Now, to continue our previous discussion, the overshoot of the system is defined as follows:

$$\sigma = e^{-\xi z}/\sqrt{1-\xi^2}$$

and the system's adjustment time, which is defined to be the time needed for the absolute difference between the output and stable value to be smaller than and equal to $\Delta\%$ of the stable value:

$$\begin{aligned} t_s &= 4/\xi w_n(\Delta = 2), \\ t_s &= 3/\xi w_n(\Delta = 5). \end{aligned}$$

When $0 < \xi < 0.9$, we can determine λ_1, λ_2 based on σ, t_s by using these equations.

Of course, practical problems of economic systems are far more complicated than what is just described. In such a case, after having successfully determined the two dominant poles, other poles and zeros can also influence the properties of the economic system. So, the locations of complex poles need to be adjusted appropriately. Sometimes, repeated adjustments are needed before ideal locations can be determined.

Another method is to select poles by optimization with particular significance. For example, we can select poles through optimization by using the criterion of minimizing the integral of time and absolute error (ITAE):

$$J = \int_0^{\infty} t|e|dt. \tag{16.12}$$

By employing this criterion, the characteristic polynomials of order 1 through 6 for systems of type 1 are given as follows:

$$\begin{aligned} &s + w_0 \\ &s^2 + 1.4w_0 s + w_0^2 \end{aligned}$$

$$s^3 + 1.75w_0 s^2 + 2.15w_0 s + w_0^3$$
$$s^4 + 2.1w_0 s^3 + 3.5w_0^2 s^2 + 2.7w_0^3 s + w_0^4$$
$$s^5 + 2.8w_0 s^4 + 5.0w_0^2 s^3 + 5.5w_0^3 s^2 + 3.4w_0^4 s + w_0^5$$
$$s^6 + 3.25w_0 s^5 + 6.6w_0^2 s^4 + 8.6w_0^3 s^3 + 7.45w_0^4 s^2 + 3.95w_0^5 s + w_0^6.$$

Next, we use these polynomials as the characteristic polynomials of the desired closed-loop systems in our design of the matrices of feedback gains. The value w_0 of these polynomials can be selected appropriately in order for the resultant closed-loop system to satisfy some other necessary properties, such as certain requirement on the circulation of money throughout the economic system.

Shanhian and Hassul (1992) provide a detailed procedure for calculating the characteristic polynomial by using this ITAE criterion.

16.3 The Problem of Eigenstructure Assignment

Other than the influence of the poles, the eigenvectors of the matrix A of the control-theory model of the economy also bear great effects on the time response of the performance of the economic system. Assume that A has n different eigenvalues $\lambda_1, \lambda_2, \cdots, \lambda_n$, and their corresponding eigenvectors are, respectively, $v_1, v_2, \cdots, v_n$. Then, by using the following transformation

$$x = Tx' = [v_1 \ \ v_2 \ \ \cdots \ \ v_n]x'$$

we can simplify our economic system of concern

$$\frac{dx}{dt} = Ax + Bu, y = Cx$$

into

$$\frac{dx'}{dt} = \begin{bmatrix} \lambda_1 & & \\ & \ddots & \\ & & \lambda_n \end{bmatrix} x' + T^{-1}Bu, y = CTx'.$$

If we denote

$$T^{-1}AT = \begin{bmatrix} \lambda_1 & & \\ & \ddots & \\ & & \lambda_n \end{bmatrix} = \Lambda,$$

then we have

$$e^{At} = I + \left(T^{-1}\Lambda T\right)t + \frac{1}{2!}\left(T^{-1}\Lambda T\right)^2 t^2 + \cdots = Te^{\Lambda t}T^{-1}.$$

Letting

$$T^{-1} = \begin{bmatrix} w_1^T \\ \vdots \\ w_n^T \end{bmatrix}$$

produces

$$e^{At} = [v_1 \;\; v_2 \;\; \cdots \;\; v_n]e^{\Lambda t}\begin{bmatrix} w_1^T \\ \vdots \\ w_n^T \end{bmatrix}.$$

So, the system's output is given as follows:

$$y(t) = Cx = \sum_{i=1}^{n} Cv_i e^{\lambda_i t} w_i^T x(0) + \sum_{j=1}^{m} \sum_{i=1}^{n} Cv_i w_j^T \int_0^t e^{\lambda_j t} uj(t-\tau)d\tau.$$

That is, the performance output of the economic system is affected not only by the eigenvalues λ_i of the system matrix but also by the eigenvectors v_i. Therefore, a natural question of how to place the eigenvectors becomes clear.

The problem of how to place the poles of the closed-loop economic system and the problem of how to place the corresponding eigenvectors together are known as the problem of eigenstructure assignment. As for how to specifically place eigenvectors, please consult with Wang (1985) and D'Azzo and Houpia (1981).

In this portion of the presentation, we introduced a computational scheme on how to place poles and how to design observers. For other different schemes, please consult with Zheng (1990) and Jamshidi et al. (1992). What needs to be noticed is that for economic systems with multiple policy inputs and multiple performance indicators, different schemes generally lead to different pole placements and different designs of observers. This end actually provides a theoretical explanation for why when facing an economic or financial emergency, there tend to be different policy tools available, although they might lead to totally different outcomes.

16.4 Conclusion

The dynamic characteristics of the economic system depend on where the poles of the closed loop are located. When the poles of a closed-loop economic system are placed at some pre-determined locations on the left half plane, we can make the economic system have not only certain desired dynamic characteristics but also an important degree of stability so that the system can withstand the shock of interference information of the environment on the performance of the economic system. Because of this reason, this chapter discusses the conditions under which the poles of a constant coefficient linear economic system can be arbitrarily placed and provides a way to calculate the matrix of feedback gain that is useful in placing the poles by using the feedback control mechanism so that the resultant constant coefficient linear economic system possesses a good quality stability and fast response speed.

As a matter of fact, the method, discussed in this chapter, mainly resolves the problem of regulating an economy through using feedback of the matrix's elements of the closed-loop system based on the eigenvalues of the closed-loop. However, when a control-theory model is employed to model the actual economy, the parameters of the model are often affected by the outside environment so that it makes it difficult for the seemingly accurate placement of the poles to meet the requirements of the expected economic performance indices. Hence, considering the existence of many uncertain factors that influence the economy, a very important question for future research regarding the pole placement of an economic system is how can we place the poles of the system within a pre-determined region such that it provides the needed possibility for designing practically useful economic policies, while it also makes the choice of poles have much greater freedom.

Additionally, at the same time, when considering how to place the poles, we should also think about the potential economic losses that could be associated with the adoption of relevant policies. In other words, a placement of poles is considered good, if it does not bear a lot of potential economic losses, while it makes the stability of the economy more able to withstand adverse effects of the outside world. Therefore, we should consider combining the methods of optimal control and pole placement in order to make the matrix of feedback gain able to not only place the poles of the closed-loop system at expected locations but also lead to the design of policies that could potentially result in optimal regulation consequences.

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Chapter 17
The Problem of Optimal Macroeconomic Regulations

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Contents

By employing systems analysis and modeling techniques, this chapter establishes a stage for us to address the problem of international contagion of financial crises, and how future financial crises could be better contained by making use of the language of systems science. In particular, this chapter develops the general concept of optimal regulation (control) of challenging economic situations. It looks at different scenarios on how particular problems of economic optimization can be formulated and when different versions of optimal regulation could come into play. One practical implication is that the established concept of optimal economic regulations can be directly employed in managing difficult economic and financial situations.

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The results in this chapter pave a road for follow-up studies on how to optimally design, introduce, and adopt fiscal and monetary policies for meeting touch economic challenges.

17.1 Introduction

Since the 1990s, along with the economic integration and financial globalization, the frequency of financial crises has been increasing with strengthening contagion (Table 17.1). That has profoundly impacted the world order of economic development, attracted the attention of national governments, and fascinated scholars to find the root causes. Specifically, the recent global financial crisis, as triggered by the US subprime crisis in 2007, had shown some new characteristics: There are not only complicated transmission channels and effects but also possibilities for non-system risks of the financial crises of a single country or region to evolve into financial system risks along the trajectories of globalization, integration, and liberation (Ying 2015; Chen and Ying 2012). The width and depth of effects had far surpassed those of the past financial crises, creating a brand-new challenge to the established theory of financial crises and regulatory policies and measures. Therefore, there is an urgent need to revisit the problem of international contagion of financial crises and to introduce improved systems to monitor the breakout and spread of new financial crises so that future financial crises could be contained. The significance of such research is more than justified theoretically.

Aiming at meeting the challenge, this chapter investigates the problem of how to optimally regulate the financial system through the means of fiscal and monetary policies by using the language of systems science in general and control theory in particular. As soon as the general concept of optimal regulation (control) of challenging economic situations is symbolically established, we look at five different particular problems of optimization (control): (1) fast stabilization within shortest time, (2) fast stabilization with minimal energy, (3) optimal policy adjustment for overheating economies, (4) effective currency state regulator of the

Table 17.1 Major financial crises since the 1990s (Forrest 2014)

Breakout year	Name of crises	Origin	Range of contagion
1994	Mexican financial crisis	Mexico	–
1997	Asian financial crisis	Thailand	Philippines, Singapore, Malaysia, Hong Kong, South Korea, Japan, Russia, etc.
1998	Russian financial crisis	Russia	Ukraine, Kazakhstan, Turkey, etc.
1999	Brazilian financial crisis	Brazil	–
2001	Argentine financial crisis	Argentina	–
2007	Subprime crisis	United States	Most European nations, Asia, South American countries

economy, and (5) monitoring the currency system. And then we examine three empirical scenarios on when different versions of optimal regulation or control would come into play: (1) the soft landing problem of the exchange rate fluctuation, (2) the steepest soft landing problem of overheating economies, and (3) the optimal control problem of a production inventory system.

The work presented in this chapter enriches the existing literature on financial and economic crises by introducing a more systemic approach, for more details and related references please consult with (Forrest 2014). It is expected that what is established in this chapter will pave the road for further follow-up studies on how to optimally design, introduce, and adopt fiscal and monetary policies when the otherwise healthy economic system faces economic challenges.

The rest of this chapter is organized as follows: Sect. 17.2 formulates the problem of optimal regulation of financial systems. Section 17.3 looks at the form of optimal regulation of several typical economic problems. Section 17.4 explores three empirical scenarios that involve optimal regulation. And Sect. 17.5 concludes the presentation of this chapter.

17.2 The Problem of Optimal Regulation

Chapter 13 establishes a method on how to design economic measures based on feedback by employing modern control theory so that the resultant closed-loop economic system possesses the desired properties. However, a natural question that needs to be addressed at this junction is: how can one tell if the adopted method of regulation is optimal under certain prespecified sense? In order words, how can one design an optimal method to regulate the economic system? For example, some economic systems have special requirements for accurate regulation without considering the cost; the adopted regulatory policy needs to lead to a minimal error. For instance, when an economy suffers from a potential devaluation crisis of its currency, how can one introduce a control method to stabilize the currency? As a matter of fact, other than seeing such problem of optimal regulation (control) in economic systems (Brock and Scheinkman 1976; Seierstad and Sydsaeter 1986), such problem appears in many other areas of learning, such as industrial processes, transportation, ecological environment, space exploration, etc. (Coverstone-Carroll and Wilkey 1995; Suplisson et al. 2015; Feng et al. 2016).

Speaking intuitively, the problem of optimal regulation of an economic system is about finding such a regulation law that it makes the performance of the system becomes optimal under some predefined sense. Generally, there are many different ways of regulation to make the economic system to reach a predefined goal; the problem of optimal regulation is how to pinpoint the best scheme among all those available under the predefined sense. In order to materialize an optimal regulation, one has to satisfy three basic conditions.

1. The control-theory model of the economic system possesses the necessary degree of accuracy:

$$\frac{dx}{dt} = f(x, u, t), x(t_0) = x_0;$$

otherwise, the obtained results cannot be practically applied to the real-life system. On the other hand, a too high requirement for accuracy leads to a very complicated model, causing major computational errors so that the obtained results would not satisfy the accuracy requirement, either.

2. Established criteria of regulation: $u(t) \in U$, U is the set of all permissible policies. Each mathematical model of the economic system is constrained by some external conditions. Generally, the more constraint conditions, the more difficult for one to obtain the optimal regulation law of the system.
3. The objective function is readily laid out:

$$J(u) = \int_{t_0}^{t_f} L(x, u, t)dt + \theta\left(x\left(t_f\right), t_f\right),$$

whose magnitude could reflect the pros and cons of the designed regulation system.

When seen from the angle of development of the optimal control theory (Berkovitz 2013), the methodology of solving optimal regulation problem mainly consists of two method classes: one is the calculus of variations and the maximum principle, and the other dynamic programming. Calculus of variations is a branch of mathematics and can be traced back to the seventeenth century (Sussmann and Willems 1997). Unconstrained optimization problems can be solved by using calculus of variations (Forsyth 2012). The maximum principle is a recent development of calculus of variations (Pontryagin 1987). As for dynamic programming, it was first established by (Bellman 1966); it is a multistage method of optimization and can be employed to solve for optimal regulatory strategies.

Although the classical calculus of variations is well developed for solving the policy variable of unconstrained optimization problems, the variable is subject to certain restrictions in real life (Calvo 1978; Chang et al. 1992). For example, in the optimal control of human population, the production coefficient is generally subject to constraints. It cannot be infinitely large or negative. Since the 1960s, modern control theory has enjoyed rapid development and wide range applications. Successful flies of satellites, attitude controls of space crafts, rocket launches and accurate flights, and other sophisticated technologies have seen the work of optimal control theory (Chang et al. 2015; Millner and Dietz 2015). However, optimal control theory has suffered from great challenges when used to solve for a sustainable optimal path for economic development. That is because each economic system represents a large-scale complex system of many variables, which makes solving large-scale nonlinear dynamic economic systems by employing the maximum principle involve an enormous amount of computation. Therefore, it is more difficult to solve a large-scale nonlinear dynamic economic system for its optimal development path than to manipulate a satellite or a spacecraft in the sky. It represents one of the challenges facing modern science.

17.3 Several Typical Forms of Optimal Regulation of Economic Systems

The exchange rate, as the rate of exchange of different currencies, is the bridge that connects the domestic economy with the world economy. Whether or not the level of the exchange rate is appropriate and whether or not the exchange rate is maintained basically stable affect not only the domestic economy but also the world economy. They greatly influence the international relations (Cushman 1983; Campa and Goldberg 2005; Haidar 2012). If the currency exchange rate system of an economy experiences severe shocks, especially if it suffers from rapid depreciation of a large magnitude, then the domestic currency will likely face the uncontrollable risk of large-scale depreciation, causing unsettlements in the international and domestic markets and worries in investors and policy makers (Li et al. 2015a, b; Li 2016; Polat and Payaslıoğlu 2015). If such unsettling and worrisome moods cannot be defused and eliminated, they can potentially cause the panic fears of the exchange market to spread, leading to greater damages to the stable development of the domestic economy and the financial markets both internal and external to the nation. Historically, it has been quite common to see the disastrous economic and financial aftermaths as caused by instabilities or collapses of exchange rates or the exchange rate systems. The collapse of the exchange rate systems of some South American countries led to long-term economic downturns and rising unemployment, making it difficult for these countries to recover even with many years of effort (Fratzscher 1998; Kaminsky and Reinhart 1998). The Asian financial storm in 1997 caused the exchange rate of Thai baht to collapse and created such a shadow of fear that still cannot be erased today (Montes 1998; Mishkin 1999a; Kawai 1998). Even for the developed nations, the exchange rate system of the United Kingdom also experienced shocks, creating very noticeable consequences (Fratianni and Artis 1996; Buiter et al. 2001). So, when the currency of an economic system might experience an uncontrollable risk of major depreciation, the monetary authority of the economic system would generally adopt different fiscal and monetary means to lower the market expectation of such major currency depreciation. In the implementation of these strategies, timely stabilization of the currency, minimizing the loss, and other objectives would become the major concerns of the policy decision-makers. In the following, we will look at several forms of optimal control (regulation) that are commonly seen during the implementation of stabilizing monetary strategies.

Example 17.1 The problem of fast stabilization within shortest time

When the currency of an economic system depreciates quickly due to some external disturbances, the monetary authority often uses such strategies as selling foreign exchange reserves, raising interest rate, etc. to swiftly lower the market expectation that the domestic currency would depreciate further in order to stabilize the domestic currency. For example, due to the Ukraine crisis, crash of international oil prices, and other factors, at the end of 2014, the ruble, Russian currency, experienced a crash-type fall with the exchange rate against the US dollar breaking 1:80, the historical low and a decline of over 50%. On December 15, 2014, Russian central bank spent nearly US$2 billion in its attempt to stop the fall of ruble. Before 1:00 a.m. in the morning of December 16, Russian central bank raised its benchmark interest rate from 10.5% to 17% in order to slow down or stop the continued depreciation of ruble. That was the sixth raise of interest rate in 2014. Although Russian government helped ruble stop its depreciation and begin rebound through interest rate hikes and sales of the US dollar, as affected by the crash in oil prices and the Western economic sanctions, the exchange rate of the ruble against the US dollar still experienced a fall of over 40% for the year of 2014, representing the largest annual decline since the debt default in 1998 (Zhu and Han 2015; Li 2015).

The aforementioned event indicates that when the currency system of the domestic economy experiences a crisis, the monetary authority hopes to stabilize its currency within a shortest period of time. That is to say, if the initial state of the currency system is x_0, then through employing a certain measure, the state of the system is transformed to the predefined state x_f, while hoping the time needed for the transition is the shortest. That is, find $u(t)$ so that under its effect, we have $x(t_f) = x_f$ while minimizing

$$J(u) = \int_{t_0}^{t_f} dt = t_f - t_0.$$

Example 17.2 The problem of fast stabilization with minimal energy

When a currency depreciates quickly, the monetary authority often employs such strategies as interest rate hikes and sales of foreign exchange reserves to materialize the stabilization of its currency. However, in implementing these strategies, the monetary authority might also hope to reach the expected goals while applying the least intensity of the measures. A good example to this end is the counter attack of the HK dollar during the Southeast Asian financial crises in 1998 (Goldstein 1998; Wang 1998).

In 1997, with the recovery of the US economy, in order to curb inflation, the Fed raised interest rate, causing the hot money to return to the United States and consequently a global tightening of liquidity. In July 1997, Thailand was forced to abandon its fixed exchange rate, and the consequent financial storm swept through eastern Asia, Russia, Latin America, and other markets. Asian stock markets and exchange rates were under great downward pressure. By taking the opportunity, international speculators carried out attacks on Thai baht, Indonesian rupiah, Malaysian ringgit, and other currencies with fixed exchange rate regimes and profited handsomely. During this time period, the HK dollar, which was pegged to the US dollar with a linked exchange rate regime, did not get ultimately spared from the event. In 1997 and 1998, the HK dollar suffered from four rounds of attacks:

1. In October 1997, international speculators attacked Hong Kong market the first time. They sold HK dollar massively in the currency market, causing the exchange rate of HK dollar to decline, and banks to sell HK dollar to the HK monetary authority, making the liquidity of HK dollar to tighten and the interbank rate to rise to 300%. Although the exchange rate of HK dollar was held steady successfully, the tightened liquidity still caused the HK stock market to crash majorly, which helped the speculators to realize their profit in the stock market.
2. In January 1998, Indonesian financial crisis broke out, causing capital flight also from Hong Kong. HK monetary authority passively bought in HK dollars. Although the purchase affected the liquidity of interbank capital and triggered a rise in the interbank rate, the rising rate did help to contain the capital flight. Because of the rapid rise in the interbank rate, the interest rates of the deposits governed by the *Interest Rate Rules* of Hong Kong Association of Banks and the best lending rate quoted by the major banks went up 75 basis points on January 12. In the middle of January, the devaluation pressure on the HK dollar gradually receded, and the interbank offered rate also started to fall.
3. The Asian financial crisis continued to ferment. In June 1998, a speculative devaluation pressure on the HK dollar reappeared, and the situation of capital outflow once again was contained by the reduced amount of liquid interbank capital and rising interest rate of the HK dollar.
4. During the first half year, by making their sufficient and advanced arrangement, international speculators attempted to conduct a large-scale manipulation crossing foreign exchange market, stock market, and futures market. A large number of hedge funds borrowed HK dollars earlier through issuing low-interest-rate HK dollar bonds in the money market (the total amount of such bonds issued during January–July 1998 reached HK$30 billion) and then shorted a large number of stock index futures during the months of June and July (the total number of open interests of the stock index futures contracts went up from 70,000 in June to 92,000 in early August). And in early August, the situations in Russia and Latin America got worse; the market also started to worry that Hong Kong would give up its pegged exchange rate system. The speculators collectively threw out their borrowed HK dollars by employing the environmental conditions hostile to the HK dollar in order to pressure the exchange rate of the HK dollar. According to the rules of the currency board, Hong Kong monetary authority could only buy in HK dollars and release US dollars by continuously using the foreign exchange reserves. That caused a squeeze on the HK dollar and made the stock market crash, which benefited the speculators who shorted the stock index futures. However, if at that particular moment the rules of the currency board were abandoned, it would be equivalent to reconstructing a new currency issuance system and an exchange system. The impact would be more than that of breaking up a fixed exchange rate regime; it would greatly

affect the market confidence on Hong Kong government and Hong Kong financial markets; and the prices of stocks and other financial assets would also crash.

In order to combat the cross-market manipulation behaviors that threaten the stability of the financial system, Hong Kong government took actions in the stock market and the futures market simultaneously by purchasing the stocks of the Hang Seng Index components and contracts of Hang Seng Index futures. At the same time, Hong Kong government maintained the stability of interest rate and exchange rate by depositing the HK dollars purchased with exchange fund into banks. In the futures market, Hong Kong government drove up the price of August Hang Seng Index futures that the speculators held a large number of short positions and pressed down the price of September Hang Seng Index futures, while making the price difference huge. That forced the speculators to absorb losses when they had to roll their positions. With the firm and generous intervention of Hong Kong government, on August 28, the delivery date of the futures contracts, Hang Seng Index settled steadily at 7829, which was much higher than the speculative cost of shorting the index. The Hong Kong government was victorious in this currency war. With the follow-up introduction of supplementary measures, speculative capital was contained, and the HK dollar crisis subsided. Along with the recovery of Hang Seng Index, the Hong Kong government gradually sold out its stocks; the exchange fund not only recovered its foreign exchange funds but also made profits. For more details, please consult with (Forrest 2014) and relevant references there.

Evidently, through spending relatively low prices, the Hong Kong government revolved the crisis of fast depreciation of its currency by employing response measures and methods. For such a process, we can use the following form of optimization to describe: let the initial state of the currency system of the economy be x_0. Then through utilizing a certain measure, one can convert the state of the currency system to a pre-determined state x_f while hoping that the cost of the measure and policy price $u(t)$ applied to reach the state are minimal. For the sake of convenience of communication, we will refer the costs of the measure and policy as the energy consumption of the economic system. That is, we solve for $u(t)$ such that $x(t_f) = x_f$, and the following is minimized:

$$J(u) = \int_{t_0}^{t_f} u^T u dt.$$

More generally, there are differences in the effort levels, such as the scale of foreign exchange reserves, interest rate bearable by the economic system, etc., at which the monetary authority implements its measures and policies. In such a case, the objective function can be modified to be the integral of the weighted sum of squares of the control variable u_i, that is,

$$J(u) = \int_{t_0}^{t_f} u^T R u dt.$$

Example 17.3 The problem of optimal policy adjustment for overheating economies

When an economic system is overheating, the relevant departments of the government need to intervene with the economic development through adopting certain fiscal and monetary policies. To prevent the overheating economy from hard landing and to avoid consequent adverse effects on the economic growth, there is a limitation on the capability of how fiscal and monetary policies of the economic system is able to mobilize to intervene with the state of the economy. Appropriate policy adjustments can effectively not only intervene with the overheating in the economic development but also avoid lasting negative effects on the future growth. Since the policy space available for intervening the overheating economy is directly proportional to the absolute value of the administrative push $u(t)$ for lowering the economic heat, the objective function for optimally adjusting the overheating economy through policies can be taken as

$$J(u) = \int_{t_0}^{t_f} \mid u(t) \mid dt.$$

Example 17.4 The problem of currency state regulator of the economy

In order to prevent the economic system from suffering from an imminent currency crisis of crashing devaluation, the economy should constantly monitor the state of its currency system that adequate warnings could be provided. When the state $x(t)$ of the currency system deviates from the expected stable state $x_c = 0$, one can use the integral of the sum of squares of the state variable to measure the accumulated error. In this case, the objective function for the state regulator of the currency system can be defined by

$$J(u) = \int_{t_0}^{t_f} x^T(t)x(t)dt.$$

Generally, the objective function is taken as the integral of a weighted sum of squares of the state variable:

$$J(u) = \int_{t_0}^{t_f} x^T(t)Qx(t)dt.$$

When the deviation of the terminal point needs to be emphasized, take the objective function as follows:

$$J(u) = \frac{1}{2}x^T(t_f)Fx(t_f) + \frac{1}{2}\int_{t_0}^{t_f} x^T Qxdt.$$

In this case, the control $u(t)$ needs to have constraints; otherwise the optimal solution would require an infinite amount of energy. By removing the constraint on the required control energy, the following objective function can be considered:

$$J(u) = \frac{1}{2}x^T(t_f)Fx(t_f) + \frac{1}{2}\int_{t_0}^{t_f} \left(x^T Qx + u^T Ru\right)dt$$

where F, Q, and R are matrices of weights.

Example 17.5 The problem of monitoring the currency system

When monitoring the currency system, other than using the integral of the sum of squared differences between the state $x(t)$ of the system and the desired stable state $x_c = 0$ as measurement of error, one can also let the trajectory $x(t)$ of the state of the currency system trace a desired trajectory $x_d(t)$. For example, to maintain the stability of the domestic currency, many nations peg their exchange rates with the US dollar. In such a case, the objective function of optimal regulation can be taken as follows:

$$\begin{aligned} J(u) = &\frac{1}{2}\left[x(t_f) - x_d(t_f)\right]^T F\left[x(t_f) - x_d(t_f)\right] \\ &+ \frac{1}{2}\int_{t_0}^{t_f} \left\{[x(t) - x_d(t)]^T Q[x(t) - x_d(t)] + u^T Ru\right\}dt. \end{aligned}$$

Because there are infinitely many situations involved in economic systems, there is no way we can list them all. So, instead in this section, we only look at five situations of optimal regulation that are commonly encountered in the study of economic systems.

17.4 Empirical Cases of Optimal Regulation Problems

As a bridge that connects the domestic economy with the rest of the world, the exchange rate needs to be within an appropriate range. Its relative stability affects not only the domestic economy but also the world economy and international relations. If the currency of an economic system experiences continued devaluation, it can cause worries in the markets, which are both internal and external to the economic system, in investors and even in the policy decision-makers. If such worries were not defused and eliminated timely, they could create and spread panic fears in exchange markets, which in turn would cause major damages to the stability of the economy and financial markets that are both internal and external to the economy.

Historically, there have been a good number of cases where exchange rate fluctuations and collapse of the existing exchange rate regimes led to consequent economic and financial disasters. In the 1990s, the collapse of the existing exchange rate regimes caused some of the South American nations to suffer from long-term economic downturns and highly escalated unemployment rates and experienced many difficult years of recovery. The 1997 Asian financial storm collapsed exchange rate regime of the Thai baht, creating a still inerasable shadow of fear for the Southeast Asian countries. As for developed nations, the exchange rate regime of England had also suffered from attacks with huge effects on all aspects (Fratianni and Artis 1996; Buiter et al. 2001). In fact, changes in the exchange rates of small economic systems can only create slight dents on their trading partner countries. However, a currency devaluation of a major industrial nation can affect the balance of payments of other countries and destabilize the international finance, will ignite trade wars and currency wars, and alter the outlook of the world economy. On the other hand, by maintaining the basic stability of the exchange rate, the economic system can expand exports, reduce the possibility of deflation, ease employment pressure, lower market uncertainty, and reduce business transaction costs, all of which help to create a favorable environment for economic development. Additionally, stable exchange rate could bring forward financial stability for the economic system. That could in turn help to expand the demand for imports, leading to expanding exports of other economic systems. Therefore, maintaining the stability of exchange rate plays not only an important role in the healthy development of the domestic economy but also a significant role in other correlated economic systems.

Therefore, when the currency of an economic system starts to depreciate, in order to maintain the stability of the currency, the economic system generally employs the method of selling its foreign exchange reserves and buying in the domestic currency to reduce the liquidity of the domestic currency in the market place. For example, during the 1998 financial crisis, at the onset of the baht crisis, the Thai government attempted to stabilize its domestic currency by selling off a large amount of the US dollar and repurchasing in baht from the market (Montes 1998; Lauridsen 1998). However, such an operation generally requires the economic system possess large foreign exchange reserves, and during such a process the government often looks at how to reach its goal of stabilizing the currency with the least amount of outlay of the foreign exchange reserves. Such a practical problem we will refer to as the soft landing of the exchange rate fluctuation.

Example 17.6 The soft landing problem of the exchange rate fluctuation

Foreign exchange reserves stands for the commonly acceptable foreign currencies, held by the national monetary authority, that are prepared for making up the deficit in international payments and maintaining the stability of the exchange rate of the domestic currency. It makes up a portion of the international reserves. A certain scale of foreign exchange reserves represents an important method for the nation to adjust its economy and to maintain its internal and external balance. When there is a deficit in international payments, using the foreign exchange reserves can help balance the payments; when the domestic economy experiences an imbalance with the aggregate demand greater than the aggregate supply, the foreign exchange reserves can be mobilized to organize imports so that the relationship between the aggregate supply and aggregate demand can be adjusted, promoting macroeconomic balance. When the exchange rate suffers from fluctuations, foreign exchange reserves can be utilized to make the rate approach stability. Hence, foreign exchange reserve is an indispensable tool useful for realizing economic balance and stability. And it is more so with the current developing economic globalization with which one nation's economy can easily be affected by the economy of another nation.

A sufficient amount of foreign exchange reserves can support the monetary authority to effectively interfere with the foreign exchange market and back the exchange rate of the domestic currency. It can guarantee the economic system to calmly deal with unexpected financial risks, to satisfactorily intervene with the foreign exchange market, and to meet the demand of maintaining the stability of the exchange rate of the domestic currency. The good performance of Renminbi (RMB) after the outbreak of the 1997 Asian financial crisis (Halloran 1998) is an example showing that having a sufficient amount of foreign exchange reserves plays an important role in stabilizing the value of the domestic currency and in maintaining investors' confidence.

In the following, we construct an optimization model for the soft landing of the varying exchange rate of the domestic currency of an economic system. Assume that the currency experiences a severe depreciation move after the economic system suffers from an external shock. At moment $t = 0$, the monetary authority starts to stabilize the exchange rate of its currency by selling its foreign currency reserves and by tightening the liquidity of the domestic currency. In other words, by selling foreign currency reserves, the monetary authority creates frictions for the falling exchange rate in order to manage a soft landing for the exchange rate so that at moment t_f the exchange rate reaches the predefined target.

Assume that the amount of foreign currencies owned by the economic system at time t is $m(t)$; the resistance to the fall of the exchange rate, created by selling foreign currencies, is $u(t)$; the distance between the depreciating exchange rate and the expected rate is $h(t)$; and the market's expected speed of the currency depreciation is $v(t)$. Let $t = 0$ be the moment when the monetary authority starts its manipulation in its attempt to stall the depreciation. Then the mathematical model for the soft landing problem of the exchange rate fluctuation of the domestic currency is

$$\begin{cases} \dfrac{dh}{dt} = v, h(0) = h_0 \\ m\dfrac{dv}{dt} = u(t) - mg, v(0) = v_0 \\ \dfrac{dm}{dt} = -Ku(t), m(0) = M + F(0) \end{cases}$$

where K is a constant, representing the resistance coefficient with every unit of the foreign exchange reserve sold on the depreciation of the domestic currency, g the acceleration of the currency depreciation, which is also a constant. Assume that at moment t_f a soft landing is materialized. That is, we have

$$h(t_f) = 0, v(t_f) = 0$$

Because the amount of the foreign exchange reserves owned by the economic system that can be employed to intervene with the foreign exchange market and to maintain the stability of the domestic currency is limited, assume that the maximum resistance that is created by mobilizing the limited amount of the foreign exchange reserves that can be used for intervening with the foreign exchange market and for maintaining the stability of the domestic currency is $u_{\max}$. Then $u(t)$ needs to satisfy the following constraint:

$$0 \le u(t) \le u_{\max}.$$

Now, the soft landing problem of fluctuating exchange rate of the domestic currency becomes: find the optimal strategy $u^*(t)$ of selling foreign exchange reserves satisfying $0 \le u \le u_{\max}$, $h(t_f) = 0$, and $v(t_f) = 0$ so that the mobilized amount of foreign currency reserves is the minimum, that is, maximize the objective function:

$$J(u) = m(t_f).$$

Example 17.7 The steepest soft landing problem of overheating economies

By overheating it means that the speed of the economy development is not proportional to the supply of resources. When the development speed is higher than the affordability of resources, the short supply will push the prices of raw materials higher, which in turn will push the overall prices of goods higher, showing the phenomenon of an overheating economy. The basic characteristic of an overheating economy is that the aggregate demand is greater than the aggregate supply that causes the overall price index to rise continuously.

Economic overheating is often instigated by excess liquidity. The regulatory tools available for monetary policy considerations of this area consist of two types: price type (interest rate) and quantity type (deposit reserve rate). Raising the deposit reserve rate could reduce the quantity of money in circulation by banks, while raising interest rate elevates the cost of financing and the return of savings, which helps to direct capital to flow back to banks so that the adverse effect of surplus funds on the normal operation of the economy is avoided. These tightening policies could slow down the economic growth; if not appropriately employed or the timing is not suitable, these policies could lead to a hard landing for the overheating economy.

The hard landing of the overheating Japanese economy in the 1980s led to serious repercussions for Japan (Hoshi and Kashyap 2000). During the mid- and later 1980s, Japanese economy enjoyed a huge trade surplus with the United States and grew rapidly. To resolve the US-Japan trade deficit, in September 1985 Japanese government signed Plaza Accord with the G5 nations of the West to increase the flexibility of exchange rates. After signing the Accord, Japan implemented interest rate liberation policies, making the yen strengthening against the US dollar and the European currencies.

The appreciation of the yen triggered a global wave of Japanese acquisitions, while it also caused the prices of Japan's exported products to rise and the international competitiveness of Japan's products to slide. To remain competitive, Japan's traditionally most competitive industries, which hired massive numbers of industrial workers, were forced to relocate their labor-intensive productions aboard in order to lower the wage costs. The outflow of large numbers of jobs and industries contributed to the so-called industrial hollowing, causing consumer confidence and purchase power of the ordinary people to fall continuously. The shrinking market caused by the sluggish domestic demand further accelerated the progress of the industrial hollowing. Therefore, Japanese economy was trapped in a vicious circle.

To stimulate domestic investment and consumption and to reduce unemployment, Japanese government adopted monetary policies. Starting in 1986, the central bank of Japan continuously cut the interest rate, reducing the benchmark interest rate to 2.5% in February 1987 from 4.5% in January 1986. However, those industries with extremely high productivities could not accommodate the excessive amounts of capital. So, the capital with very low costs flooded into such nonproduction areas as stocks, real estates, etc., which caused the prices of stocks and real estate properties to rise drastically within a very short period of time. Those investors who made huge gains in the market once again confidently expanded into their new rounds of investment by using newly acquired funds from banks with their financial securities and real estate properties as collaterals. So, the prices of the stocks and real estate properties were further lifted higher. Because of the unstoppable rise in the housing price index, the rational investment of the public was gradually evolved into a feverish speculative gambling; Japan's economy was embarking on a bubbling trip one step after another, showing a false prosperity.

In 1989, Japanese government finally realized that the prices of stocks and real estate properties were overly overvalued with the bust of the bubble predestined. So, the government turned to tightening monetary policies. Starting in 1990, the stock market began to fall sharply, and in 1992 the bubble of the real estate property market popped. Although at the time when the international speculators escaped Japan did not suffer from a similar monstrous disaster as those suffered by

Thailand, Indonesia, South Korea, and others, which almost collapsed the entire respective national economic systems, the capital flight still caused huge and long lasting damages to the powerful Japanese economy. Not only instantly was the wealth created over a long period of time by the Japanese nationals handed over to others, but also avalanche-kind crash in the stock and real estate property prices created a hard landing for the Japan's economy. Ever since, Japanese economy fell into a quagmire for over 10 years, known as the "lost 10 years" (Inoue and Okimoto 2008).

What is in stark contract was the soft landing of the overheated Chinese economy of the 1990s. The time period when economic overheating staged a classic show in China was the early part of the 1990s. During that time span, Chinese GDP grew over 10% 1 year after another because the aggregate demand was obviously greater than the aggregate supply, and elevated inflation continued for several years. During 1992 and 1993, the economic growth of China reached 13% per year, surpassing the potential economic growth rate by 4%, and accordingly the issuance of the currency grew 34%. During these 2 years, investments were, respectively, up to 70% and 40%, while the price of production materials went up 50%. The inflation rate was beyond what China's economy could bear, showing the sign for a hyperinflation to appear.

In 1993, Chinese government started to employ its economic control by adopting the so-called double-tightening economic policy, *a comprehensive investment and consumption austerity* and *a moderate fiscal and monetary tightening policy*, in its attack of the bubble economy and in its suppression of the overheated economy. These policies helped steadily and gradually lower the two-digit growth rate back down to the appropriate range of within 10%. After simultaneously employing various economic, administrative, planning, and market instruments, the elevated inflation rate of China's economy dropped to 8.3% in 1996 from 21.7% in 1994 while the economic growth maintained its rate of 9.7%. By 1997, China's inflation rate was lowered to 2.8%, while the economic growth rate was 8.8%. That is, Chinese economy had smoothly materialized a soft landing (Zhou et al. 1998).

An overheating economy can not only make the inflation of the economic system severely elevated but also cause repeated investment, production overcapacity, and large backlog of products. At the same time, a lot of hot money will also enter the economic system into strongly speculative industries, such as real estate, stock market, energy, and others. Once these hot money withdraw suddenly from the economic system, the economic bubble will bust, making the economic system face a great risk. Therefore, how to make an overheating economy land softly within an appropriate short time period is an important objective of the policy making of the economic system's decision-makers. In the following, we construct an optimal regulation model for the soft landing of an overheating economy.

Assume that at time $t = 0$ the decision-makers of the economic system start to utilize fiscal and monetary policies to land the overheating economy softly by reducing the money supply, and at time t_f the state of the economy reaches the pre-determined objective. Assume that as of the time t_f, the economic system needs to reduce a total amount m of money, while at time t the adopted fiscal and monetary policies create a resistance $u(t)$ for the overheating of the economy, the distance between the state of the overheating economy and the expected objective is $x_1(t)$, and the expected speed of worsening of the overheating economy is $x_2(t)$. Then a mathematical model for the soft landing problem of an overheating economy is

$$\begin{cases} \dfrac{dx_1}{dt} = x_2, x_1(0) = x_{10} \\ \dfrac{dx_2}{dt} = \dfrac{1}{m}u - g, x_2(0) = x_{20} \end{cases}$$

where x_{10} and x_{20} stand, respectively, for the distance between the state of the overheating economy and the expected objective and the market's expected heating speed of the economy at $t = 0$, and g is a constant, representing the worsening acceleration of the overheating economy without any external influences.

Assume that the maximum resistance fiscal and monetary policies could create for the overheating of the economy is $u_{\max}$. Then the steepest soft landing problem for an overheating economy is: find the optimal fiscal and monetary policies $u^*(t)$ such that $|u| < u_{\max}$, $x_1(t_f) = 0$, $x_2(t_f) = 0$, and $J(u) = \int_0^{t_f} dt = t_f$ is minimized.

Example 17.8 The optimal control problem of a production inventory system

The state equation of a production inventory system is

$$x(k+1) = x(k) + u(k) - S(k).$$

Let $u(d)$ and $x(d)$ be, respectively, the ideal production and stocks of the production inventory system. Then the class of optimal control problems of production inventory systems is: find the optimal control sequence $u(0), u(1), \cdots, u(N-1)$ that minimize the objective function

$$J(u) = \sum_{k=0}^{N-1} \left[h(x(k) - x_d)^2 + c(u(k) - u_d)^2 \right]$$

where $h > 0, c > 0$ are coefficients.

17.5 Some Final Words

This chapter formulates the problem of how to optimally regulate the financial system through the means of fiscal and monetary policies by using the language of control theory. After the concept is symbolically established, we look at five different particular problems of optimization and then three empirical scenarios on when different versions of optimal regulation or control would come into play. What is laid out in this chapter is expected to pave the road for further follow-up studies on how to optimally design and adopt fiscal and monetary policies when the otherwise healthy economic system faces economic challenges.

Chapter 18
Steepest Optimal Policies for Regulating Capital Flows and Exchange Rates

Jeffrey Yi-Lin Forrest, Yirong Ying, Zaiwu Gong, Guosheng Zhang, and John Golden

Contents

This chapter investigates how an economic system should adjust its exchange rate and capital movement within the shortest time possible in order to reduce the disastrous aftermath of a financial crisis to the minimum. The main results of this chapter are produced by employing the logical thinking of general systems theory and the analytical manipulation of control-theory models.

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In particular, this chapter establishes an elementary model for the steepest optimal regulation problem, symbolically derives at a solution of the model, and clearly spells out the systemic significance of the solution and how the solution could be practically applied in the design of the trajectory of financial reforms. The results obtained herein imply that as one of the follow-up research topics, one should look at empirical case analyses with real-life data. Such empirical analyses would provide additional insights into how to apply the results of this chapter. Other than the fact that the results obtained in this chapter are new and practically useful, the discussions in this chapter have the potential of opening up a brand-new research direction in terms of fiscal and monetary policy making.

18.1 Introduction

Major financial crises since the start of the 1990s have profoundly impacted the world economy through creating disastrous aftermath (Forrest 2014). To this end, this chapter starts with the impossible trinity and explains why steepest optimization problem for an economic system to adjust its exchange rate and capital control within the shortest time possible is extremely important by visiting the British pound crisis in 1992, Asian financial crises in 1997, and Russia's "foreign exchange corridor" of 1998. After this background information is clearly laid out, the paper establishes an elementary model to describe this problem, proposes a method to theoretically solve the model along with a geometric intuition about what the solution indicates, and then provides practically useful guidelines on how an economy should reform its system of capital movement and exchange rate regime. Comparing to the existing literature, which is cited throughout the rest of this chapter, on the general systems theory in general and control-theory methods in particular, this chapter establishes its practically useful results.

The rest of this chapter is organized as follows: Section 18.2 reviews the impossible trinity and demonstrates how different combinations of the trinity actually appeared in history. Section 18.3 establishes an elementary steepest optimal regulation model to describe the floating exchange rate and capital control of an economic system. Section 18.4 looks at how to solve the optimal regulation model established in the previous section symbolically. Section 18.5 explores a symbolic expression of the steepest reform path, and Sect. 18.6 provides a systemic understanding of the solution of the steepest optimal regulation problem while providing some practically useful guidelines on what kind of financial reform path should be implemented. And this chapter is concluded in Sect. 18.7 by relating what is addressed herein with real-life problems that face the current world economy.

18.2 Three Different Combinations of the Impossible Trinity

In 1963, Robert Mondell established the Mundell-Fleming model, published his article, entitled "capital mobility and stabilization policy under fixed and flexible exchange rates', and was one of the early scholars who expounded the macroeconomic instability under the condition of capital flow. He put forward the well-known "impossible triangle law" and, therefore, fully disclosed the inherent macroeconomic conflicts (Mundell 1963). After the Asian financial crisis of the 1990s, Paul Krugman clearly stated the principle of the "impossible trinity" (Krugman et al. 1999). This principle states that no nation can simultaneously achieve the following three financial goals: monetary policy independence, exchange rate stability, and free movement of capital; instead, only two of these three goals can be concurrently selected.

The three corners of the triangle in Fig. 18.1 represent, respectively, the following three macroeconomic goals: free movement of capital, monetary policy independence, and exchange rate stability, while the three edges, respectively, capital control, floating exchange rate system, and fixed exchange rate system. If a floating exchange rate system is selected, then the nation has to give up the option of having stable exchange rate and cannot have independent monetary policies; and when comprehensive capital controls are implemented, the nation has to sacrifice free capital mobility.

Most nations, if not all, like to maintain a full convertibility of currencies without any regulatory requirement in the areas of importing, exporting, and exchanging, while achieving international financial integration. Each nation hopes that it could maintain its independent monetary policy, the process for its

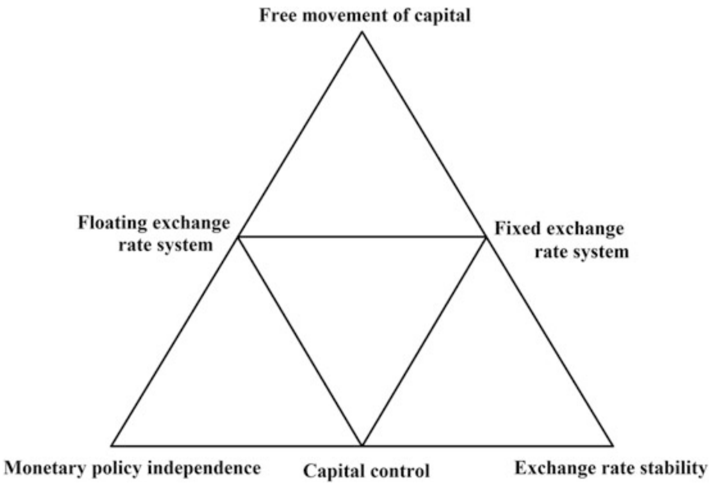

Fig. 18.1 The impossible trinity

monetary policy to play its role without any interference from foreign capital, and effective self-adjustment according to the domestic environment and that it could cope with its recession by lowering the interest rate and with inflation by raising the interest rate. Every nation also hopes to maintain the exchange rate stability for its currency so that the rate only fluctuates within the allowed range in order to promote the development of international trades and economic and financial stability, resist the impact of financial crises.

Looking back to history leads to a clear discovery: all the institutional arrangements of different times have been constrained by the impossible trinity. Under the gold standard, people selected the combination of free movement of capital and stable exchange rates. Consequently, nations did not have autonomous monetary policies. Within the Bretton Woods system, the combination of self-directed monetary policy and exchange rate stability was selected in order to maintain the stability of exchange rates. Each nation had to implement strong capital controls, leading to poor capital liquidity. Under the Jamaica system, most advanced industrial nations selected to open their capital markets to the outside world, while at the same time they did not want to lose their monetary policy independence. Therefore, they chose the floating exchange rate regime. Since the floating exchange rate regime was widely implemented, foreign exchange markets have often experienced high volatilities in exchange rates. No matter which combination of selections is made, one of the three major financial objectives has to be given up; each nation at each time period is working on the problem of selecting two out of three possible choices.

1. If one nation wants to maintain its monetary policy independence and complete liquidity of capital, then it has to sacrifice the stability of the exchange rate of its currency and implement the floating exchange rate regime. Monetary policy independence implies that the central bank makes macroeconomic adjustments according to the domestic economic situations without being interfered by political and other factors. The economy of a nation goes up and down alternatively according its own cycles. So, when the capital can move freely, there naturally appear large-scale capital outflows (when the economy is depressed) and inflows (when the economy is looking good); and frequent inflows and outflows of domestic and international capital cause the situation of international payments unstable. If the domestic monetary authority does not intervene, that is, maintains its monetary policy independence, then the exchange rate of the domestic currency will have to fluctuate frequently along with changes in the supply and demand of money. By adjusting the exchange rate to the level that truly reflects the economic reality, the monetary authority can improve the import and export payments and influence the movement of international capital. Although exchange rate adjustment itself suffers from flaws, implementing a floating exchange rate regime indeed resolves the difficulty of "selecting among the difficult three" relatively well. However, for the nation which suffers from a financial crisis, especially if it is a developing nation, the existence of confidence crises can greatly weaken the effectiveness of exchange rate adjustment, and it

can even play the role of making the financial crisis worse. When exchange rate adjustment is not effective, in order to stabilize the situation, the government might eventually decide to use capital control.

2. For a nation to maintain its monetary policy independence and exchange rate stability, the nation has to sacrifice complete liquidity of capital and implement capital control. Under the serious impact of a financial crisis, if the strategy of exchange rate depreciation is ineffective, then implementing capital control becomes a unique choice. By implementing such a strategy, the government in fact tries to maintain the stability of its exchange rate and monetary policy independence by sacrificing the complete liquidity of capital. Most economically underdeveloped nations, such as China, select and implement this policy combination. That is because, on one hand, these nations need relatively stable exchange rate systems to maintain their stable economic ties with the outside world, and on the other hand, due to their weak regulatory capabilities, these nations cannot effectively manage the capital that moves freely.
3. To maintain complete movement of capital and the stability of the exchange rate, the nation has to abandon the independence of its domestic monetary policies. According to the Mundell-Fleming model, when capital moves completely freely, if a fixed exchange rate regime is adopted, then the effect of any alteration in the domestic monetary policy will be neutralized by the consequent capital movements so that the domestic currency loses its autonomy. Under such conditions, the nation would either join a monetary union or much more rigorously implement a currency board system; the situations would make it difficult for the nation to adjust its domestic economy by introducing independent monetary policies based on the domestic economic situation. The most the nation could do is to maintain its fixed exchange rate regime by passively adjusting the domestic interest rate within a short period of time when faced with speculative attacks. Hence, to materialize complete liquidity of capital and stability of exchange rate, the domestic economy has to pay the great price of abandoning monetary policies. The British pound crisis and the sharp currency depreciations caused by the Southeast Asian financial crises of the 1990s and Russia's ruble crisis of 1998 are all classical cases of when a sovereign state had to abandon its exchange rate promise.

18.2.1 The British Pound Crisis in 1992

In 1979, in order to stabilize the economic decline, lower the inflation, and prepare for the monetary integration, both France and Germany proposed to create a European monetary system so that each member nation's currency would be linked to the European currency unit.

At the beginning, United Kingdom was not a member of the monetary system. However, it eventually joined the exchange rate mechanism in 1990 while stipulating the exchange rate of 2.95 mark per British pound with a floating range of ±

6.0%. Under the leadership of Deutsche Bank, the exchange rate mechanism worked well; the inflation of the entire Europe was lowered. However, what was implied was that in order to maintain the exchange rate mechanism, the Bank of England, the central bank of United Kingdom, would have to be subject to the monetary policies of the central bank of Germany.

In 1989, Berlin Wall fell and German unification appeared. That greatly increased the fiscal expenditure of German government. So, German central bank issued additional currency and caused steady rise in inflation. To combat the inflation, German central bank raised its interest rate. However, the raised interest rate placed an appreciation pressure on the mark. To maintain the established exchange rates, other central banks were also forced to raise their interest rates. To protect the national credit and to honor the promise to the linked exchange rate, England did not let the pound depreciate.

At this junction, international speculative capital recognized the fact that England's weak economy and high unemployment would not allow England to maintain such a policy for long. George Soros, a representative of the international hot money, started to take his actions by selling British pounds valued over US $10 billion on the collateral of US $1 billion, all of his worth and by sufficiently employing futures and options. Other international speculators followed the suit; the pound experienced sharp sell-off under heavy downside pressure.

At the beginning, the Bank of England strived to maintain the exchange rate mechanism and bought in over 17 billion pounds by mobilizing its foreign reserves. However, the effect of the intervention was limited; the pound fell to the lower limit of its fluctuation range and faced crisis.

On September 16, 1992, to improve the attractiveness of the pound, the Bank of England raised interest rate from 10.0% to 12.0% and to 15.0% several hours later. However, these interest rate changes did not alter the market expectation; speculators did not budge and continued their shorting of the pound, while the Bank of England continued its purchase of the pound until 7:00 p.m. when United Kingdom announced its withdrawal from the exchange rate mechanism and return the interest rate back to 10.0%. Within 24 h, the pound slumped nearly 5000 points (Rausch 2013; Dury 2011; Litterick 2002).

18.2.2 Asian Financial Crises in 1997

Before the 1997 crises broke out, many investors were attracted by the future outlook of Asian countries, such as Malaysia, Indonesia, the Philippines, Thailand, etc. Large amounts of capital flew into the region while mainly concentrated in real estate markets and stock markets. After implementing the fixed exchange rate system that was pegged to the US dollar, these countries obtained external loans. With the domestic currencies pegged with the dollar, the stability of exchange rates promoted that of the financial markets, which in turn stimulated foreign trades. The economic growth encouraged speculators to establish long positions in Asian currencies, which pushed up the value of Asian currencies.

In 1997, it became more and more difficult for these Asian countries to cope with the increasingly expanding deficits in international payments and to maintain the then-current speed of growth by relying on external financing, while internal corruptions shook the economic foundation. Asset quality deteriorated rapidly, capital outflowed, and the stretched foreign reserves of these Asian countries evaporated quickly. Although central banks attempted to intervene, none availed. So, these countries renounced the fixed exchange rate system, leading to large-scale sellings of their currencies. Large magnitude depreciations followed with Thai baht depreciating as much as 48.0% and then nearly 100.0% the following year. The currencies of other Southeast Asian countries also depreciated similarly or more severely (Radelet and Sachs 1998a; Rajan and Zingales 1998).

18.2.3 Russia's "Foreign Exchange Corridor" of 1998

During 1995 and August 1998 after the Soviet Union disintegrated, Russia implemented "foreign exchange corridor," which means that the Russian government stipulated the floating rate range for the exchange between the ruble and the US dollar, known as exchange rate margin, in order to make the exchange rate of ruble relatively stable.

With the effect of the Asian financial crises, a large number of foreign capitals withdrew from Russian markets. From October 28, 1997 to November 10 of the same year, Russian stock market fell sharply in the scale of 30%, which also brought disasters to the bond and foreign exchange markets. After Russian central bank's bailout, there were still more than US $10 billion that flew outward. During May and June, 1998, the total amount of Russian domestic debts and foreign debts reached such a high level as US $200 billion with the debt service reaching 58% of the fiscal expenditure of the government budget. At the same time, Russian parliament amended the law and changed the proportion of shares held by foreign capital in Russia. That exacerbated the flight of international capital; the yields of Russian treasury skyrocketed to 80%, ruble depreciated severely, and nobody was interested in financial assets.

Attempting to stabilize the financial market, Russian government expanded the upper limit of floating exchange rate of ruble against the US dollar from 1:6.295 to 1:9.5, that is, proactively depreciated ruble by 50%, and delayed payments for national debts. With investors' confidence totally shattered, the stock market, bond market, and foreign exchange market all plummeted (Chiodo and Owyang 2002; Gobbin and Merlevede 2000; Online NewsHour 2010).

18.3 An Elementary Steepest Optimal Regulation Model

All the afore-described historical facts indicate that each economic system has to make certain trade-off selections from among the three macroeconomic objectives: free movement of capital, independence of monetary policy, and exchange rate stability of the domestic currency. To respond to financial crises that might appear and to insure the effectiveness of independent national monetary policy, the economic system needs to have a degree of free movement of capital and a certain level of floating exchange rate regime. That is, the economic system has to undertake a certain financial reform. Hence, the decision-makers of the economic system would face such a problem: given the economy's magnitude of the economic system, how could one design the path of financial improvement so that the current state of capital control and the current exchange rate system reach the pre-determined objective state within a relatively short period of time? In the following we will establish an elementary steepest optimal regulation model to reflect the floating exchange rate and limited capital control of the economic system in order to provide the necessary decision support for designing a path for financial improvement of the economic system.

Assume that the economic magnitude of the economy is M. To maintain the autonomy of the monetary policy of the economic system and to implement some appropriate control on the free movement of capital and some effective management of the exchange rate fluctuation, the monetary authority needs to reform its current financial management. If the state of free capital movement and the exchange rate policy at the start of the reform is denoted as A, then our problem becomes: Along what path should the financial policy of the economic system be reformed so that it would take the shortest time for the current state of capital control and the exchange rate policy to be adjusted to the pre-determined objective state B? We will refer this problem to as the steepest optimal regulation problem regarding the capital movement and exchange rate control of the economic system.

Now, let us abstractly imagine the previous problem on the two-dimensional plane in Fig. 18.2, and we want to know along which curve the state of the economic system located at point A would be adjusted through a financial reform to point B with the shortest time. In particular, we set the origin of the coordinate system at point A, the initial point of our reference, with the horizontal x-axis representing the float of exchange rate and the vertical y-axis the magnitude of free movement of capital. Assume that the financial reform follows the curve $y(x)$, that when the economic system is adjusted to the location (x, y), the growth rate of the economic development is v, and the economic momentum is $mv^2/2$. This economic momentum is determined by the potential of change in the state of free capital movement. Without loss of generality, assume that the momentum and potential at point A are zero. Then at point (x, y), we have

$$\frac{1}{2}mv^2 = mgy \tag{18.1}$$

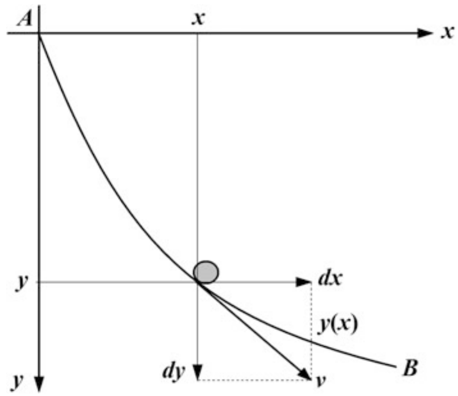

Fig. 18.2 The problem of steepest optimal regulation

where g stands for the acceleration of the economic development of the economy as caused by the free movement of capital.

At point (x, y), the growth rate of the economic system is dx/dt along the horizontal direction and dy/dt along the vertical direction so that the overall growth rate v is

$$v = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \times \frac{dx}{dt}$$

Insert Eq. (18.1) into this equation provides

$$\sqrt{2gy} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \times \frac{dx}{dt}$$

from which we obtain

$$dt = \frac{\sqrt{1 + \left(\frac{dy}{dx}\right)^2}}{\sqrt{2gy}} \times dx. \tag{18.2}$$

If the first coordinate of point B in Fig. 18.2 is x_1, then the time t needed to move from point A to point B is

$$t = \int_0^{x_1} \frac{\sqrt{1 + (dy/dx)^2}}{\sqrt{2gy}} dx$$

By combining what is discussed above, we obtain the following model for the steepest optimization problem for the regulation of floating exchange rate and limited capital control of an economic system:

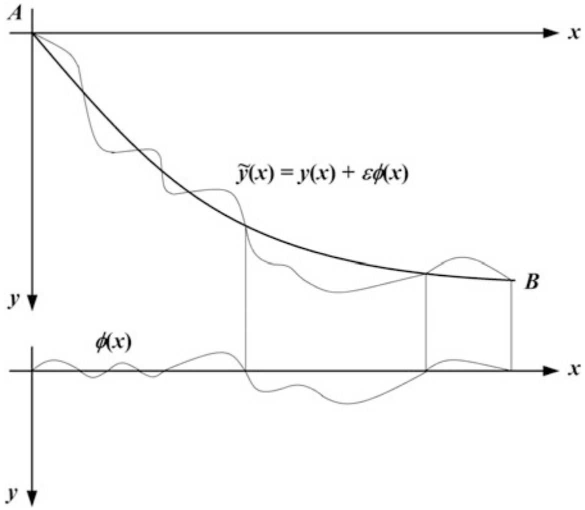

Fig. 18.3 A slight change to the optimal path

$$\begin{cases} \min \quad t = \int_0^{x_1} \frac{\sqrt{1 + (dy/dx)^2}}{\sqrt{2gy}} dx s.t \quad y(0) = 0, y(x_1) = y_1 \end{cases} \tag{18.3}$$

Because points A and B are fixed, this is referred to as a fixed boundary extreme value problem, where at point A, $x = 0$ and $y = 0$; and at point B, $x = x_1$ and $y = y_1$. Since the integrant in Eq. (18.3) is a function in y and dy/dx, the general extreme value problem of fixed boundary can be modelled as follows:

$$\begin{cases} \min \quad J = \int_{x_0}^{x_1} F(x, y(x), dy/dx)dx \\ s.t \quad y(x_0) = y_0, y(x_1) = y_1 \end{cases} \tag{18.4}$$

where J is the objective value, (x_0, y_0) and (x_1, y_1) the fixed end points, and $y(x)$ the optimal curve we solve for.

18.4 Solving the Optimal Regulation Model

Firstly, let us assume that $y(x)$ is an optimal path that makes the objective value J minimum. Now, we let $y(x)$ change slightly as shown in Fig. 18.3. By adding $\varepsilon\phi(x)$ to $y(x)$, we obtain another curve.

From Fig. 18.3, it follows that $y(x)$ and $\tilde{y}(x) = y(x) + \varepsilon\phi(x)$ are related as follows:

$$\begin{cases} \text{When the optimal curve } y(x) \text{ changes to } \tilde{y}(x) = y(x) + \varepsilon\phi(x) \\ \text{The corresponding } dy/dx \text{ changes to } \frac{d\tilde{y}}{dx} = \frac{dy}{dx} + \varepsilon\frac{d\phi}{dx} \end{cases} \tag{18.5}$$

where ε is an arbitrary small real number, $\phi(x)$ an arbitrary continuously differentiable function such that $\phi(x_0) = \phi(x_1) = 0$.

When a slight change is applied to the optimal path $y(x)$, the objective value also changes accordingly. For example, if the time spent for the economic system to reform its finance from state A to state B along path $y(x)$ is t_1, and the time from state A to state B along $\tilde{y}(x)$ is t_2, then $t_2 - t_1 \geq 0$. So, in terms of Eq. (18.4) with slight change in $y(x)$ the change in the objective ΔJ is:

$$\begin{aligned} \Delta J &= \int_{x_0}^{x_1} F\left(x, y(x), +\varepsilon\phi(x), \frac{dy}{dx} + \varepsilon\frac{d\phi}{dx}\right) dx - \int_{x_0}^{x_1} F\left(x, y(x), \frac{dy}{dx}\right) dx \\ &= \int_{x_0}^{x_1} \left[F\left(x, y(x), +\varepsilon\phi(x), \frac{dy}{dx} + \varepsilon\frac{d\phi}{dx}\right) - F\left(x, y(x), \frac{dy}{dx}\right)\right] dx \geq 0 \end{aligned} \tag{18.6}$$

By using the following variable institutions,

$$\frac{dy}{dx} = z, \Delta z = \varepsilon\frac{d\phi}{dx}, \Delta y = \varepsilon\phi$$

Eq. (18.6) is simplified into:

$$\Delta J = \int_{x_0}^{x_1} \left[F\left(x, y(x) + \Delta y, \frac{dy}{dx} + \Delta z\right) - F\left(x, y(x), \frac{dy}{dx}\right)\right] dx \geq 0. \tag{18.7}$$

By employing Taylor expansion, we obtain the following equation ($\Delta x, \Delta y, \Delta z \to 0$):

$$\Delta F = F(x + \Delta x, y + \Delta y, z + \Delta z) - F(x, y, z) = \frac{\partial F}{\partial x}\Delta x + \frac{\partial F}{\partial x}\Delta y + \frac{\partial F}{\partial x}\Delta z$$

Because $\Delta x \to 0$, this equation becomes

$$F(x, y + \Delta y, z + \Delta z) - F(x, y, z) = \frac{\partial F}{\partial x}\Delta y + \frac{\partial F}{\partial x}\Delta z.$$

Substituting this equation into Eq. (18.7) produces

$$\Delta J = \int_{x_0}^{x_1} \left(\frac{\partial F}{\partial x}\Delta y + \frac{\partial F}{\partial x}\Delta z\right) dx \geq 0.$$

By noticing that $\Delta y = \varepsilon\phi$ and $\Delta z = \varepsilon d\phi/dx$, the previous equation becomes

$$\Delta J = \int_{x_0}^{x_1} \left(\frac{\partial F}{\partial x}\varepsilon\phi + \frac{\partial F}{\partial x}\varepsilon\frac{d\phi}{dx}\right)dx = \varepsilon\int_{x_0}^{x_1} \left(\frac{\partial F}{\partial x}\phi + \frac{\partial F}{\partial x}\frac{d\phi}{dx}\right)dx \geq 0.$$

Because ε can be any positive or negative real number, the following must hold true:

$$\int_{x_0}^{x_1} \left(\frac{\partial F}{\partial y}\phi + \frac{\partial F}{\partial z}\frac{d\phi}{dx}\right)dx = 0$$

which can be simplified into

$$\int_{x_0}^{x_1} \frac{\partial F}{\partial y}\phi dx + \int_{x_0}^{x_1} \frac{\partial F}{\partial z} d\phi = 0.$$

By using the method of integration by parts, the previous equation is simplified into

$$\int_{x_0}^{x_1} \frac{\partial F}{\partial y}\phi dx + \frac{\partial F}{\partial z}\phi\bigg|_{x_0}^{x_1} - \int_{x_0}^{x_1} d\left(\frac{\partial F}{\partial z}\right) \times \phi = 0 \tag{18.8}$$

Because $\phi(x)$ satisfies the following property

$$\phi(x_0) = \phi(x_1) = 0,$$

we have

$$\frac{\partial F}{\partial z}\phi\bigg|_{x_0}^{x_1} = \frac{\partial F}{\partial z}\bigg|_{x_1}\phi(x_1) - \frac{\partial F}{\partial z}\bigg|_{x_0}\phi(x_0) = 0.$$

Therefore, Eq. (18.8) is further simplified into

$$\int_{x_0}^{x_1} \frac{\partial F}{\partial y}\phi dx + -\int_{x_0}^{x_1} \frac{d(\partial F/\partial z)}{dx}\cdot\phi\cdot dx = \int_{x_0}^{x_1} \phi\left[\frac{\partial F}{\partial y} - \frac{d(\partial F/\partial z)}{dx}\right]dx = 0.$$

Because ϕ is an arbitrary non-zero curve and the previous integral is equal to constant 0, the following must hold true:

$$\frac{\partial F}{\partial y} - \frac{d(\partial F/\partial z)}{dx} = 0$$

By substituting $z = dy/dx$ into the previous equation, we obtain the following well-known Euler problem (formula):

$$\begin{cases} \dfrac{\partial F}{\partial y} - \dfrac{d}{dx}\left(\dfrac{\partial F}{\partial y}\right) = 0 \\ \dot{y} = \dfrac{dy}{dx} \\ \text{boundary condition}: \begin{cases} y(x_0) = y_0 \\ y(x_1) = y_1 \end{cases} \end{cases} \tag{18.9}$$

What is shown above is that the extreme value problem with known initial economic state and pre-determined objective state for the economy could be simplified to solving the Euler problem in Eq. (18.9), the optimal solution $y(x)$of which can be obtained theoretically. Although it is not an easy task to solve the Euler problem in general, for each particular economic situation, specific method needs to be employed in order to solve the Euler problem.

18.5 A Symbolic Expression for the Steepest Reform Path

In this section, we use the Euler formula to solve the symbolic model of the steepest reform path as given in Eq. (18.3). Let

$$F = \frac{\sqrt{1 + (dy/dx)^2}}{\sqrt{2gy}} = F(x, y), \dot{y} = \frac{dy}{dx}. \tag{18.10}$$

Differentiating F with respect to x provides

$$\frac{d}{dx}F(y, \dot{y}) = \frac{\partial F}{\partial y}\frac{dy}{dx} + \frac{\partial F}{\partial \dot{y}}\frac{d\dot{y}}{dx}.$$

Because

$$\begin{aligned} \frac{d}{dx}\left(F - \frac{\partial F}{\partial \dot{y}}\dot{y}\right) = \frac{d}{dx}F(y, \dot{y}) - \frac{d}{dx}\left(\frac{\partial F}{\partial \dot{y}}\dot{y}\right) \\ = \frac{\partial F}{\partial y}\frac{dy}{dx} + \frac{\partial F}{\partial \dot{y}}\frac{d\dot{y}}{dx} - \frac{d\dfrac{\partial F}{\partial \dot{y}}}{dx}\dot{y} - \frac{\partial F}{\partial \dot{y}}\frac{d\dot{y}}{dx} \\ = \left[\frac{\partial F}{\partial y} - \frac{d}{dx}\left(\frac{\partial F}{\partial \dot{y}}\right)\right]\frac{dy}{dx} \end{aligned}$$

and the Euler formula in Eq. (18.9) implies that the previous expression is 0, we have

$$F - \frac{\partial F}{\partial \dot{y}}\dot{y} = c, c \text{ is a constant} \quad (18.11)$$

which is the Euler formula without explicitly showing F as a function in x (that is, $F$is only a function in y and $\dot{y}$). In other words, when we need to solve the steepest optimal regulation problem regarding the capital movement and exchange rate control, F is only a function in variables y and $\dot{y}$. By substituting Eq. (18.10) into Eq. (18.11), we have

$$\frac{\sqrt{1+(dy/dx)^2}}{\sqrt{2gy}} - \frac{\partial\left(\frac{\sqrt{1+(dy/dx)^2}}{\sqrt{2gy}}\right)}{\partial y} \cdot \dot{y} = c, \dot{y} = \frac{dy}{dx}. \quad (18.12)$$

Because

$$\frac{\partial\left(\frac{\sqrt{1+(\dot{y})^2}}{\sqrt{2gy}}\right)}{\partial y} = \frac{\dot{y}}{\sqrt{2gy} \times \sqrt{1+(\dot{y})^2}}$$

from Eq. (18.12) we obtain

$$\frac{\sqrt{1+(\dot{y})^2}}{\sqrt{2gy}} - \frac{\dot{y}}{\sqrt{2gy} \times \sqrt{1+(\dot{y})^2}} \cdot \dot{y} = c$$

Multiplying both sides of this equation by $\sqrt{2gy} \times \sqrt{1+(\dot{y})^2}$ leads to

$$1 + (\dot{y})^2 - (\dot{y})^2 = c \times \sqrt{2gy} \times \sqrt{1+(\dot{y})^2}$$

that is,

$$1 = c^2 \times 2gy \times \left[1 + (\dot{y})^2\right]$$

and

$$y \times \left[1 + (\dot{y})^2\right] = \frac{1}{c^2 \times 2g} = c_1, c_1 \text{ is a constant.} \quad (18.13)$$

Letting $\dot{y} = cot\varphi$ and substituting it into Eq. (18.13) produces

$$y = \frac{c_1}{1 + (\dot{y})^2} = \frac{c_1}{1 + cot^2\varphi} = c_1 sin^2\varphi = \frac{1}{2}c_1(1 - \cos 2\varphi) \tag{18.14}$$

Because

$$dx = \frac{dy}{dy/dx} = \frac{dy}{\dot{y}} = \frac{dy}{\operatorname{ctg}\varphi}$$

from Eq. (18.14), we have

$$dx = \frac{c_1 \sin 2\varphi \times d\varphi}{\operatorname{ctg}\varphi} = \frac{2c_1 \sin\varphi \times \cos\varphi \times d\varphi}{\cos\varphi / \sin\varphi} = 2c_1 \sin^2\varphi d\varphi.$$

Integrating both sides gives

$$x = c_1\left(\varphi - \frac{1}{2}\sin^2\varphi\right) + c_2.$$

This expression and Eq. (18.14) jointly give us the solution of our steepest optimal regulation problem:

$$\begin{cases} x = c_1\left(\varphi - \frac{1}{2}\sin^2\varphi\right) + c_2 \\ y = \frac{1}{2}c_1(1 - \cos 2\varphi) \end{cases} \tag{18.15}$$

which is the parametric equation of a cycloid that is the curve traced by a point on the circle of radius c_1 as the circle rolls along the x-axis straight line (Fig. 18.4).

From Fig. 18.4, it follows that AG = the length of arc DG, the measurement of the angle DOG is 2φ, and the length of arc DG is $(c_1/2) \times 2\varphi$. When the particular point is at location D, its x coordinate is

$$x = AK = AG - DH = \frac{1}{2}c_1\varphi - \frac{1}{2}c_1\sin^2\varphi = \frac{1}{2}c_1(2\varphi - \sin 2\varphi)$$

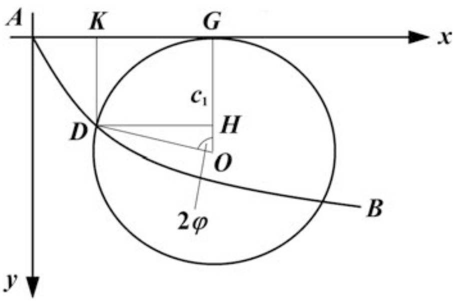

Fig. 18.4 How a cycloid is formed

which is the same as the x-value given in Eq. (18.15), and its y coordinate is

$$y = GH = \frac{1}{2}c_1 - \frac{1}{2}c_1 \cos 2\varphi = \frac{1}{2}c_1(1 - \cos 2\varphi)$$

which is the same as the y-value given in Eq. (18.15).

As of this point, we have completely resolved the steepest optimal regulation problem regarding the capital movement and exchange rate control of the economic system with fixed boundary.

18.6 Systemically Understanding the Solution of the Steepest Optimal Regulation Problem

From Bjerknes circulation theorem (Wu and Lin 2002), it follows that anything can start to spin when its density (or internal structure) is uneven; and the more uneven the internal structure is, the more twisting force the thing is under and the faster the thing spins. In other words, the internal unevenness of the thing creates twisting force that naturally leads to the appearance of a spin field that surrounds the thing. In terms of economic systems, because of the internal differences in economic developments, geographical locations, natural resources, labor qualities, levels of investments, etc., there is always unevenness with each and every economic system. Such unevenness creates a spin field that surrounds the economic system. According to the yoyo model of the general systems theory (Lin 2008), the economic system can be seen as a spinning yoyo. Additionally, along with the globalization of the world economy, the domestic economic policies are established to be in line with the international practice, while the economic system gradually opens up to the outside world. Such exchanges with the outside world make the yoyo structure of the economic system naturally placed under the effect of the yoyo field of the outside world. Because exchanges with more developed economic systems can bring in advanced technology, mature management systems, equipment, new information, etc., the yoyo structure of the outside world can be seen as being at a higher level. When the spin field of a yoyo structure is influenced by that of another yoyo structure of a higher level, the form of the internal movement of the former economic system will change accordingly.

Hence, to be in line with the international practice while still guaranteeing the independent effectiveness of the domestic monetary policy, the economic system needs to take certain measures of financial reform in order to perfect the domestic system of capital movement and exchange rate regime. At the same time, changes in how capitals flow and how exchange rate is set will reconfigure the production factors that are internal to the economic system; and the reconfiguration of production factors will lead to changes in the spinning intensity of the yoyo structure of the economic system. To this end, general systems theory (Lin 1999, 2008) tells us that when the internal spinning intensity of the economic system is high; the entire

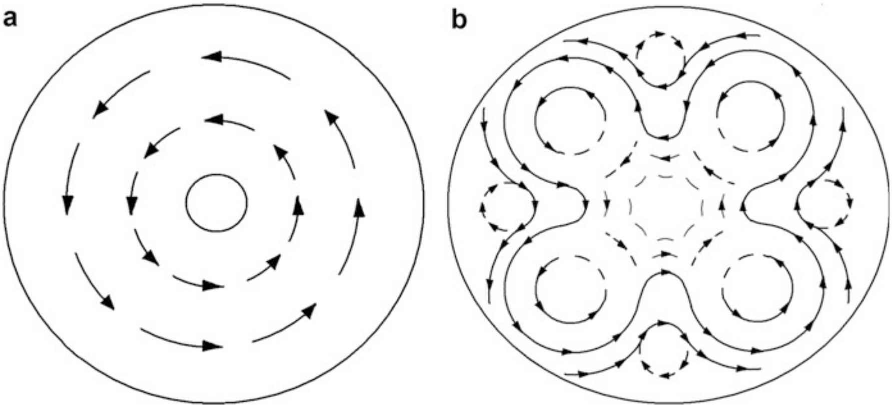

Fig. 18.5 Evolution of an economic system under intense policy changes

economic system will evolve from a relatively orderly state (Fig. 18.5a) into a chaotic state (Fig. 18.5b).

So, the solution, obtained in the previous section, to the steepest optimal regulation problem regarding the capital movement and exchange rate control of the economic system with fixed boundary indicates to us that when an economic system reforms its system of capital movement and exchange rate regime, one conservative method is to make the reform route gradual, similar to the trajectory of a cycloid. Especially, when the state of the internal development of the economic system is not mature enough to handle various outside pressure and disturbances, such an approach of gradual change should be adopted. If, instead, a linear full-scale reform measure is implemented, it will greatly increase the difference in the spin intensities within the yoyo structure of the economic system, which will cause chaos to appear within the economy. That will in turn create hidden dangers to the economic security of the economic system. For example, the real cause beneath the breakout of the 1998 financial crisis in Thailand is exactly what is described here (Montes 1998; Mishkin 1999a; Kawai 1998). On one hand, the internal economic development in Thailand suffered from various problems; on the other hand, a linear type financial reform measure, complete liberation of capital movement, was adopted. Such a measure caused additional unevenness in the internal configuration of the economic development factors, which eventually led to breakout of the financial crisis.

18.7 Some Final Words

Capital control with fixed boundary for an individual economic system has been an extremely sensitive problem in the liberation process of the capital accounts of the five BRICS nations (Zaman, et al. 2016). As a matter of fact, the liberation of a capital account is a gradual process; it includes several main steps: (1) gradually relax capital controls, (2) allow citizens and noncitizens to hold cross-border assets and to trade their assets, and (3) materialize free exchange of currencies (Yuan and Chen 2015). For the five BRICS nations, including China, capital account liberation has its advantages and disadvantages. Firstly, the domestic financial industry faces large external shocks. For example, since China started to implement the policy of reform and opening up to the outside world, the commodities market was the first to experience shocks. It can be expected that as the capital account opens up further, the entire financial industry of China will also face large external shocks. For example, let us look at the insurance industry, which is seen as a sunrise industry in China. Recognizing its huge potential, foreign invested insurance companies have vied for China. The high percentage of foreign invested and jointly funded insurance companies will have profound impact on China's insurance industry. Most directly, the high percentage will alter how competition of China's insurance industry will play out; additionally, shocks will appear in the areas of technology, management, and organizational culture (Ying 2015). Secondly, a large number of international hot money inflows. For China, capital inflows are mainly through direct foreign investments, qualified foreign institutional investors, and the B-share stock market. Although since 2005 there has been less influx of international hot money in terms of statistics, such money has still entered China in large amount by being disguised as trade capital in order to stay out of the surveillance. That explains why China has experienced increasing amount of international investments. In general, excessive inflow of international hot money can cause credit expansion, overinvestment, and other adverse economic consequences for the receiving nation (Syriopoulos et al. 2015). At the same time, if for whatever reason the outflowing nation withdraws its hot money, it can cause the nation's foreign reserves to dwindle and interest rate to change drastically, forcing many ongoing projects to stop and making the entire economy fall potentially in chaos.

Additionally, the steepest optimization problem for exchange rate adjustment represents another unignorable important problem. Since the 1990s, along with the relaxation of capital controls and acceleration in the globalization of financial markets, currency competition has crossed national borders and entered deeply into the territories of sovereign countries. Various currencies have gradually formed their own spheres of influence, and the international system of currencies has evolved into such a competitive structure that it is dominated by a few strong currencies (Meng 2016; He et al. 2016). At 1:00 a.m. of Beijing time on December 1, 2015, the International Monetary Fund officially announced that China's Renminbi (RMB) will join the SDR (special drawing right) on October 1, 2016, which represents an important milestone in China's integration into the world financial system and a recognition of China's progress made in the past years in the reform of currency and financial systems (Wang and Gao 2015).

Kawai and Pontines (2016) believe that having acquired the qualification of being an "international reserve currency" means that in the coming mid- and long-term period of time, foreign reserves would flow to Renminbi. Presently, the foreign reserves of world central banks hold such a number of SDR units that is approximately equal to US $282 billion. The proportion of RMB in the world foreign reserves is very small and is equal to about 1% of the world reserve assets totaling over the worth of US $11300 billion (Wang and Gao 2015). As estimated by UBS AG, a Swiss global financial services company, if by 2020 the proportion of RMB rises to 5%, it might mean in the coming 5 years, assets worth approximately US $80–100 billion will flow into RMB each year (Wang and Gao 2015).

As for RMB as the fifth dominant currency to be formally accepted into the international "basket of reserve currencies," a signed article in the "economy" section of the paper "Süddeutsche Zeitung" points out (Cankao Information Network 2015) that it was due to political considerations that the Western powers abandoned their obstruct attitude; these considerations have given Beijing sufficient face, because they vividly demonstrate that in these past years the world economy has experienced huge power shifts, which is not a temporary phenomenon but will be for long term. In fact, in terms of the heavy-weight nations of the IMF, the United States, Japan, Germany, France, and England, they also looked at similar overall considerations. Firstly, those representatives of the old world economic order hope that with the rising status, China would also assume more international responsibilities and participate in more coordinating organizations. Secondly, the West hopes that the relevant decisions could help strengthen the force of reform in Beijing so that its liberation policy would get on a path of no return, where the liberation policy includes further opening of China's market, providing foreign companies with better investment conditions, and slowly deregulating the present rigorous control of China's capital account.

To make RMB a freely convertible currency, China still needs to make a lot of hard effort in terms of its floating exchange rate. As for RMB becoming one of dominant currencies, it is merely of a symbolic significance, because whether or not it carries any substantive significance only the global business practice of the coming years can demonstrate. Additionally, although RMB becomes the fifth currency in the basket of the international reserve currencies, China still has to implement a lot of supporting measures of reform in order to reach the state that similar to the US dollar and the Euro, RMB can be completely freely traded. To this end, China still has a long way to go.

Chapter 19
The Problem of Optimal Path for Financial Reform

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Contents

This chapter studies the problem that when an emerging market economy attempts to emerge into the process of economic globalization and financial integration, how could it design a quickest path of financial reform in order to avoid potential crises and to minimize the disastrous aftermath of crises? All the results obtained herein are established by using methods of systems modeling and analyses of control theory.

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After successfully modeled the general problem of concern, necessary conditions are established for the steepest financial reform path problem with variable boundaries. As a particular scenario, this chapter also looks at the situation of limited resources so that the resources should be rationally employed with the greatest economic effect generated. This chapter is the first of its kind on how to theoretically design a quickest path of financial reform while reducing the disastrous aftermath of economic crises to the minimum. The results are expected to provide practically useful guideline for policy decision-makers.

19.1 Introduction

With financial reforms, some of the emerging market economies suffered greatly from severe financial crises due to various reasons, one of which is some kinds of structural weaknesses that exist in the economic systems. That is, in order to improve the situation and to promote sustained economic growth, each emerging market economy needs to undertake economic reforms. To this end, this chapter explores the problem of how to design a concrete path of financial reform for an economic system through analyzing the characteristics of the steepest reform path with variable boundaries from the angle of optimal financial development.

The rest of the chapter is organized as follows: By reviewing the relevant literature, Sect. 2 poses the problem of concern: find the steepest optimal reform path with variable boundaries. Section 3 investigates the details on how to model the situation and how to solve the model. Section 4 studies a special case: the problem of fixed amount of money, which implies that when the available amount of money within an economic system is fixed, the limited amount of money can be rationally employed to generate the greatest economic effect. Section 5 concludes the discussion of this chapter.

19.2 The Problem to Be Addressed

Since the 1970s, along with the continuous development of financial liberation and globalization, developed nations implemented financial liberation and loosened up financial regulations. Especially, during the end of the 1980s and the start of the 1990s, all the industrialized nations accelerated their processes of capital account liberation (Table 19.1) and in terms of the form of liberation, most of the developed nations evolved gradually (Luo 1996).

With changes in the international currency system, development of information technology, relaxation of regulations, and strengthening integration of financial globalization, the nations of emerging markets also implemented a series of financial reforms and measures of capital account liberation. Influx of international capital helped to fill the gaps existing in savings and investments, while providing

Table 19.1 Some developed nations' times of capital account liberation

Nation	Time of capital account liberation	Nation	Time of capital account liberation
United States	1973	Germany	1981
Japan	1980	Australia	1983
Holland	1986	Denmark	1988
France	1989	Austria	1990
Belgium	1990	Italy	1990
Finland	1990	Norway	1990

Table 19.2 Financial crises during 1975–1997 and corresponding losses in output

Type of crisis	Type of nation	# of crises	Mean recovery time (year)	Accumulated loss in output (%)
Balance of international payments	Industrial nations	42	1.9	5.6
	Emerging markets	116	1.5	7.6
	Total	158	1.6	7.1
Bank crisis	Industrial nations	12	4.1	15.2
	Emerging markets	42	2.8	14
	Total	54	3.1	14.2
Twin crisis	Industrial nations	6	5.8	17.6
	Emerging markets	16	2.6	18.8
	Total	22	3.2	18.5

the necessary funds for and satisfying the demands of consumption and investment. So, in their economic development, emerging market nations, on one hand, enjoyed the abundant returns of globalization and, on the other hand, suffered from the great pains inflicted on them by financial crises. What is shown in (Zhang 2009b indicates that during the time period of the so-called financial repression from 1945 to 1971, there appeared 38 financial crises, 7of which were twin crises, while the emerging market economies experienced only 16 foreign exchange crises, 1 of which was a twin crisis; however, during 1973–1997, a total of 95 financial crises broke out in emerging market economies while developed nations experienced 44. Mussa et al. (1998) collected the statistics of the financial crises that broke out during 1975–1997 and the corresponding losses in the national outputs (Table 19.2). During this time period, the proportions of international payment balance crises, bank crises, and twin crises that appeared to emerging market nations in the world were, respectively, 73.4%, 77.8%, and 72.7%, where a total of 234 such crises were tallied, while 174 appeared to emerging market economies, amounting to 74% of the total. To a great degree, financial crises broke out within emerging market nations with relatively immature financial systems. In other words, emerging markets had been hardest hit by financial crises.

Since the 1990s, the international financial market, which has been based on the liberation of various regional markets, has not been effectively supervised; huge amounts of international capital, especially short-term capital, have moved across national borders freely, making it difficult for East Asian countries to resist their impacts. When there is still immaturity in the development of an economic system, a high degree of financial liberation combined with a fixed exchange rate system can potentially lead to hidden dangers for the economic security of the economic system due to interferences of foreign capital. Specifically when the international economic situation changes, international capital can flow adversely and inevitably creates shocks to the financial industry of the country in transition. As a matter of fact, the 1997 financial crisis of Thailand was partially due to structural problems that inherently existed within the economic development and partially due to the immature liberation of the financial market and the fixed exchange rate system.

During the second half of the 1990s, Thailand and some other Southeast Asian countries gradually entered the upgrading period from labor-intensive industries into capital- and technology-intensive industries. In this period of time, the demand for capital experienced a jumping growth. Because the demand for huge amounts of capital went beyond the domestic capability of finance of those upgrading countries, the needed capital had to be financed on favorable terms from the international financial market. However, because there were breakpoints along the transfer chain of industries, the number of industries transferred out of Asian's "four little dragons" decreased steadily; that made the long-term capital that was carried by the transferring industries and was obtainable by the Southeast Asian upgrading countries drop. At the same time, because of the lack of upgrading industries, large amounts of short-term capitals flew into real estates, infrastructure, and other indirect production areas, making the investment structure imbalanced. That caused an imbalance in the industrial structure and consequently an overall imbalance in the domestic economy (Corsetti et al. 1999; Lindgren et al. 1999).

1. Imbalance in the investment structure led to worsened imbalance in the industrial structure

   In the second half of the 1990s, Thailand's economy boomed, making the domestic investment and consumption explode unprecedentedly. To pursue after high rates of return, many banks and financial firms actively expanded their scales of assets and invested heavily in the high profit but risky real estate, securities industry, and other tertiary service industries, while the investment in the infrastructure, energy, transportation, and other important industries experienced a serious shortage. According to the relevant statistics (Corsetti et al. 1999; Lindgren et al. 1999), after entering the 1990s, Thailand's economy enjoyed a fast growth of an average of 8% per year for nearly 10 years. And behind that high-speed growth, the investment rate was maintained for many years above 40%, a large proportion of which was invested in the real estate industry. Consequently, such investment of distorted proportions inevitably caused surplus in the domestic real estate industry, securities industry, and other tertiary industries. However, the development in infrastructure, energy, transportation, and other important industries that were badly needed for the fast economic growth was seriously lagging behind. That in turn made further economic development not have the necessary stamina and eventually caused the economic growth to slow down, the real estate bubble to bust, the number of banks' bad debts to increase, and the financial payment risks and crisis to go up. Since entering the 1990s, Thailand was in the critical time of industrialization; the requirement for adjusting the industrial structure and upgrading the technology structure needed to be satisfied imminently. However, it was at such a critical time that the imbalance in investment structure caused the lagging industries to lag further behind and the industries with surplus to suffer from additional surplus so that the imbalance in the industrial structure was worsened.

2. The speed of the financial liberation was too fast

   During the second half of the 1980s and the early part of the 1990s, the sustained economic prosperity in Thailand inspired Thai authority to accelerate its process of financial liberation so that Thailand could replace Hong Kong to become the financial center of Asia. Under this background, Thai authority made its currency freely convertible ahead of the right time and at the same time relaxed its financial supervision without considering its domestic economic strength and its ability of financial supervision. As a consequence, what was done impulsively not only provided the opportunity for huge amounts of short-term international hot money that aimed at speculative arbitrage to brazenly wander in and out of country, which affected the stability of the domestic financial market, but also made most of Thai financial organizations operate within high risks due to the relaxed financial supervision. Hence a hidden danger for severe financial crises was bred. As shown in Corsetti et al. (1999) and Lindgren et al. (1999), in Thailand's process of advancing the financial liberation, on one hand, Thai financial and security firms gained considerable development and played very important roles in the financial operations of Thailand. For example, the total assets of 91 financial and security firms of Thailand amounted to one fourth of the country's financial assets and were mainly distributed in the following four high risk areas that were sensitive to market fluctuations: real estate, consumer loans, individual security investment loans, and security investment. During the time from 1993 to 1996, over 50% of the investments of Thailand's financial and security firms were in these four areas. On the other hand, when the real estate market and securities market were overheating, with credit expansion, commercial banks also blindly entered these markets due to a lack of necessary self-discipline and internal control. And from 1993 to 1996, the private sector borrowing as a proportion of the GDP grew from 39% to 123%; and the real estate bad debts of the commercial banks reached US$20 billion, causing crises to numerous banks.

3. Reform in the exchange rate system lagged behind

The Thailand's financial crisis stemmed directly from the lagging reform of its fixed exchange rate system. As shown in Corsetti et al. (1999) and Lindgren et al. (1999), for many years, Thailand's exchange rate only floated within the interval 0.15–0.16%, and the exchange rate system suffered from flexibility. That not only became powerless when the export declined but also could not help effectively regulate the flow of funds and market demand and supply because Thailand's exchange rate and interest rate were not closely lined up.

Theoretically speaking, a fixed exchange rate system has many advantages, such as the convenience for investors to estimate their costs and returns, the convenience for settling international trades, the enhancement of confidence of international investors, the conduciveness to the inflow of foreign capital, the usefulness for controlling inflation, etc. However, the prerequisite for successfully employing the fixed exchange rate system is that the free fluctuations in other prices, such as interest rate, wages, etc., have to follow those of the pegged currency. For example, if pegged to the US dollar, it means that the country will have to follow the macroeconomic policies of the United States without the ability to implement its own independent monetary policy. That implicitly means that these two countries have very similar economic conditions. A difficulty the fixed exchange rate system suffers from is that it is readily to go upward but not downward. For example, if a major economic decision is made based on the fixed exchange rate system, then altering the decision will bear a very high price tag, and if depreciation is necessary, then unnecessary additional depreciation and fluctuations might well be experienced. That is, under the condition of fixed exchange rate and liberated capital market, there is a real danger for currency crisis to break out. At the early stage of Thailand's fast economic development, its exchange rate system could still adapt to the changes of the international financial market. However, with increasing deficit in its current account and decreasing competitiveness in the international arena, the depreciation pressure on Thai baht went up daily. Additionally, due to the sustained strength of the US dollar, Thai authority was forced to intervene in the exchange market in order to maintain its fixed exchange rate with the US dollar by selling a lot of US dollar reserve. That end tightened the domestic money supply, causing it difficult for the central bank to control effectively and flexibly its base currency. When facing the depreciation pressure, Thai authority was also attacked by international speculative hot money. Therefore, the breakout of a currency crisis became inevitable. At the same time, to attract foreign capital in order to make up the deficit in the current account, Thailand correspondingly introduced a high interest rate policy. Although such a policy played its role of stabilizing the value of Thai baht, it also attracted the inflow of a much larger amount of short-term arbitrage capital. That exacerbated the inflation pressure, causing the economic growth stagnant. The increasing number of bed bank debts in turn caused both stock market and foreign exchange market to decline, which greatly shaken the stability in the value of Thai currency. Eventually, Thailand gave up its fixed exchange rate system, the lagging reform of the fixed exchange rate system led to the breakout of the financial crisis, and Thailand paid a heavy price.

In terms of the literature on the relevant topics, the financial deepening theory, as proposed by McKinnon (1973) and Shaw (1973), opened the prelude of financial reforms of developing countries. The financial liberation, consisting mainly of interest rate liberation, access liberation by financial businesses and institutions, and capital account liberation, has become the direction of financial reform for all the developing countries and some developed countries. As for the reason behind the frequent occurrence of currency crises since the 1990s, there are many different explanations, where the theory on the financial liberation, as characterized by capital account liberation, and capital movement that occurs in the process has been noticeable.

Sequencing is one of the important problems studied in the liberation of capital accounts. It started in the debates on why the economic liberation plans of the South American countries failed and on whether it was because of the errors in the design of policies or because of the incorrect sequencing of detailed reform steps. Quite a few scholars (Edwards 1984, 1989a; Choksi and Papageorgiou 1986) believe that the failure of the economic reform of Chile in the 1970s and that of Argentina in the 1980s were originated in the fact that the reforms did not follow the correct sequence and that, because of the problems appearing in the economic transformations, not all markets should be opened simultaneously. After investigating the East Asian experience, Bhattacharya and Linn (1988) believe that the ideal sequence should be first reform the real economic sectors, then financial sectors, and then lastly liberate the capital account. After analyzing the experiences of some developing countries, such as Costa Rica, El Salvador, Guyana, Indonesia, Jamaica, Trinidad, Tobago, and Venezuela, Quirk (1994) points out that there is no need to consider the sequencing problem; instead, capital control can be removed, and exchange rate reform, domestic money market, and credit market reforms can be quickly implemented in order to make the interest rate and exchange rate more flexible. Considering the fact that no government could have unlimited power and could control all policy changes, policy actions need to be implemented in phases (McPherson 1995). Johnston (1998) maintains that the liberation of capital account is sequenced for the purpose of maximizing the benefit while controlling the risk to the minimum. Accompanying the liberation of capital account, there is risk, and the relevant benefits are determined by the implementation of certain prerequisites and the choice of liberation sequence (Schneider 2001). Edwards (2001) shows by employing empirical analysis of cross-nation data that capital account liberation is beneficial for the financial systems of relatively advanced countries and could possibly produce negative effects for countries that have relatively lower levels of financial development. That is, there is a problem of optimal sequencing for the liberation of capital account. Edwards (2002) points out that in terms of the sequencing problem, the main focus of debate is whether to place the liberation of capital account at the early stage of the reform or the later stage. Additionally, the sequencing problems of capital accounts and current accounts and the sequencing of the liberations of various parts of the capital account are also the main focus of study.

After the Asian financial crises of the 1990s, people (Ishii et al. 2002) realized that financial crises might have something to do with capital account liberation. Demirgüç-Kunt and Deragiache (1998) analyzed a set of data collected from 53 countries for the time span from 1980 to 1995. Their results indicate that when the macroeconomy, economic policy, international payments, and some other factors are under control, there is clear positive correlation between financial liberation and financial crises. That is, when the macroscopic economy is very stable, financial liberation can increase the financial fragility of the economy. Mehrez and Kaufmann (2000), Glick and Hutchison (2001), and Noy (2004) also produced the same conclusion: financial liberation can obviously increase banks' fragility. When he investigates the Chilean experience of financial liberation of the late 1970s, Diaz-Alejandro (1985) discovers that the financial liberation brought Chile its financial crisis. Caprio and Klingebiel (1996) learn that, since the late 1970s, bank crises have been increasingly becoming a common phenomenon for countries that have already realized their financial liberation. Weller (2001) discovers based on the economic data of 27 emerging market countries for the time span from 1973 to 1998 that, after materializing financial liberation, these countries are more vulnerable to the attacks of currency crises and bank crises. Through empirical univariate and multivariate analyses of economic data, he discovers that after financial liberation the chance for having bank crises and currency crises increases drastically. Dooley (1995), Edwards (2000), and Rossi (1999) jointly point out that financial liberation could more easily lead to adverse effects for countries of immature financial systems, and if the reform of financial liberation is unfortunately combined with bad policies and institutional environment, then a great financial risk will be created.

Lindgren et al. (1999) point out that liberating the capital account without having the prerequisites satisfied first is extremely risky. Williamson (1998) believes that whether or not an Asian country suffers from the shock of financial crises is whether or not the country has liberated its capital account. There might be a threshold effect for the benefits created by capital account liberation: only when the economy, the system, and the financial market reach a certain set of standards, the country will benefit from its capital account liberation (Kose et al. 2006). Eichengreen, Gullapalli, and Panizza (2011) point out that in order for a nation to benefit from capital account liberation, the institutional and economic developments of the nation have to reach a certain height.

According to the analysis of Demirg-Kunt and Detragiache (1998) for over 50 countries for the time span 1980–1995, it is much easier for financial crises to break out within liberated financial systems (Xu 2008). From the angle of international financial globalization, Agenor (2001) demonstrates the risks that accompany capital account liberation. In its "Transition Report 2009," the European Bank for Reconstruction and Development (EBRD 2009) points out that Eastern Europe obtained the benefit of long-term economic growth from the financial globalization and integration; although cross-border flows of capital caused crisis of the Western Europe to spread to Eastern Europe, it can be said that the effect of financial integration on the Central and Eastern European nations is still of more good than harm. However, measures should still be taken to cope with the financial fragility caused by financial integration. Wang (2009) points out that when looking at the scope and depth of the 2008 global financial crisis, it can be said that Eastern Europe suffered from major shocks and losses; it is essentially because mistakes were made by the Eastern European nations in their transition and development strategies: they sacrificed their economic autonomy and independence. Rodrik and Subramanian (2009) believes that in terms of emerging market countries, financial liberation cannot play the roles of promoting investment, accelerating economic growth, etc.

The fact that emerging markets experienced many currency crises during the 1990s makes more and more economists and decision-makers hold positive attitude toward progressive reforms (Ries and Sweeney 1997). McKinnon (1982) and Edwards (1990) investigate the practical experience of various countries and explain why capital account should not be liberated prematurely. For example, the economic performance of Chile, which liberated its capital account toward the later stage of its reform, was better than Argentina and Uruguay, which liberated their capital accounts at the early stages of their reforms. Cerny (1993) maintains that countries that liberate their capital accounts must conduct their key financial reforms, and capital account liberation should be the last step of their regulatory policies (Kasekende and Martin 1995). Williamson (1997) indicates that it is correct to schedule capital account liberation to the later part of the reform and simultaneous liberation could lead to danger. Guitian (1997) points out that the conditions that must be first satisfied before liberating the capital account might be never met, which means permanent capital control; therefore, capital account liberation should not have any prerequisite. The author also believes that if the external environment is stable and domestic policies are sound, then there is no need to follow any order to liberate the capital account and the current account. A report by a group of government officers from Finland, France, South Korea, Singapore, Thailand, England, and European Union discovers (Nyberg 2001) that there is not any rational, timely, and well-sequenced way for a nation to liberate its markets. Stiglitz (2002) investigates the risks developing countries might experience when they liberate their capital accounts. The author points out that capital account liberation might not bring forward efficiency for developing countries; instead, it would attract the influx of large amounts of hot money so that the chance for financial crises to break out is greatly increased without creating positive effects on the domestic investment, output, and other aspects of the real economy. Kaminsky (2004) analyzes pro-cyclical characteristics of international capital movements. The so-called pro-cyclicality means that large amounts of international capital flow inward when the receiving country enjoys an economic prosperity and outward when the economy of the host country appears to be declining. Such pro-cyclical capital movement exacerbates the price fluctuation, puts pressure on the macroeconomic management, and increases the economic and financial instability of the host country.

Kindleberger (1984) believes that in the past 400 years, on the average one financial crisis broke out in industrialized nations every 10 years, where capital control was one of the important reasons. Since 1973, most developed nations and some developing countries liberated their capital accounts, while the consequence has been very intriguing. Echeverrial et al. (1997) summarize the lessons learned from the failures of capital account liberation of Chile, Indonesia, South Korea, and Thailand. The study in Eichengreen (2001) discovers that since 1880, the occurrence frequencies of financial crises are different from one time period to another. For example, the frequency of financial crises for the period from 1945 to 1973 is clearly smaller than that for the time period from 1973 to 1997, and it is clearly more so for bank crises, in particular, and for the twin currency and bank crises. During the period from 1945 to 1973, each country used capital control and then started to liberate capital accounts. That fact seems to suggest that capital control might have played the important role of inhibiting financial crises. Echeverrial et al. (1997), respectively, investigate Chile, Indonesia, and South Korea for the triggering effect of capital account liberation on the occurrence of financial crises. From the angle of capital movement and herd effect that appear after capital account liberation, Radelet and Sachs (1998a) consider five Asian countries, including Thailand and South Korea, and discover that capital account surplus/GDP is closed related to the occurrence of financial crises, where these authors define a sudden capital movement change from inflow to outflow as a financial crisis. Additionally, after analyzing the 102 financial crises that occurred during 1970 to 1995 in 20 different countries, Kaminsky and Reinhart (1998) discover that with a nation's development of financial liberation, including capital account liberation, and the relaxation of financial supervision, the probability for a financial crisis to occur increases with amassing extent of disastrous aftermath. By employing the method of time series, Sarno and Taylor (1999) conduct an empirical study on the 1998 Asian financial crisis. Their study indicates that all the Asian countries the said crisis touched on shared a common characteristic: with the liberation of capital account, the influx of large amounts of foreign capital caused the prices of domestic assets to swell; after the bubble was greatly inflated, the international hot money withdrew abruptly, causing sharp decline in the domestic foreign exchange reserves until exhaustion, which then leads to the occurrence of the financial crisis. The investigation of Glick et al. (2006) shows that countries that implement capital control are more prone to crises.

By using Indonesia, South Korea, Malaysia, and Thailand during the Asian crisis from 1997 to 1998 as sample countries, Rajan (2007) unveils that for small open economies, capital outflow exacerbates the chance for a financial crisis to occur, while suggesting the adoption of capital control at the brink of occurrence of a crisis in order to ease the negative effects of capital outflow. By considering a large amount of cross-border data, including Central and Eastern European countries, Edwards (2008) analyzes mutual reactions between commercial trades and capital account liberation and how they affect the occurrence of financial crises. Lane and Milesi-Ferretti (2011) examine whether the cross-country incidence and severity of the 2008–2009 global recession are systematically related to pre-crisis macroeconomic and financial factors. They find that the pre-crisis level of development, increases in the ratio of private credit to GDP, current account deficits, and openness to trade are helpful in understanding the intensity of the crisis and that international risk sharing did little to shield domestic demand from the country-specific component of output declines, while those countries with large pre-crisis current account deficits saw domestic demand fall by much more than domestic output during the crisis.

Kindleberger (2015) shows that capital account liberation is negatively correlated to financial stability. Agur and Demertzis (2015) show that the regulator allows interest rate changes to partly "pass through" to bank's soundness by not neutralizing the risk-taking channel of monetary policy. Thus, monetary policy affects financial stability, even in the presence of macro-prudential regulation. Rey (2015) presents that for the past few decades international macroeconomics has postulated the following "trilemma": with free capital mobility, independent monetary policies are feasible if and only if exchange rates are floating. The global financial cycle transforms the trilemma into a "dilemma" or an "irreconcilable duo": independent monetary policies are possible if and only if the capital account is managed. Moraes et al. (2016) analyze the link between monetary policy and capital regulation through the risk-taking channel in Brazil. Their findings suggest that there exists a paradox between the micro-prudential view and the macro-prudential view.

Selecting an appropriate exchange rate system is also one of the important questions that need to be addressed in financial reforms. Goldstein and Turner (1996), Chang and Velasco (1998), and others maintain that the floating exchange rate system can more effectively avoid financial crises and that the fixed exchange rate system cannot satisfy the demand for emerging market countries to stand external shocks. Barry et al. (1996), Calvo and Reinhart (2000), and others believe that the fixed exchange rate system can dampen the impacts of financial crises and reduce inflation so that it is beneficial for the stable economic growth of developing countries. By employing the theory of information asymmetry, Mishkin (1999a) powerfully explains why it is extremely dangerous for emerging market countries to implement the pegged exchange rate system, including those that peg or crawling peg a single currency. Hausmann and Fernandez-Arias (2000) shows that the fixed exchange rate system exacerbates the fragility of the banking system when experiencing adverse shocks from the outside.

Relevant studies show that capital account liberation can optimize the allocation of resources and promote economic development. For example, Bailliu et al. (2001) discover that capital account liberation is beneficial to financial development, which in turn stimulates the economic growth. After carefully summarizing how financial liberation promotes economic growth, Bekaert et al. (2001) conclude that because financial openness affects the cost of capital, opportunity of growth, relaxation of financial supervision, the development of finance, and other aspects of the economy, it promotes investment with increasing efficiency so that financial liberation plays the role of stimulating economic growth. Based on a sample of over 100 countries, Gruben and Mcleod (2002) find that since the early 1990s, capital account openness can obviously lower the inflation so that it plays a stabilizing role for the macroeconomic development.

Based on the literature review above, it can be seen that since the start of the second half of the twentieth century, the characteristics of economic globalization have become increasingly obvious; the speed of economic and financial liberation accelerated gradually. Especially since the time when Iceland, as the last industrialized nation, declared to liberate its capital account, the world has focused on how developing countries would take their next steps. Financial reform, especially capital account liberation, is a double-edged sword. At the same time, when it provides a driving force for the domestic economy, it can also bring forward relatively huge impacts on the domestic economy, especially if it is a developing country with immature economic and financial infrastructure. The 1998 financial crisis in Thailand also indicates that in the process of economic reform, the economic system needs to not only revolve structural problems existing within the system's economic development but also constantly adjust its financial reform strategies according to the economic development situations that are both internal and external to the system. That is, financial liberation and the objectives of exchange rate policy reform do not generally stand for some fixed states. Instead, the government and monetary authorities need to constantly adjust their target state according to the development situation of the domestic economy and changes of the external economic environment. In other words, the target state is really a point located on a curve so that the particular location of the point on the curve varies with time.

From the nineteenth century until the 1930s, panics and crises occurred infrequently, almost once per 20 years, to the banking industry in the United States. The 1929 outbreak of the stock market crash was the most severe financial crisis in the early American history. It brought American economy into the Great Depression from 1930 to 1933. Since the 1990s when Latin American countries started to be open to foreign capital, many countries experienced disastrous financial crises and consequent economic recessions (Mishkin 2006). At the same time, when the liberation of capital accounts helps to increase the movement of capital in developing countries, it also increases the probability for crises to occur (Stiglitz 1998). This fact indicates that the stimulating effect capital account liberation exerts on the economic growth is not as significant as imagined and for developing countries immature capital account liberation would impair their economic growth. The previous review of the literature shows that capital account liberation indeed affects the occurrence of currency crises and that with the development of economic globalization and financial integration, the liberation of any developing country's capital account is under increasing external influences. As for how to take advantages while avoiding disadvantages, in other words, how to enjoy the benefits of liberation while effectively avoiding all risks, the key is to choose the appropriate and operational mode of liberation, including selecting the right degree of openness, the appropriate order of opening, strong supporting policy arrangement, etc.

Therefore, the natural question we will address in the rest of this chapter is to find an optimal path of financial reform with variable boundary conditions. In particular, for an economic system of magnitude M, if we fixate the present financial state A as the initial point of reference, that is, the origin of the Cartesian coordinate system, and assume that the curve of the objective state for the economic system is $\xi(x)$, then for the manager of the financial reform of the economic system, how can he/she design a path $y(x)$ for the financial reform so that the actual financial reform will evolve along the curve of the equation $y(x)$ and reach an objective state point that is located on the curve $\xi(x)$ within the minimum length of time? See Fig. 19.1 for the relevant geometry of this steepest reform path problem.

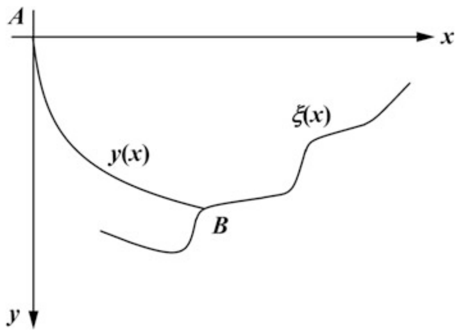


Fig. 19.1 The steepest reform path with variable boundary

From Fig. 19.1, it follows that due to the financial reform, the economic system evolves from state A to state B, where B is not a fixed point but an arbitrary point on the curve $\xi(x)$. Now, we need to find a point B on the curve $\xi(x)$ such that the amount of time it takes the economic system to evolve from A to B is the minimum. To this end, we will successfully reach the policy objective and make financial policy reach its optimal outcome by adjusting the order of implementation of policy variables.

19.3 The Model and Solution

In Chap. 18, the following general optimization model for the path of financial reform with two fixed boundaries is established:

$$\begin{cases} \min & J = \int_{x_0}^{x_1} F(x, y(x), dy/dx)dx \\ s.t & y(x_0) = y_0, y(x_1) = y_1 \end{cases}$$

where J is the objective value, (x_0, y_0) and (x_1, y_1) the initial and objective state points of the financial reform path, and $y(x)$ the desired optimal reform path.

For our current problem of steepest reform path with a variable boundary, the desired objective state needs to be located on the curve $\xi(x)$. So, similar to the previous symbolic model of fixed boundary extreme value problem, we can use the following to depict our current extreme value problem with a variable boundary:

$$\begin{cases} \min & J = \int_{x_0}^{x_1} F\left(x, y(x), \dfrac{d}{dx}y(x)\right)dx \\ s.t & y(x_0) = y_0 \\ & y(x_1) = \xi(x_1) \end{cases} \tag{19.1}$$

where J is the objective function, (x_0, y_0) and $(x_1, y(x_1))$ the initial and the objective states of the path of the financial reform, and $y(x)$ the desired optimal reform path.

From the discussion in Chap. 18, it follows that the optimal solution curve $y(x)$ must satisfy the following Euler condition:

$$\begin{cases} \dfrac{\partial F}{\partial y} - \dfrac{d}{dx}\left(\dfrac{\partial F}{\partial \dot{y}}\right) = 0 \\ \dot{y} = \dfrac{dy}{dx} \\ boundary\ condition: \begin{cases} y(x_0) = y_0 \\ y(x_1) = y_1 \end{cases} \end{cases}. \tag{19.2}$$

In the following, we will derive the necessary condition for the optimal solution curve $y(x)$ of our steepest path of financial reform to satisfy, and then we will provide the particular form of the optimal solution curve $y(x)$ based on the specified conditions of given situations.

Assume that (x_1, y_1) is the terminal point of the optimal curve $y(x)$. Let (x_1, y_1) move slightly along $\xi(x)$ to point $(x_1 + \Delta x_1, y_1 + \Delta y_1)$ so that both points (x_1, y_1) and $(x_1 + \Delta x_1, y_1 + \Delta y_1)$ are located on the curve $\xi(x)$.

As shown in Fig. 19.2, when the terminal point B moves to point C, the optimal solution curve $y(x)$ becomes $\tilde{y}(x)$. Let

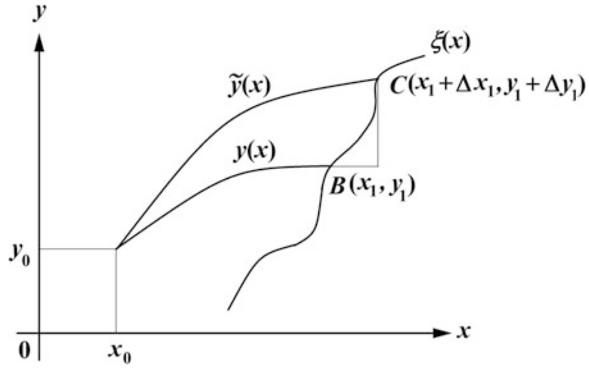
$$\tilde{y}(x) = y(x) + \varepsilon\phi(x) \tag{19.3}$$

where ε is an arbitrarily small real number. Because $\tilde{y}(x) - y(x)$ is equal to zero at x_0, we have

$$\phi(x_0) = 0. \tag{19.4}$$

However, different from the optimization problem with fixed terminal point, either $\phi(x_1)$ or $\phi(x_1 + \Delta x_1)$ now might not be 0. As ε changes in its value, because $\phi(x)$ is a fixed curve, the intersection of $\tilde{y}(x)$ and $\xi(x)$ also varies. That is, the values of Δx_1

Fig. 19.2 Slight movement along the optimal curve



and Δy_1 are related to that of ε. However, if ε is an infinitesimal, both Δx_1 and Δy_1 are also infinitesimals.

When the terminal point eventually moves from $B(x_1, y_1)$ to $C(x_1 + \Delta x_1, y_1 + \Delta y_1)$, the objective value J changes accordingly an amount ΔJ. So, if both Δx_1 and Δy_1 are infinitesimals, then ΔJ is also an infinitesimal and can be seen as zero:

$$\Delta J = \int_{x_0}^{x_1+\Delta x_1} F\big(x, y+\varepsilon\phi, \dot{y}+\varepsilon\dot{\phi}\big)dx - \int_{x_0}^{x_1} F\big(x, y, \dot{y}\big)dx = 0.$$

Simplifying this expression gives

$$\begin{aligned}\Delta J = &\int_{x_0}^{x_1+\Delta x_1} F\big(x, y+\varepsilon\phi, \dot{y}+\varepsilon\dot{\phi}\big)dx+ \\ &+\int_{x_0}^{x_1} F\big(x, y+\varepsilon\phi, \dot{y}+\varepsilon\dot{\phi}\big)dx - \int_{x_0}^{x_1} F\big(x, y, \dot{y}\big)dx = 0.\end{aligned} \tag{19.5}$$

First of all, let us consider the first term in Eq. 19.5. When Δx_1 and $\varepsilon\phi$ are sufficiently small, we can think of the following:

$$\int_{x_0}^{x_1+\Delta x_1} F\big(x, y+\varepsilon\phi, \dot{y}+\varepsilon\dot{\phi}\big)dx = F\big(x, y, \dot{y}\big)\big|_{x_1} \times \Delta x_1 \tag{19.6}$$

which can be understood readily by using the fundamental concepts of finding areas in calculus, where the error will be high order infinitesimal terms in Δx_1 and ε.

Next, let us consider the second and third terms in Eq. 19.5:

$$\int_{x_0}^{x_1} F\big(x, y+\varepsilon\phi, \dot{y}+\varepsilon\dot{\phi}\big)dx - \int_{x_0}^{x_1} F\big(x, y, \dot{y}\big)dx. \tag{19.7}$$

By using Taylor expansion, we obtain (Δx , Δy , $\Delta z \rightarrow 0$):

$$\Delta F = F(x+\Delta x, y+\Delta y, z+\Delta z) - F(x, y, z) = \frac{\partial F}{\partial x}\Delta x + \frac{\partial F}{\partial x}\Delta y + \frac{\partial F}{\partial x}\Delta z.$$

Because $\Delta x \rightarrow 0$, this equation becomes

$F(x, y+\Delta y, z+\Delta z) - F(x, y, z) = \frac{\partial F}{\partial x}\Delta y + \frac{\partial F}{\partial x}\Delta z$.Substituting this equation into Eq. 19.6 produces

Eq. 19.6 $= \displaystyle\int_{x_0}^{x_1}\left(\frac{\partial F}{\partial x}\Delta y + \frac{\partial F}{\partial x}\Delta z\right)dx$.By noticing that $\Delta y = \varepsilon\phi$ and $\Delta z = \varepsilon d\phi/dx$, the previous equation becomes

Eq. 19.6 $= \displaystyle\int_{x_0}^{x_1}\left(\frac{\partial F}{\partial x}\varepsilon\phi + \frac{\partial F}{\partial x}\varepsilon\frac{d\phi}{dx}\right)dx = \varepsilon\int_{x_0}^{x_1}\left(\frac{\partial F}{\partial x}\phi + \frac{\partial F}{\partial x}\frac{d\phi}{dx}\right)dx$

$$= \varepsilon \int_{x_0}^{x_1} \frac{\partial F}{\partial y} \phi dx + \frac{\partial F}{\partial z} \varepsilon \phi \bigg|_{x_0}^{x_1} - \varepsilon \int_{x_0}^{x_1} d\left(\frac{\partial F}{\partial z}\right) \times \phi$$

where $\dot{z} = \dot{y}$. Different from the extreme value problem with fixed boundary, the middle term in the previous expression is not equal to 0. Therefore, we have

$$\text{Previous expression} = \tfrac{\partial F}{\partial z} \varepsilon \phi \big|_{x_0}^{x_1} + \varepsilon \int_{x_0}^{x_1} \frac{\partial F}{\partial y} \phi dx - \varepsilon \int_{x_0}^{x_1} \frac{d}{dx}\left(\frac{\partial F}{\partial y}\right) \times \phi dx$$

$$= \frac{\partial F}{\partial z} \varepsilon \phi \bigg|_{x_0}^{x_1} + \varepsilon \int_{x_0}^{x_1} \phi \left[\frac{\partial F}{\partial y} - \frac{d}{dx}\left(\frac{\partial F}{\partial y}\right)\right] dx.$$

Because the optimal trajectory must satisfy the Euler equation in Eq. 19.2, it means that the second term of the previous expression has to be equal to 0. So, we have

$$\text{Previous expression} = \frac{\partial F}{\partial z} \times \varepsilon \phi \bigg|_{x_0}^{x_1} = \frac{\partial F}{\partial y} \times \varepsilon \phi \bigg|_{x_0}^{x_1}. \tag{19.8}$$

Substituting Eqs. 19.6 and 19.8 into Eq. 19.5 produces

$$\Delta J = F(x, y, \dot{y})\big|_{x=x_1} \times \Delta x_1 + \frac{\partial F}{\partial y} \times \varepsilon \phi \big|_{x_0}^{x_1}$$

$$= F(x, y, \dot{y})\big|_{x=x_1} \times \Delta x_1 + \frac{\partial F}{\partial y}\bigg|_{x=x_1} \times \varepsilon \phi(x_1) - \frac{\partial F}{\partial y}\bigg|_{x=x_0} \times \varepsilon \phi(x_0) = 0.$$

By noticing that $\phi(x_0) = 0$, the previous expression simplifies into

$$\Delta J = F(x, y, \dot{y})\big|_{x=x_1} \times \Delta x_1 + \frac{\partial F}{\partial y}\bigg|_{x=x_1} \times \varepsilon \phi(x_1) = 0. \tag{19.9}$$

Now, from Fig. 19.2, it follows that

$$[\tilde{y}(x) - y(x)]|_{x=x_1} = \varepsilon \phi(x)|_{x=x_1} = BD \tag{19.10}$$

$$FC = \Delta y_1$$

$$\frac{d\xi(x)}{dx}\bigg|_{x=x_1} = \frac{FC}{BF} = \frac{EF + EC}{\Delta x_1} = \frac{BD + EC}{\Delta x_1}. \tag{19.11}$$

There are two points that we need to note. The first one

$$\frac{FC}{BF} = \frac{\Delta y_1}{\Delta x_1} \neq \frac{dy}{dx}\bigg|_{x=x_1}$$

which is the slope of the constraint curve $\xi(x)$ of the terminal point instead of the slope of the optimal trajectory $y(x)$.

The second one is EC/DE, the slope of $\tilde{y}(x)$ at x_1. That is, we have

$$\frac{EC}{\Delta x_1} = \frac{d\tilde{y}\,(x)}{dx}\bigg|_{x=x_1}.$$

Substituting Eq. 19.3 into the previous expression leads to

$$\frac{EC}{\Delta x_1} = \frac{dy}{dx}\bigg|_{x=x_1} + \varepsilon\frac{d\phi(x)}{dx}\bigg|_{x=x_1}.$$

Because ε is an infinitesimal, we have

$$\frac{EC}{\Delta x_1} = \frac{dy(x)}{dx}\bigg|_{x=x_1}. \tag{19.12}$$

Therefore, from Eqs. 19.10, 19.11, and 19.12, it follows that

$$\begin{aligned}\varepsilon\phi(x_1) = BD &= \frac{d\xi(x)}{dx}\bigg|_{x=x_1} \times \Delta x_1 - EC \\ &= \frac{d\xi(x)}{dx}\bigg|_{x=x_1} \times \Delta x_1 - \frac{EC}{\Delta x_1} \times \Delta x_1 = \left[\frac{d\xi(x)}{dx} - \frac{dy(x)}{dx}\right]_{x=x_1} \times \Delta x_1.\end{aligned}$$

Now, substituting this expression into Eq. 19.9 produces

$$\begin{aligned}\Delta J &= F(x, y, \dot{y})\big|_{x=x_1} \times \Delta x_1 + \frac{\partial F}{\partial y}\bigg|_{x=x_1} \times \varepsilon\phi(x_1) \\ &= F(x, y, \dot{y})\big|_{x=x_1} \times \Delta x_1 + \frac{\partial F}{\partial y}\bigg|_{x=x_1} \times \left[\frac{d\xi(x)}{dx} - \frac{dy(x)}{dx}\right]_{x=x_1} \times \Delta x_1 = 0.\end{aligned}$$

So, we obtain

$$\left[F(x, y, \dot{y}) + \left(\frac{d\xi}{dx} - \frac{dy}{dx}\right)\frac{\partial F}{\partial y}\right]\Big|_{x=x_1} = 0 \tag{19.13}$$

which establishes a relationship the slopes $dy/dx$and $d\xi/dx$of the optimal trajectory $y(x)$ and the constraint curve $\xi(x)$ at the terminal point (x_1, y_1)should satisfy.

Both the condition in Eq. 19.13 and the Euler equation in Eq. 19.2 constitute necessary conditions for the steepest financial reform path problem with variable boundaries. They can be written together as follows:

$$\begin{cases} \dfrac{\partial F}{\partial y} - \dfrac{d}{dx}\left(\dfrac{\partial F}{\partial y}\right) = 0 \\ \left[F + \left(\dot{\xi} - \dot{y}\right) \times \dfrac{\partial F}{\partial y}\right]\Big|_{x=x_1} = 0 \end{cases} \tag{19.14}$$

where $\dot{y} = dy/dx$ and $\dot{\xi} = d\xi/dx$.

In other words, for any given steepest financial reform path problem with variable boundaries, the optimal trajectory $y(x)$ must satisfy the conditions in Eq. 19.14. Hence, for any given particular specifications, one will be able to construct the concrete structure of the optimal trajectory $y(x)$.

19.4 The Problem of Fixed Amount of Money

So, as of this point, we have discussed the optimal financial reform trajectory problem with either two fixed boundary values or the terminal point is movable on a constraint curve. Among economic systems other than these two types of optimal trajectories, there is another type of optimal trajectory with constraint – the problem of fixed amount of money. This problem implies that when the available amount of money within an economic system is fixed, how the limited amount of money can be rationally employed in order to generate the greatest economic effect to the economic system. For example, during a financial crisis, the amount of foreign exchange reserves that can be used to intervene in the foreign exchange market is limited. Then the problem is: how can one rationally use the limited amount of foreign exchange reserves to intervene in the market so that the devaluation crisis of the domestic currency can be revolved and the economic loss to the economic system is minimized?

Similar to this problem of fixed amount of money, there has been the famous isoperimetric problem throughout the history. As early in the time as ancient Greece, people have known that when a fence of a fixed length encircles an area, in order to have the area as great as possible, the fence has to be a circle. In economic systems, the following scenario often appears: when facing the possibility of a devaluation crisis for the domestic currency, the monetary authority frequently protects the stability of the exchange rate of the domestic currency by selling foreign exchange reserves and buying domestic currency that is circulating in the market place; it is especially so when the economic system employs the fixed exchange rate system. For example, during the 1998 Southeast Asian financial crisis, Thailand, Indonesia, Malaysia, and South Korea all applied this method to counter the suddenly appearing devaluation crises of the domestic currencies during the early stages of the financial crisis. However, due to the limited supply of the foreign exchange reserves each of these economic systems had, for example, the foreign exchange reserve of Thailand at the time was merely about US$35 billion (during the financial crisis, as much as US$20 billion was mobilized to intervene in the foreign exchange market (Corsetti et al. 1999; Lindgren et al. 1999)), one of the important decisions the monetary authorities had to make when they had to intervene in the foreign exchange markets was: how can they employ the limited supply of foreign exchange reserves appropriately to counter the devaluation crisis of their domestic currencies in order to minimize the economic losses to the minimum?

During the 1998 Southeast Asian financial crisis, although Thailand, Indonesia, Malaysia, South Korea, and some other economic systems almost exhausted their entire foreign exchange reserves, they still did not successfully avoid the occurrence of the devaluation crises of their domestic currencies. Contrary to all of these difficulties, during this same financial crisis, Hong Kong not only kept the stability of its dollar but also defended its economic achievements that were accumulated through many years of development by adopting an appropriate exchange rate protection route.

1998 Hong Kong's Financial Crisis and Response (Corsetti et al. 1999; Forrest 2014)

Historically, Hong Kong has employed different currency systems in different times. During the time from 1863 to 1935, Hong Kong had applied the silver standard. Because of the global silver crisis, the government later gave up the silver standard and pegged its dollar with the British pound at HK\$16 = £1. That pegging to the British pound in reality meant that Hong Kong applied the currency board system. That is, if the monetary authority needed to issue additional money, it had to use certificates of indebtedness from purchasing the pound as its legal support. In 1972 when the free floatation of British pound obviously affected the stability of the HK dollar, the monetary authority began pegging its currency to the US dollar. Starting in 1983, Hong Kong government began to implement the linked exchange rate system and the currency board system simultaneously. Different from the ordinary fixed exchange rate system, other than the relatively stable exchange rate with the US dollar, according to the rules of the currency board system, any change to the currency base in the HK dollar must be accompanied by corresponding change in the foreign exchange reserves.

Under the currency board system, the stability of HK dollar's exchange rate is maintained at the expense of interest rate fluctuations. If there is a large influx of foreign capital into Hong Kong, it means that the relevant organizations and individuals purchase HK dollars by using foreign currency(ies) from HK banks so that the bank will satisfy the demand of the organizations and individuals through exchanging US dollars with HK dollars from the monetary authority (Hong Kong's capital account is very open; if there were no currency exchange, there would be no way to tell whether or not any capital movement exists so that Hong Kong's exchange rate would not be affected). Hence the currency base expands, it creates an easing in the liquidity of HK dollar, and the interest rate falls. Conversely, if a large outflow of capital occurs in Hong Kong, it means that the relevant organizations and individuals exchanged HK dollars into foreign currencies so that the bank will have to purchase foreign currencies from the monetary authority by using HK dollars. That implies the currency base shrinks, the liquidity of the HK dollar tightens, and the interest rate of the HK dollar goes higher.

In 1997, as American economy recovered, to curb the inflation the Federal Reserve started to raise its interest rate, causing hot money to return to the United States and making the global liquidity tighten. In July 1997, Thailand was forced to give up its fixed exchange rate system; the financial storm engulfed the markets in Eastern Asia, Russia, and Latin America; and the stock markets and exchange rates in Asia suffered from great downward pressure. Taking advantage of the opportunity, international speculators carried out attacks on Thai baht, Indonesian rupiah, Malaysian ringgit, and other fixed exchange rate currencies and profited magnificently, where the HK dollar, which was under the linked exchange rate system and pegged with the US dollar, was also eventually under attack. As an international financial center, especially as a financial center that has special connections with American financial markets, it is extremely important for Hong Kong to hold its linked exchange rate with the US dollar. The linked exchange rate was seen as the life line for Hong Kong. Once the Hong Kong currency were devalued, its linked exchange rate system would not be maintained and the confidence of the international investors would be shattered; because of that, Hong Kong would lose its position as an international financial center. Therefore, protecting its linked exchange rate system became the basic policy of Hong Kong government. However, due to the fact that Hong Kong government had long pursued "positive nonintervention" policy, it made it extremely difficult for Hong Kong to cope with the shocks of well-planned, large-scale attacks of international speculators.

In the first half of 1998, international speculators attempted a large-scale manipulation across multiple markets, such as the foreign exchange market, the stock market, and the futures market. In early August, when the situations in Russia and Latin America worsened day by day, the market started to worry that Hong Kong would give up its linked exchange rate system. By making use of the situation that was disadvantageous to the HK dollar, international speculators synchronously sold out their borrowed HK dollars in order to pressure the HK currency downwardly. According to the currency board system, Hong Kong's monetary authority could only use its foreign exchange reserves continuously to buy in HK dollars while release US dollars. That would consequently make the liquidity of the HK dollar to tighten, causing the stock market to fall so that international speculators would profit from their short stock index futures contracts. However, if at this time moment Hong Kong's monetary authority gave up the currency board system, it would be equivalent to reconstructing its currency issuance system and its exchange rate system; the effect would be way beyond that as caused by the collapse of the fixed exchange rate system; it would seriously damage the market confidence on Hong Kong government and its financial markets, which would force the prices of assets, such as stocks, to tumble. As a matter of fact, at the same time when international speculators attacked the HK dollar, they also shorted Hang Seng Index futures substantially in order to profit massively by making use of the interest rate fluctuation as caused by the regulatory mechanism between the exchange rate and interest rate under the currency board system.

In order to combat the cross-market manipulation behavior that threatened the stability of the financial system and to avoid the market being manipulated, Hong Kong government took resolute actions simultaneously in the stock and futures markets. It longed the component stocks of Hang Seng Index and purchased Hang Seng Index futures contracts in order to counter the market manipulation. Additionally, Hong Kong government bought in HK dollars by mobilizing foreign exchange funds and then deposited the purchased HK dollars into the bank to simultaneously maintain the stability of the interest rate and the exchange rate. In the futures market, Hong Kong government raised the price of the August-maturing Hang Seng Index futures contracts that were massively held by the speculators while pressuring down the September Hang Seng Index Futures so that the expanding price difference forced the other side of the market to take losses when attempting to roll their short positions. With Hong Kong government's firm and generous intervention and gradual introduction of supplementary measures that limited the available speculative capital, the force of speculating bears was hit significantly and the HK dollar crisis started to calm down. In the entire bailout, Hong Kong government mobilized approximately HK$118 billion. As the Hang Seng Index bounced, Hong Kong government gradually sold out their stocks so that the foreign exchange funds not only recovered its foreign currencies but also won some surplus.

In this crisis response, Hong Kong government acted simultaneously in the stock and futures markets with the following main response measures:

1. The monetary authority allowed the government of Hong Kong Special Administrative Region to purchase HK dollars by using its foreign exchange funds and to deposit the acquired HK dollars into Hong Kong banks. That helped to balance the supply and demand of the foreign exchange market and the currency market, which helped to maintain the stability of the exchange rate and interest rate.
2. In the stock market, the monetary authority propped up the market by employing its foreign exchange funds to purchase a big hand of constituent stocks of Hang Seng Index.
3. In the futures market, the monetary authority widened the price gap between the spot and distant stock index contracts by mobilizing foreign exchange funds in order to increase the speculators' cost margin.
4. Hong Kong government introduced seven measures to limit short selling: restrict shorting the HK dollar, greatly shorten stocks and futures delivery periods, increase the liquid capital within the banking system, lower the leverage of the index futures, etc.

From the previous example of how Hong Kong dealt with the 1998 financial crisis, it can be seen that when constrained by the limited amount of foreign exchange reserves, designing an appropriate path of response strategies cannot only relatively well resolve the crisis of currency devaluation but also effectively protect the available foreign exchange assets from losses. Hence, in the following, we will consider, with the constraint that the available money is limited, how to design a response path in order to make the money be of the greatest possible effectiveness, where the concept of effectiveness is expressed as the benefit (or profit) acquired (if necessary, the objective can also be expressed as the minimum loss).

19.4.1 The Model

Let us now construct a mathematical model for the problem of fixed amount of money. Without loss of generality, let us assume that the parametric equations of the strategy curve on how to make use of the money are

$$x = x(t), y = y(t), t_1 \leq t \leq t_2$$

such that the curve forms a closed loop and does not intersect with itself. Symbolically, this end means that $x(t_1) = x(t)$ and $y(t_1) = y(t)$ only when $t = t_1, t_2$ for $t_1 \leq t \leq t_2$. This assumption means that the available money at the start of time is maintained at the end of time. Therefore, the total length of the curve is

$$l = \int_{t_1}^{t_2} \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2}\, dt \tag{19.15}$$

where l is a fixed constant. By using Green's theorem in calculus, we know that the area enclosed by the curve is given by

$$S = \iint_R dxdy = \frac{1}{2} \oint (xdy - ydx) = \frac{1}{2} \int_{t_1}^{t_2} \left(x\frac{dy}{dt} - y\frac{dx}{dt}\right) dt$$

where R stands for the region enclosed by the curve $x = x(t), y = y(t)$, and S the area of the region or the benefit acquired.

So, a mathematical model for our problem of fixed amount of money is

$$\begin{cases} \max \quad S = \frac{1}{2} \int_{t_1}^{t_2} \left(x\frac{dy}{dt} - y\frac{dx}{dt}\right) dt \\ s.t \quad \int_{t_1}^{t_2} \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2}\, dt = l \end{cases} \tag{19.16}$$

from which, it can be seen that the resource that can be mobilized by the optimal trajectory is limited.

Based on the previous simple problem of fixed amount of money, let us consider how to resolve the problem in the general situation. To this end, the general problem of optimal trajectory with constraints can be symbolically expressed as follows:

$$\begin{aligned} \min \quad & J = \int_{x_0}^{x_1} F(x, y, \dot{y})dx. \\ s.t \quad & \varphi(x, y, \dot{y}) = 0 \end{aligned} \tag{19.17}$$

19.4.2 The Solution

Now, let us see how to solve the extreme value problem in Eq. 19.17. First let us construct a function H as follows:

$$H = F(x, y, \dot{y}) + \lambda\varphi(x, y, \dot{y}) \tag{19.18}$$

where λ is the Lagrange operator.

Next, let us consider the following extreme value problem without any constraint:

$$\min \quad \tilde{J} = \int_{x_0}^{x_1} [F(x, y, \dot{y}) + \lambda\varphi(x, y, \dot{y})]dx. \tag{19.19}$$

Because of $\varphi(x, y, \dot{y})$, the necessary conditions for $\tilde{J}$ to take the minimum and for J to take the minimum should be the same. In terms of Eq. 19.19, the minimum value should satisfy the following Euler equation:

$$\frac{\partial H}{\partial y} - \frac{d}{dx}\left(\frac{\partial H}{\partial \dot{y}}\right) = 0. \tag{19.20}$$

So, the extreme value of Eq. 19.17 should also satisfy this necessary condition and the condition of the constraint. Hence, the overall necessary condition for the extreme value of Eq. 19.17 is the following:

$$\begin{cases} \dfrac{\partial H}{\partial y} - \dfrac{d}{dx}\left(\dfrac{\partial H}{\partial \dot{y}}\right) = 0 \\ \varphi(x, y, \dot{y}) = 0 \end{cases}. \tag{19.21}$$

Solving this system of equation produces the equation of the desired optimal trajectory.

Next, let us consider the extreme value problem with an integral sign in the constraint condition. The mathematical model can be written as follows:

$$\begin{cases} \min & J = \int_{x_0}^{x_1} F(x, y, \dot{y}) dx \\ s.t & \int_{x_0}^{x_1} \varphi(x, y, \dot{y}) dx = l \end{cases}. \tag{19.22}$$

We can transform the extreme value problem in Eq. 19.22 into the form in Eq. 19.17. In particular, let us denote

$$\int_{x_0}^{x_1} \varphi(x, y, \dot{y}) dx = z(x). \tag{19.23}$$

Evidently, we have $z(x_0) = 0$ and

$$\int_{x_0}^{x_1} \varphi(x, y, \dot{y}) dx = l = z(x_1).$$

Integrating Eq. 19.23 leads to

$$\frac{dz(x)}{dx} = \varphi(x, y, \dot{y}).$$

Therefore, the extreme value problem in Eq. 19.22 is equivalent to the following extreme value problem:

$$\begin{cases} \min & J = \int_{x_0}^{x_1} F(x, y, \dot{y}) dx \\ t & \\ s.t & \varphi(x, y, \dot{y}) - \dfrac{dz(x)}{dx} = 0 \end{cases} \tag{19.24}$$
$$z(x_0) = 0, z(x_1) = l$$

which is of the same form as the extreme value problem in Eq. 19.17.

Next, we construct the following function:

$$H = F(x, y, \dot{y}) + \lambda \left[\varphi(x, y, \dot{y}) - \frac{dz(x)}{dx} \right] \tag{19.25}$$

where λ is the Lagrange operator.

The corresponding Euler equation is

$$\frac{\partial H}{\partial y} - \frac{d}{dx} \left(\frac{\partial H}{\partial \dot{y}} \right) = 0. \tag{19.26}$$

Because $z(x)$ is a function in only x, we have

$$\frac{\partial \left(\frac{dz(x)}{dx} \right)}{\partial y} = 0, \frac{\partial \left(\frac{dz(x)}{dx} \right)}{\partial \dot{y}} = 0.$$

Substituting Eq. 19.25 into Eq. 19.26 produces

$$\frac{\partial F}{\partial y} + \lambda \frac{\partial \varphi}{\partial y} - \frac{d}{dx}\left[\frac{\partial F}{\partial \dot{y}} + \lambda \frac{\partial \varphi}{\partial \dot{y}}\right] = 0.$$

Hence, the extreme value of Eq. 19.24 satisfies the following necessary condition:

$$\begin{cases} \dfrac{\partial F}{\partial y} + \lambda \dfrac{\partial \varphi}{\partial y} - \dfrac{d}{dx}\left[\dfrac{\partial F}{\partial \dot{y}} + \lambda \dfrac{\partial \varphi}{\partial \dot{y}}\right] = 0 \\ \displaystyle\int_{x_0}^{x_1} \varphi(x, y, \dot{y})dx = l \end{cases}. \tag{19.27}$$

From this necessary condition, one can obtain the general solution, where the arbitrary constant will be determined by the boundary condition.

19.4.3 A Revisit to the Problem of Maximum Area

In terms of such an economic system that employs either the fixed or linked exchange rate system, when it faces a currency devaluation crisis, the system has two methods to defend its exchange rate: mobilize its foreign exchange reserves or raise the interest rate. For example, within the linked exchange rate system of the HK dollar, when the market exchange rate goes up, there appears speculative arbitrage, causing losses to the foreign exchange reserves; if the HK dollar's interest rate goes higher, it will not only hit the stock market and the real estate market but also trigger activities of speculative arbitrage while the high interest rate cannot stay deviated from the interest rate of the US dollar for long. Because Hong Kong government could no longer raise the interest rate, it instead fought back the attacks of the speculative and manipulative capital on the index futures market by mobilizing the foreign exchange reserves. The government directly entered the market when US$1.00 exchanged for 7.75 HK dollars. By using about US$23 billion, the Hong Kong monetary authority took over all the HK dollars the speculators threw into the market. On August 6, the speculators once again sold short HK dollars in an amount equivalent to US$2 billion, the monetary authority took the opposite side by mobilizing HK$15 billion. On August 7, there again appeared short orders in the amount of HK$10 billion, which once again was absorbed by the monetary authority by using the reserves. The fiscal reserves of Hong Kong government were mostly deposited in banks in the form of the US dollars. After converted some of the reserves into HK dollars, they were still kept in the banking system so that the conversion did not raise the interbank offered rate. However, the speculators still pushed up the forward rate by short selling more distant forward contracts of the HK dollar. What the international speculators calculated was that as soon as the Hong Kong government could not hold on to the linked exchange rate, then the HK dollar could easily devaluate 30%, which meant that these speculators could easily make 30% from the exchange rate difference (Corsetti et al. 1999; Forrest 2014).

Hence, when an economic system responds to a potential currency devaluation crisis, the challenging problem is how to justifiably apply the limited amount of foreign exchange reserves to protect the exchange rate of its domestic currency so that the effect of the reserves could be maximized. For the sake of convenience of conversation, assume that the initial exchange rate of the economic system at the start of the currency crisis is equal to that when the crisis ends and that the exchange rate of the domestic currency stays constant during the process when foreign exchange reserves were employed to intervene with possible changes in the exchange rate, that is, from the start to the end when the intervention was employed, the exchange rate of the economic system's currency stays unchanging. Then, a mathematical model for how to spend the limited foreign exchange reserves to maintain the stability in the exchange rate, satisfying the condition that the exchange rate is the same at both the start and end of the intervention, while acquiring the maximum economic benefits, is the following:

$$\begin{cases} \max \quad S = \int_a^b y(x)dx \\ s.t \quad \int_a^b \sqrt{1 + (\dot{y})^2}dx = l \end{cases}. \tag{19.28}$$

Next, let us see how to solve this model. To this end, define the following function:

$$H = y(x) + \lambda\sqrt{1 + (\dot{y})^2} \tag{19.29}$$

where λ is the Lagrange operator. Next, we substitute this function H into the Euler equation

$$\frac{\partial H}{\partial y} - \frac{d}{dx}\left(\frac{\partial H}{\partial \dot{y}}\right) = 0.$$

Because H does not explicitly contain x, from Eq. 19.25, this Euler equation can be rewritten as follows:

$$\frac{d}{dx}\left[H - \frac{\partial H}{\partial \dot{y}}\dot{y}\right] = 0.$$

Therefore, we have

$$H - \frac{\partial H}{\partial \dot{y}}\dot{y} = c, c \text{ is a constant.}$$

Substituting function H in Eq. 19.29 into this expression produces

$$y + \lambda\sqrt{1 + (\dot{y})^2} - \frac{\lambda\dot{y}}{\sqrt{1 + (\dot{y})^2}}\dot{y} = c$$

which can be simplified into

$$y - c = -\frac{\lambda}{\sqrt{1 + (\dot{y})^2}}.$$

By introducing a parameter k such that $\dot{y} = \tan k$, we then have

$$y - c = -\lambda\cos k.$$

Because $\dot{y} = dy/dx = \tan k$, we have

$$dx = \frac{dy}{\tan k} = \frac{\lambda \sin k}{\tan k}dk = \lambda \cos k dk.$$

Solving this equation for x produces

$$x = \lambda\sin k + c_1, c_1 \text{ is a constant.}$$

So, the extreme value curve is

$$\begin{cases} x = \lambda\sin k + c_1 \\ y = -\lambda\cos k + c \end{cases}.$$

By eliminating k, we have

$$(x - c_1)^2 + (y - c)^2 = \lambda^2 \tag{19.30}$$

where c, c_1, and λ are determined by the following boundary and constraint conditions:

$$y(a) = 0, y(b) = 0, \int_a^b \sqrt{1 + (\dot{y})^2}dx = l.$$

From the solution in Eq. 19.30, it can be seen that the optimal trajectory for obtaining the maximum economic benefit is a circle. If when responding to a currency crisis the change in the exchange rate of the economic system's domestic currency is an arbitrary bending curve, it can also be shown that the optimal curve is again a circle. This end from a brand-new angle shows the validity of the systemic thinking based on the yoyo model (Lin 2008).

19.5 Some Final Words

In the present day of economic globalization and international financial integration, along with the continuous opening of foreign trades and the liberation of current accounts, capital account liberation in fact has become a natural choice for developing countries. Financial integration plays an important role for the economic growth of developing countries; however it also brings forward with some negative effects to the sustained development of the economies of these countries (Lane and Milesi-Ferretti 2007). Speaking historically, in the process of financial reforms, different countries evolved differently with their respective individual experiences. Especially some of the emerging market countries suffered from a series of financial crises because of the quick and anxious opening of their domestic financial industries, which made their already accumulated financial wealth dissipate completely and instantly. All the existing literature and relevant experiences of the developing countries indicate that when capital accounts are liberated with disadvantageous constraints, it will be very difficult for the involved economic systems to walk out of the strange cycle of negative growth.

Maintaining financial security and preventing the occurrence of financial crises are two important prerequisites for the healthy development of an economic system's finance. How to strengthen the financial stability and how to reduce the economic damage caused by financial crises during the integration into the process of international financial liberation and economic globalization have been challenges facing all developing countries. It is on top of such background that this chapter explores the problem of how to design a concrete path of financial reform for an economic system through analyzing the characteristics of the steepest reform path problem with variable boundaries from the angle of optimal economic development.

Relevant literature, see those listed in Sect. 2, indicates that along with the further development and gradual realization of economic globalization, the particular path of financial reform and other related problems need to be understood deeply. This theoretical need and practical demand are what this chapter attempts to satisfy.

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Part VI
Specific Case Analyses

Chapter 20
Renminbi: A New Reserve Currency

Contents

This chapter focuses on the study of what China has done and might need to further do in order to make its Renminbi a successful reserve currency of the world. It consists of five sections. Section 20.1 attempts from three angles to analyze the following issues related to RMB offshore market: how cross-border flows of RMB impact the domestic economy, how the expected RMB appreciation/depreciation influences the development of the offshore market, and how the RMB offshore market lacks liquidity. It also tries to develop a design for the circulation mechanism between the offshore and onshore market while providing advices on how to promote positive interactions between the two. Section 20.2 theoretically considers how the development of RMB offshore market impacts China's domestic base currency and foreign exchange reserves and analyzes the mechanism of interest rate and its influence factors based on the principle of logistics by using methods of differential dynamical systems. Section 20.3 investigates what offshore non-deliverable forward market data can tell about the prospect for further RMB appreciation, as well as the development of Chinese financial market since July 2005 when the band for RMB to fluctuate was widened, and how the continuing volatility of the US dollar against the Japanese yen affects the development.

Under the name of internationalization, Sect. 20.4 looks at how China has been promoting the use of its currency for international trade and investment and

J. Yi-Lin Forrest et al., *Currency Wars*, Contemporary Systems Thinking,
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relevant short-term and long-term challenges. And Sect. 20.5 concludes the presentation of this chapter.

20.1 Strongly Fortified: Strengthen RMB Onshore Market

What is the linkage between the offshore Renminbi (RMB) exchange rate and the onshore RMB exchange rate? Although China separates these two markets with different rates because China's capital account is not fully convertibility, these rates can actually interact with each other. The creation of RMB off shore market is an important event in the process of liberating China's financial market so that more participants can join the market and market forces can influence and determine the exchange rate. That is, price discovery is an important function of the offshore market.

Despite its rapid development, the offshore RMB market is still small when compared to the mainland market. Even so, the rate discovered by the offshore market provides at least some indications about the onshore market rate (Cheung and Rime 2014). Debin Liu (2007) proposed a three-stage framework on the RMB full convertibility while trying to solve China's problem of huge foreign exchange reserves, long-term trade surplus, and the appreciation pressure of RMB, Table 20.1. Qiao (2013) believes that RMB internationalization represents a general trend, but the process is only limited to the capital projects that have not been fully opened, the exchange rate system is not ideal and the interest rate is still not market oriented. Su, He, and Tang (2014) studied the effect of Hong Kong RMB offshore market on the onshore market in terms of the base currency, foreign exchange reserves, interest rate, exchange rate, etc. They found that the offshore market brings a series of challenges for the central bank to make its estimates, control the money supply, maintain the stability of the currency, and formulate and implement monetary policies.

By using econometrics, Wang and Liu (2009) looked at the relationship and the information transmission of the base period exchange rate between RMB and the non-deliverable forward (NDF). These authors concluded that the RMB NDF market have a mean spillover effect on the RMB spot market. Therefore, there is a two-way volatility spillover effect between RMB spot exchange rate and NDF, and the offshore market of RMB NDF leads the onshore spot market. Fuquan Wang (2014) analyzed Hong Kong RMB deposit, China's domestic foreign exchange reserves (FEX), and domestic credit scale effect on M_2 by establishing an econometric model.

The literature considers the internationalization of a currency and offshore markets as two relatively independent problems without pinpointing out the relationship between the two theoretically, which is what is addressed in this section while specialized with the RMB. It will be shown intuitively that the internationalization of RMB and RMB offshore market are related to each other by using charts. Although Niu (2014) advised to make Hong Kong offshore market into a

Table 20.1 A three-stage framework on RMB full convertibility

Category	Individual	Enterprise	Nonresident
The first stage	Sources of funds: personally owned foreign currencies or purchased from the government (limited) Investments in securities: can be used to invest in foreign bonds	Sources of funds: personally owned foreign currencies used for direct investments; exchange is open for private enterprises while state-owned enterprises need approval Investments in securities: can be used to invest in foreign bonds	Investments in securities: allow some nonresidents to issue bonds Foreign banks can offer loans, but the loan size is limited
The second stage	Sources of funds: personally owned foreign currencies or purchased from the government (unlimited) Investments in securities: can be used for equity securities investment	Sources of funds: personally owned foreign currencies or purchased from the government (limited). The state-owned enterprises change to approval system Investments in securities: can be used for equity securities investment with individualized supervision over direct investment accounts	Nonresidents allowed to invest in China's bonds and stocks with restriction on stocks and excessive speculation
The third stage	Investments: can be used to invest in financial derivatives	Allow enterprises to issue bonds in foreign countries and stocks in foreign countries with restrictions on industries	Can buy bonds with dual currencies and issue bonds and stocks

true offshore market by analyzing influences of pure offshore trading and pure two-way trading on the economy and by finding the characteristics of Hong Kong market and the risks implied while compared to the Eurodollar market, this section suggests that the proportion of pure offshore transactions needs to be improved and the impact of a pure two-way trade needs to be weakened. And it also suggests a full expansion of Hong Kong offshore RMB business by increasing the participation of nonresidents and promotion of an orderly internationalization of RMB. Other than attempting to analyze some problems related to RMB offshore market from three angles, how cross-border flows of RMB impact the domestic economy, how the expected RMB appreciation/depreciation influences the development of the offshore market, and how the RMB offshore market lacks liquidity, this section also tries to develop a design for the circulation mechanism between the offshore and onshore market while providing advices on how to promote positive interactions between the two.

By considering of the link between the offshore market and the onshore market, let us build the following model based on the principles of the logistic model:

$$\begin{cases} \dfrac{dx}{dt} = R_{off}x[N_1(x,y) - x] \\ \dfrac{dy}{dt} = R_{in}\mathrm{y}[N_2(x,y) - y] \end{cases} \tag{20.1}$$

where R_{off} stands for the rate of return obtained by investors from investing in offshore banks, R_{in} the rate of return from investing in onshore banks, x the offshore banks' interest rate, and y the onshore banks' interest rate.

Case 1:
Both $N_1(x, y)$ and $N_2(\mathrm{x, y})$ are constants. By letting $x(0) = N_0, y(0) = \mathrm{N}_0$, we can solve Eq. (20.1) and obtain

$$\frac{dx}{dt} = R_{off}x(N_1 - x).$$

By using the method of separation of variables, we obtain

$$x(t) = \frac{N_0 N_1 e^{N_1 R_{off} t}}{(\mathrm{N}_1 - N_0) + N_0 e^{N_1 R_{off} t}}.$$

Similarly, we can solve $\mathrm{y}(t)$:

$$\mathrm{y}(t) = \frac{N_0 N_2 e^{N_2 R_{in} t}}{(\mathrm{N}_2 - N_0) + N_0 e^{N_2 R_{in} t}}$$

Since $\lim\limits_{t\to\infty} x(t) = N_1, x(0) = N_0$; $\lim\limits_{t\to\infty} \mathrm{y}(t) = N_2, \mathrm{y}(0) = N_0$ (Fig. 20.1, where both x and y are shown as "s-curves"), both $x(t)$ and $y(t)$ are bounded.

Case 2:
Both $N_1(x, y)$ and $N_2(\mathrm{x, y})$ are linear functions. We have

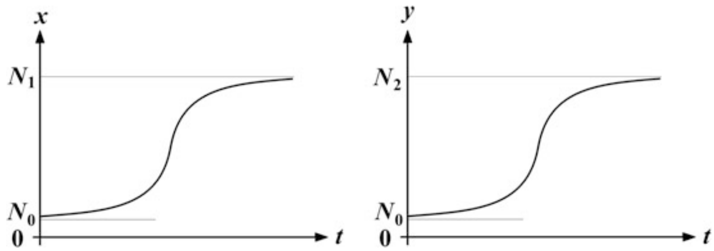


Fig. 20.1 The solutions of $x(t)$ and $y(t)$

$$\begin{cases} \dfrac{dx}{dt} = R_{off}x[N_1(x,y) - x] = R_{off}x[a_1x + b_1y + c_1 - x] \\ \dfrac{dy}{dt} = R_{in}y[N_2(x,y) - y] = \mathrm{R}_{in}y[a_2x + b_2y + c_2 - y] \end{cases}. \tag{20.2}$$

where a_1 stands for the proportion of illegal investors in the offshore market, a_2 the proportion of legal investors in the offshore market, b_1 the proportion of illegal investors in the onshore market, b_2 the proportion of legal investors in the onshore market, c_1 the largest offshore market interest rate under no regulatory supervision, and c_2 the largest onshore market interest rate under no regulatory supervision, satisfying $0 < a_i, b_i, c_i < 1$.

Denote

$$\begin{cases} F_1 = a_1x + b_1y + c_1 - x = (a_1 - 1)x + b_1y + c_1 = \alpha_1x + \beta_1y + \gamma_1 \\ F_2 = a_2x + b_2y + c_2 - y = a_2x + (b_2 - 1)y + c_2 = \alpha_2x + \beta_2y + \gamma_2 \end{cases} \tag{20.3}$$

and

$$\begin{cases} l_1 : \alpha_1x + \beta_1y + \gamma_1 = 0 \\ l_2 : \alpha_2x + \beta_2y + \gamma_2 = 0 \end{cases} \tag{20.4}$$

where $\alpha_1 = a_1 - 1 < 0, \beta_1 = b_1 > 0, \gamma_1 = c_1 > 0$, $\alpha_2 = a_2 > 0, \beta_2 = b_2 - 1 < 0$, $\gamma_2 = c_2 > 0$.

From Eq. (20.4), we can calculate the equilibrium interest rate in the two markets as follows:

$$\begin{cases} x^\theta = \dfrac{\gamma_2\beta_1 - \gamma_1\beta_2}{\alpha_1\beta_2 - \alpha_2\beta_1} > 0 \\ y^\theta = \dfrac{\gamma_1\alpha_2 - \gamma_2\alpha_1}{\alpha_1\beta_2 - \alpha_2\beta_1} > 0 \end{cases}. \tag{20.5}$$

As shown in Fig. 20.2, when the slope of l_1 is larger than that of l_2, an equilibrium solution existence, that is, $-\frac{\alpha_1}{\beta_1} > -\frac{\alpha_2}{\beta_2} \Rightarrow \alpha_1\beta_2 < \alpha_2\beta_1$. Since both x^θ and y^θ are rates, they were greater than 0 so that we can derive $\alpha_1\beta_2 - \alpha_2\beta_1 < 0$, $\gamma_2\beta_1 - \gamma_1\beta_2 < 0$, $\gamma_1\alpha_2 - \gamma_2\alpha_1 < 0$.

Because the equilibrium solution is determined by the parameters α_1, α_2, β_1, β_2, γ_1, and γ_2, a natural question arises: How would the equilibrium solution change with changes in the parameters? To this end, we have the following results.

Theorem 20.1 If $\alpha_1 < 0, \alpha_2 > 0$, $\beta_1 > 0, \beta_2 < 0$, $\alpha_1 > \alpha_1 >$, then

$$\frac{\partial x^\theta}{\partial \gamma_1} = \frac{-\beta_2}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} > 0,\ \frac{\partial y^\theta}{\partial \gamma_1} = \frac{\alpha_2}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} > 0;$$

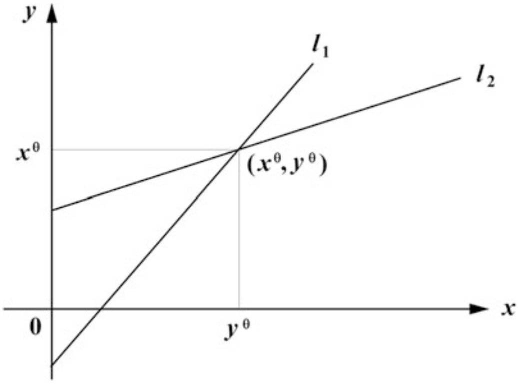


Fig. 20.2 The equilibrium interest rate in the two markets

$$\frac{\partial x^{\theta}}{\partial \gamma_2} = \frac{\beta_1}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} > 0, \ \frac{\partial y^{\theta}}{\partial \gamma_2} = \frac{-\alpha_1}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} > 0.$$

Theorem 20.2 If $\alpha_1 < 0, \alpha_2 > 0, \beta_1 > 0, \beta_2 < 0, \alpha_1 > \alpha_1 > \beta_1\gamma_2 < \beta_2\gamma_1$, then

$$\frac{\partial x^{\theta}}{\partial \alpha_1} = \frac{-\beta_2(\gamma_2\beta_1 - \gamma_1\beta_2)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} < 0, \ \frac{\partial y^{\theta}}{\partial \alpha_1} = \frac{\alpha_2(\gamma_2\beta_1 - \gamma_1\beta_2)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} < 0;$$
$$\frac{\partial x^{\theta}}{\partial \alpha_2} = \frac{\beta_1(\gamma_2\beta_1 - \gamma_1\beta_2)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} < 0, \ \frac{\partial y^{\theta}}{\partial \alpha_2} = \frac{\alpha_1(\gamma_1\beta_2 - \gamma_2\beta_1)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} < 0.$$

Theorem 20.3 If $\alpha_1 < 0, \alpha_2 > 0, \beta_1 > 0, \beta_2 < 0, \alpha_1\gamma_2 > \alpha_2\gamma_1, \alpha_1 > \alpha_1 >$, then

$$\frac{\partial x^{\theta}}{\partial \beta_1} = \frac{\beta_2(\gamma_2\alpha_1 - \gamma_1\alpha_2)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} < 0, \ \frac{\partial y^{\theta}}{\partial \beta_1} = \frac{\alpha_2(\gamma_1\alpha_2 - \gamma_2\alpha_1)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} < 0;$$
$$\frac{\partial x^{\theta}}{\partial \beta_2} = \frac{\beta_1(\gamma_2\alpha_1 - \gamma_1\alpha_2)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} > 0, \ \frac{\partial y^{\theta}}{\partial \beta_2} = \frac{\alpha_2(\gamma_2\alpha_1 - \gamma_1\alpha_2)}{(\alpha_1\beta_2 - \alpha_2\beta_1)^2} > 0,$$

where $\alpha_1 = a_1 - 1 < 0, \beta_1 = b_1 > 0, \gamma_1 = c_1 > 0, \alpha_2 = a_2 > 0, \beta_2 = b_2 - 1 < 0, \gamma_2 = c_2 > 0$.

By analyzing the partial derivatives for each parameter, as given in the previous theorems, we can judge the positive and negative signs of each parameter in order to determine the influence of the parameters on the equilibrium solution. In particular, through the partial derivatives, the following conclusions can be drawn:

1. When either c_1, the largest offshore market interest rate under no regulatory supervision, or c_2, the largest onshore market interest rate under no regulatory supervision, increases, the offshore and the onshore bank interest rates will increase at the same time.

2. When b_1, the proportion of illegal investors in the onshore market, increases, the offshore and the onshore bank interest rates will decrease at the same time. Similarly, as b_2, the proportion of legal investors in the onshore market, increases, the offshore and the onshore bank interest rates will increase at the same time.
3. When a_1, the proportion of illegal investors in the offshore market, increases, the offshore and the onshore bank interest rates will decrease at the same time. Similarly, when a_2, the proportion of legal investors in the offshore market, the offshore and the onshore bank interest rates will increase at the same time.

Theorem 20.4 If $\frac{\alpha_2}{\alpha_1} > \frac{4\beta_2}{\beta_1}$, $\frac{2\beta_2}{\beta_1} > \frac{\gamma_2}{\gamma_1}$, $\frac{\alpha_2}{\alpha_1} > \frac{2\gamma_2}{\gamma_1}$, and $2\alpha_1 R_{off} + \alpha_2 R_{in} > 0$, $2\beta_2 R_{in} + \beta_1 R_{off} > 0$, then the system in Eq. (20.3) does not have any limit cycle (or periodic solution).

Proof: Denote

$$\begin{cases} \dfrac{dx}{dt} = R_{off}x[N_1(x,y) - x] = R_{off}x[\alpha_1 x + \beta_1 y + \gamma_1] = P(x,y) \\ \dfrac{dy}{dt} = R_{in}y[N_2(x,y) - y] = \mathrm{R}_{in}y[\alpha_2 x + \beta_2 y + \gamma_2] = Q(x,y) \end{cases}$$

If the condition of Theorem 20.4 is satisfied, then we have

$$\left(2\alpha_1 R_{off} + \alpha_2 R_{in}\right)x + \left(2\beta_2 R_{in} + \beta_1 R_{off}\right)y + \gamma_1 R_{off} + \gamma_2 R_{in} > 0$$

which means that div $= \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} > 0$ for all $x > 0$, $y > 0$.

Due to the fact that div > 0 in the first quadrant, Dulac theorem (Ye 1984) implies that the system in Eq. (20.3) does not have any limit cycle in the first quadrant.

Now, let us see what conclusions of practical significance can be derived from the established results in the previous paragraphs.

1. In the long run, the Hong Kong RMB offshore market will influence the mainland China's banking system and its monetary policy.

The main risks the mainland financial market faces include: Firstly, the banking system will suffer from shocks of the credit scale. Hong Kong has been an international financial center, its financial services' sector has been acting as an international role model, and it enjoys various advantages of preferential taxes. From Table 20.2, the deposit and loan interest margins of Hong Kong and the mainland, the differences between Hong Kong and the mainland, can be seen. One of the main reasons for the differences to exist is the banking monopoly in the mainland, where the interest rate is determined by the government instead of by the market.

With the establishment of Hong Kong offshore financial center, commercial banks in Hong Kong will start RMB deposit and loan businesses. That would help undermine the banking monopoly in the mainland, and the resultant competition

Table 20.2 The deposit and loan interest margins of Hong Kong and mainland China

Account	Hong Kong	Mainland China
Deposit	Not all banks are the same; the average is, respectively, 0.33% (current) and 0.59% (1 year)	0.35% (current); 2.75% (1 year)
Loan	Not all banks are the same with HSBC being 2.4%	5.6% (1 year)
Interest margin	Generally between 1% and 2%	Around 3%

will reduce the deposit and loan interest margin and place a great pressure on the mainland's banking system.

Secondly, monetary policy tools will fail at least partially. On one hand, part of the central bank deposit reserve policy will fail. According to Mackinnon (Ying 2016), the key whether or not European banks can cause credit creation is their net increase in the supply of the US dollar when compared to the increase of global supply of the dollar without European banks. He establishes two ratios: the Eurodollar-credit ratio and Eurodollar monetary multiplier. The first ratio implies that the larger proportion of funds is deposited in the European monetary banking system, the lower European bank reserve ratio will be, and the Eurodollar market will be more developed. The second ratio should be greater than 1, which means that if US$1 deposit from the American money market is shifted to the Eurodollar market, the Eurodollar market will expand more than US$1 with the expansion being deposited into both America and European banks. Because the dollars deposited in America cannot be readily lend out while the dollars deposited in European banks can continue to generate additional credit, the Eurodollar market exerts expansionary effects on the world money supply. In comparison, when the mainland China expands or contracts its money supply, part of the RMB in circulation will outflow from or inflow into the mainland due to that fact that the Hong Kong RMB offshore financial center does not have any statutory reserve requirement. Funds flow between Hong Kong RMB offshore financial center and the mainland market because of the close connections between the markets. When such flow reaches a certain scale, it will affect the monetary control of China's central bank. So, the reserve system established to adjust the RMB supply might fail at least partially. Through analyzing the partial derivatives in the previous model, it is found that to improve the interest rates in either the offshore or the onshore market under the condition of no supervision, one simply improves the offshore bank interest rate x and the onshore bank interest rate y at the same time. By increasing the proportion of illegal investment in the onshore market, it will cause the offshore bank interest rate x and the onshore bank interest rate y to reduce. Additionally, by increasing the proportion of illegal investment in the offshore market, it will cause the offshore bank interest rate x and the onshore bank interest rate y to reduce. That is, the linkage between the offshore and the onshore markets might make monetary policies fail. On the other hand, part of the central bank's rates and exchange rates policies will fail. In particular, Hong Kong offshore RMB market interest rate and exchange rate fluctuate with the international financial markets, while the degree of how much the interest rate is market determined and the exchange rate on the onshore markets are generally lower. So, a certain gap exists between the international market and the mainland market. Since the fluctuations in the main variables that affect Hong Kong RMB offshore financial center are likely to affect the similar variables on the mainland financial market, these variables will indirectly influence the effectiveness of the mainland financial and the monetary policies.

Thirdly, RMB will eventually take the HK dollar out of circulation. In the short term, it is unlikely for RMB to replace the HK dollar as the main medium of payments in Hong Kong. However, in the long term, the HK dollar as a fiat money of Hong Kong, it is a clear establishment in the basic law. Even so, it will eventually be marginalized and completely replaced by RMB when the following conditions arise in Hong Kong: continued appreciation of RMB and fully convertibility of RMB.

Currently, the exchange rate of RMB has already exceeded the sensitive rate of US$1 = ¥7.8. On July 1, 2008, RMB's central parity rate was 6.8591, the fiftieth new high. Statistical data shows (Ying 2016) that since the RMB exchange system is being reformed, there have been 9 years, and the exchange rate of RMB to the US dollar has appreciated 25.2%. (On July 21, 2005, before the reform of the exchange rate formation, the exchange rate was US$1 = ¥8.2765; and on December 12, 2014, the exchange rate was US$1 = ¥6.1864.) If RMB continues to appreciate, the pressure on the HK dollar will grow increasingly. In terms of the convertibility of RMB, when RMB becomes fully convertible with the HK dollar, the substitution capacity of RMB against the HK dollar will become stronger, and Hong Kong's currency system will inevitably face a number of choices. From the experience of relevant economies (Ying 2016), currency selection depends mainly on such factors as risk, return, politics, and others. With the increasing integration of the two economies, currency functions will mutually penetrate the economies, and RMB will end its situation of double coin circulation in Hong Kong and eventually substitute the HK dollar.

2. Risk prevention of China's financial market

The development of offshore financial markets is a double-edged sword; a smooth development can enhance the process of RMB internationalization, promote the reform and maturity of the banking system and China's financial market, and guide the marketization of the evolution of the interest rate and exchange rate regime. However, if the path of development is not chosen appropriately or the necessary supervision is inadequate, then it is possible to create systemic risks in the onshore market through the linkage between the offshore and onshore markets and destroy the stability of China's financial system. Therefore, it is important to establish a system of risk prevention when developing offshore financial markets in order to maintain the stability of China's financial system.

The primary problem that Chinese government faces is to prevent money laundering. The financial action task force (FATF) has established 40 regulatory standards for money laundering. The government did not introduce the anti-money laundering law until 2007, and some of the local financial institutions still have not fully realized the importance of anti-money laundering. The strict confidentiality system in the offshore financial market has been the umbrella of money laundering.

Another crucial issue that Chinese government faces is its supervision system. The government has been trying to strengthen the cross-border supervision and coordination between these two markets. Starting in 2000, the International Monetary Fund (IMF) regularly assesses the world's major offshore markets and has developed more than 40 offshore financial centers in order to more accurately assess international money flows. Based on such valuable establishment, China can develop its own risk assessment system.

20.2 Going Abroad: Expand the RMB Offshore Market

China's financial market has not been fully opened to the outside world as of this writing, while there are offshore financial businesses inside China priced in the US dollar. So, in this sense, the RMB offshore market has not been truly established. In order for China to develop the RMB onshore and offshore markets and internationalize its RMB, let us analyze the conditions in China and consider the relevant experiences of other countries.

Based on cost-benefit analysis, Zengan Gao, Baojiang Zhang, and Jiang Yu (2012) built a financial freedom model for the RMB offshore market and discussed anti-money laundering regulatory issues of the RMB offshore market based on the principle of revenue maximization. This work shows that the benefit of the society is positively correlated with financial freedom, that is, less financial freedom means less benefit for the society, and conversely, higher financial freedom higher benefit for the society. Jing Xiu (2012) found that the spot rates of Chinese Yuan (CNY), the HK dollar (CNH), and the forward exchange rate of NDF are interactively related, and there is volatility spillover effect between different markets. This author eliminated the autocorrelation between the spot rates of CNY, CNH, and the forward exchange rate of NDF by using DCC-MVGARCH (Chen 2014). She analyzed the relevance of these rates intuitively through a graphical method. By using IS-LM-BP (investment-saving, liquidity preference-money supply, and balance of international payments), Meng (2013) analyzed the formation mechanism of the exchange rate spreads between the RMB onshore and offshore markets and concluded that prospective changes in the earnings of different currency assets are the main factor that influences the RMB exchange rate in the RMB offshore market. When the exchange rate spreads between the RMB onshore and offshore markets is greater than the cost of arbitrage, a large amount of RMB will flow across the border into China, causing possibly an offshore currency risk.

Qiao (2013) investigated the RMB offshore market from two different angles. First, from the angle of statics, he carted the successful experiences of the London offshore market, the IMF offshore market in America, and the JOM (Japanese Open Market) offshore market in Japan and expressed the current situation of the RMB offshore market by using charts and data. Second, from the angle of dynamics, the author analyzed the development of the Hong Kong offshore market and provided suggestions on the development of the RMB offshore market at both the macroscopic and microscopic levels. Niu (2014) studied the influence of pure offshore trades and pure two-way trades in the Eurodollar market and extended his conclusion to the Hong Kong offshore market by using analogy. The author concluded that China should improve the proportion of pure offshore trades in CNH offshore market in order to weaken the influence of pure two-way trades. Su, He, and Tang (2014) considered the influence of the Hong Kong RMB offshore market on the base currency, foreign exchange reserves, interest rates, exchange rates, and other operational goals within the territory.

In the rest of this section, let us look at the following model in order to theoretically study how the development of RMB offshore market impacts China's domestic base currency and foreign exchange reserves and analyze the mechanism of interest rate and its influence factors based on the principle of logistics by using methods of differential dynamical systems:

$$\begin{cases} \dfrac{dx}{dt} = R_{off}x[N_1(x,y) - x] \\ \dfrac{dy}{dt} = R_{in}y[N_2(x,y) - y] \end{cases} \tag{20.6}$$

where x stands for the interest rate of offshore banks, y the interest rate of onshore banks, R_{off} the rate of return of offshore investments, and R_{in} the rate of return of onshore investments.

When N_1 and N_2 are linear functions, equations in Eq. (20.8) become

$$\begin{cases} \dfrac{dx}{dt} = R_{off}x(a_1x + b_1y + c_1 - x) = R_{off}x(\alpha_1x + \beta_1y + \gamma_1) \\ \dfrac{dy}{dt} = R_{in}y(a_2x + b_2y + c_2 - y) = R_{in}y(\alpha_2x + \beta_2y + \gamma_2) \end{cases} \tag{20.7}$$

where a_1 and a_2 stand, respectively, for the proportions of illegal and legal investors in the offshore markets, satisfying $0 < a_1, a_2 < 1$; b_1 and b_2, respectively, the proportions of illegal and legal investors in the onshore markets, satisfying $0 < b_1$, $b_2 < 1$; and c_1 and c_2, respectively, the maximum rates of interest in the offshore and onshore markets without regulatory supervision, satisfying $c_1, c_2 > 0$, and $\alpha_1 = a_1 - 1(\alpha_1 < 0)$, $\beta_1 = b_1(0 < \beta_1 < 1)$, $\gamma_1 = c_1(\gamma_1 > 0)$, $\alpha_2 = a_2(0 < \alpha_2 < 1)$, $\beta_2 = b_2 - 1(\beta_2 < 0)$, $\gamma_2 = c_2(\gamma_2 > 0)$.

Letting the linear parts in Eq. (20.8) be 0 gives the following:

$$\begin{cases} l_1 : \alpha_1x + \beta_1y + \gamma_1 = 0 \\ l_2 : \alpha_2x + \beta_2y + \gamma_2 = 0 \end{cases}. \tag{20.8}$$

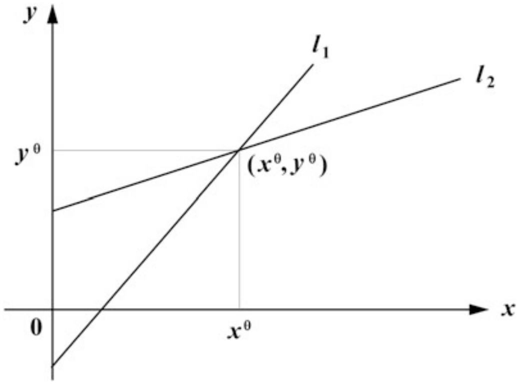


Fig. 20.3 The equilibrium point of the system in Eq. (20.8)

So, when $\alpha_i + \beta_i < 0 (i = 1, 2)$, there is an effective equilibrium solution,(x^θ, y^θ), Fig. 20.3, where

$$\begin{cases} x^\theta = \dfrac{\beta_2\gamma_1 - \beta_1\gamma_2}{\beta_1\alpha_2 - \beta_2\alpha_1} \\ y^\theta = \dfrac{\alpha_1\gamma_2 - \alpha_2\gamma_1}{\beta_1\alpha_2 - \beta_2\alpha_1} \end{cases}. \tag{20.9}$$

Denote

$$\begin{cases} F_1(x,y) = R_{off}x(\alpha_1 x + \beta_1 y + \gamma_1) \\ F_2(x,y) = R_{in}y(\alpha_2 x + \beta_2 y + \gamma_2) \end{cases} \tag{20.10}$$

Then, by taking the linear parts nearby the equilibrium point of Eq. (20.8) into consideration, we have

$$\begin{cases} \dfrac{dx}{dt} = A\left(x - x^\theta\right) + B\left(y - y^\theta\right) \\ \dfrac{dy}{dt} = C\left(x - x^\theta\right) + D\left(y - y^\theta\right) \end{cases} \tag{20.11}$$

where

$$A = \frac{\partial F_1}{\partial x}\bigg|_{\left(x^\theta, y^\theta\right)} = R_{off}\alpha_1 x^\theta = R_{off}\alpha_1 \frac{\beta_2\gamma_1 - \beta_1\gamma_2}{\beta_1\alpha_2 - \beta_2\alpha_1},$$
$$B = \frac{\partial F_1}{\partial y}\bigg|_{\left(x^\theta, y^\theta\right)} = R_{off}\beta_1 x^\theta = R_{off}\beta_1 \frac{\beta_2\gamma_1 - \beta_1\gamma_2}{\beta_1\alpha_2 - \beta_2\alpha_1},$$
$$C = \frac{\partial F_2}{\partial x}\bigg|_{\left(x^\theta, y^\theta\right)} = R_{in}\alpha_2 y^\theta = R_{in}\alpha_2 \frac{\alpha_1\gamma_2 - \alpha_2\gamma_1}{\beta_1\alpha_2 - \beta_2\alpha_1},$$

$$D = \frac{\partial F_2}{\partial y}\bigg|_{(x^\theta, y^\theta)} = R_{in}\beta_2 y^\theta = R_{in}\beta_2 \frac{\alpha_1\gamma_2 - \alpha_2\gamma_1}{\beta_1\alpha_2 - \beta_2\alpha_1}.$$

The characteristic equation of the linear parts of Eq. (20.8) is

$$\lambda^2 - (A + D)\lambda + (AD - BC) = 0$$

By letting $p = A + D$ and $q = AD + BC$, we derive the following basic quadratic equation:

$$\lambda^2 - p\lambda + q = 0$$

whose discriminant is

$$\Delta = p^2 - 4q = (A + D)^2 - 4(AD - BC)$$

By analyzing the stability using the eigenvalues of this characteristic equation, we obtain the following results.

Theorem 20.5 If $R_{off} < R_{in}\frac{\beta_2(\alpha_2\gamma_1 - \alpha_1\gamma_2)}{\alpha_1(\beta_2\gamma_1 - \beta_1\gamma_2)}$, $\alpha_1\beta_2 - \alpha_2\beta_1 > 0$, $w\alpha_1^2 + \frac{1}{w}\beta_2^2 > 2(\alpha_1\beta_2 - 2\alpha_2\beta_1)$, and $w = \frac{R_{off}(\beta_2\gamma_1 - \beta_1\gamma_2)}{R_{in}(\alpha_1\gamma_2 - \alpha_2\gamma_1)}$, then the equilibrium point is a stable node. QED

Theorem 20.6 If $R_{off} > R_{in}\frac{\beta_2(\alpha_2\gamma_1 - \alpha_1\gamma_2)}{\alpha_1(\beta_2\gamma_1 - \beta_1\gamma_2)}$, $\alpha_1\beta_2 - \alpha_2\beta_1 > 0$, and $w\alpha_1^2 + \frac{1}{w}\beta_2^2 > 2(\alpha_1\beta_2 - 2\alpha_2\beta_1)$, then the equilibrium point is a stable node. QED

Theorem 20.7 If $R_{off} < R_{in}\frac{\beta_2(\alpha_2\gamma_1 - \alpha_1\gamma_2)}{\alpha_1(\beta_2\gamma_1 - \beta_1\gamma_2)}$, $\alpha_1\beta_2 - \alpha_2\beta_1 > 0$, $w\alpha_1^2 + \frac{1}{w}\beta_2^2 < 2(\alpha_1\beta_2 - 2\alpha_2\beta_1)$, then the equilibrium point is a stable focus. QED

Theorem 20.8 If $R_{off} > R_{in}\frac{\beta_2(\alpha_2\gamma_1 - \alpha_1\gamma_2)}{\alpha_1(\beta_2\gamma_1 - \beta_1\gamma_2)}$, $\alpha_1\beta_2 - \alpha_2\beta_1 > 0$, and $w\alpha_1^2 + \frac{1}{w}\beta_2^2 < 2(\alpha_1\beta_2 - 2\alpha_2\beta_1)$, then the equilibrium point is an unstable focus, QED.

Theorem 20.9 If $\alpha_1\beta_2 - \alpha_2\beta_1 < 0$, then the equilibrium point is an unstable saddle point, QED.

The significance of these theorems includes:

(i) When the equilibrium point is a stable node, the interest rates of both onshore and offshore markets approach the equilibrium position gradually in an S-shaped trail. And eventually, they approach the equilibrium level infinitely.
(ii) When the equilibrium point is an unstable node, the interest rates of both onshore and offshore markets deviate away from the equilibrium position and, gradually, infinitely approach the maximum in the onshore/offshore markets without regulatory supervision.

(iii) When the equilibrium point is a stable focus, the interest rates of both onshore and offshore markets fluctuate around the equilibrium position with gradually decreasing fluctuation range and increasing frequency.
(iv) When the equilibrium point is an unstable focus, the interest rates of both onshore and offshore markets fluctuate around the equilibrium position in a volatile cycle with gradually increasing fluctuation range and decreasing frequency.
(v) When the equilibrium point is an unstable saddle point, the interest rates of both onshore and offshore markets approach the equilibrium position first and then deviate away from the equilibrium position later.

The theoretical analysis above leads to the following conclusions in terms of the short-term shocks and development of offshore financial centers, risk prevention, and lessons learned from the Eurodollar market.

I. Short-term shocks of the Hong Kong offshore center

China's Securities Regulatory Commission and Hong Kong's Securities and Futures Commission approved the pilot project of the interconnection mechanism with Shanghai and Hong Kong stock trading. This Shanghai-Hong Kong Stock Connect program officially began on November 17, 2014. By the end of February 2015, Hong Kong became the largest offshore RMB liquidity pool in the world with a total of 1.13 billion yuan in CNH-denominated deposits and deposit certificates. However, the convertibility of RMB and interest rate liberalization in the mainland China had not been fully implemented. So, arbitrage opportunities existed for investors in the incipient stage of the offshore RMB business development. In the following, we look at the potential risks that either appeared or might appear during the initial stage of the Hong Kong RMB offshore financial center into five categories:

1. Arbitrage of deposits and loans. Due to the differences between Hong Kong and the mainland in terms of both the levels of interest rates and their formation mechanisms, RMB frequently flows cross-border with changes in the interest rates of the two markets. The offshore market is usually less controlled by any monetary authority, and banks in the offshore market do not need to pay deposit reserves so that they can afford to offer loans at lower rates. Under such circumstances, banks and business entities in the onshore market are more likely to take out loans from Hong Kong. Additionally, there appear opportunities for arbitrage of deposits and currency: When the interest rate of RMB in the mainland is higher, the RMB will flow from Hong Kong and other surrounding areas into the mainland; when the interest rate of RMB in Hong Kong is higher, RMB will flow into Hong Kong and other surrounding countries from the mainland. When the interest rate of RMB deposits is higher than the HK dollar deposit rate of the same period, arbitrageurs will convert their HK dollars into RMB; conversely, they will take the opposite operation.
2. Arbitrage opportunities. Theoretically, if a mainland company is listed on both the mainland and Hong Kong stock markets, the intrinsic values of the

company's A shares and H shares are the same. So, they should be traded at the same price. But due to the different characteristics of the A shares and H shares, a big price tag might and generally exist and that is why arbitrage opportunities exist.

3. Arbitrage of exchanges. Hong Kong has already started its RMB exchange business and formed the market-based exchange rate since 1993. But until the present day, the free convertibility of RMB in the mainland has not been completely achieved. And the different formation mechanisms of exchange rate in the two different places have caused spreads of exchange to exist between the market-based exchange rate in Hong Kong and the controlled rate in the mainland. That eventually causes the arbitrage of exchange. When the exchange rate of CNY is overestimated (respectively, undervalued) in one of the markets, a large magnitude of RMB will flow across the border and cause currency volatility in both the mainland and Hong Kong.
4. Tax avoidance. The income tax rate of banks in the mainland is currently 25%, while the Hong Kong RMB business profits tax rate is only 17.5%. That attracts many banks in the mainland to go to Hong Kong for the purpose of tax avoidance.
5. Money laundering. With the development of the RMB business in Hong Kong, it has provided another platform and tools for money laundering. Meanwhile, the low tax rate in Hong Kong cuts the opportunity cost of money laundering.

II. The development of the offshore financial center

Considering that RMB is still not fully convertible and the interest rate liberalization is not yet implemented in China, the construction of Hong Kong's RMB offshore center must be done step by step with the pace of RMB convertibility in the capital account and interest rate liberalization.

1. The opening stage of personal RMB business in Hong Kong. On February 25, 2004, banks in Hong Kong formally launched personal RMB deposits, exchanges, remittances, and bank cards businesses. Up to this present day, all of these businesses have been run well; they have brought forward great convenience to investors in both places. At the same time, Hong Kong's position, as an international financial center, has been largely strengthened. Thirty-eight HK banks launched the personal RMB business, nearly all these banks have engaged in the retail business. For a detailed list of policy development regarding the offshore center, see Table 20.3.

In this stage, the policy requirement of the offshore activities is maintained consistent with the foreign exchange management system in the mainland.

2. The expanding stage of RMB bonds business in Hong Kong. Since June 8, 2007, the China Development Bank, the Export-Import Bank of China, and the Bank of China have been, respectively, allowed to issue bonds in Hong Kong, which is warmly welcomed by Hong Kong financial market. With the rapid growth of the offshore RMB investment demand, China is expected to gradually expand the

Table 20.3 Policies regarding the construction of the HK offshore center by the State Council of China

Time	Policies
November 1, 2005	The liquidation range of RMB businesses for banks in Hong Kong is extended; Hong Kong residents' RMB business is expanded; and the personal cash limit is increased
December 28, 2005	Increase, respectively, the ceilings on small amount US and HK dollar deposit rates by 0.5 and 0.25% points for commercial banks within China so that the limits of interest rates are, respectively, 3% and 2.625%
December 29, 2006	Establish the independent clearing house of the Foreign Exchange Transaction Center of China, which will help to improve the infrastructure construction of the financial market, control the risk of liquidation, increase the efficiency of liquidation market, and improve liquidity
January 14, 2007	Financial institutions in the mainland are approved to issue RMB bonds in Hong Kong, which further expands the range of RMB business in Hong Kong and creates a new channel for the RMB held by HK residents and enterprises to flow back to the mainland
June 8, 2007	The People's Bank of China and the National Development and Reform Commission joint issued "the administration of RMB bonds issuances in Hong Kong for financial institutions of the mainland," which strictly limited the qualification of the bond issuers
June 26, 2007	RMB bonds begin to be issued in Hong Kong
January 20, 2009	The People's Bank of China signs a swap agreement with the Hong Kong Monetary Authority with the amount of 200 billion yuan/227 billion HK dollars for the duration of 3 years
May 14, 2009 June 24, 2009	As approved by the State Council of China and the People's Bank of China, the bank of Asia and HSBC are allowed to issue RMB bonds for 40 billion and 30 billion yuan in Hong Kong, respectively
March 8, 2010	The People's Bank of China issued "the administration of information system for RMB cross-border flow" to guarantee the effectiveness and security of the cross-border RMB transactions
August 16, 2010	The People's Bank of China issued "the notice of related matters on the pilot of the bond market among RMB investment banks using the offshore RMB clearing bank and other three categories of institutions"
September 2, 2010	The People's Bank of China issued "the administration of overseas institutions' RMB bank settlement account," which allows overseas institutions open RMB bank settlement accounts to carry out various cross-border RMB businesses
November 9, 2010	The State Administration of Exchange Control released "the notice on issues relevant to strengthening the control of exchange business" to prevent the financial risks causing by the cross-border capital flows
August 2011	The State Council approved the issuance of RMB bonds in Hong Kong by domestic institutions with the total amount of 50 billion yuan, and domestic and foreign financial institutions each get half
November 22, 2011	The People's Bank of China redraw a swap agreement with the Hong Kong Monetary Authority with the amount of 400 billion yuan/490 billion HK dollars and the duration extended
December 16, 2011	China's Securities Regulatory Commission, the People's Bank of China, and the State Administration of Exchange Control jointly issued "the pilot measures for fund management companies and securities companies as RMB-qualified foreign institutional investors, subsidiaries of which are allowed to run the securities investment business using the money they have collected in Hong Kong

(continued)

Table 20.3 (continued)

Time	Policies
April 3, 2012	As approved by the State Council of China, enhance the limit of RQFII (RMB Qualified Foreign Institutional Investors) by 50 billion Yuan for special use of ETF (Exchange Traded Fund)
July 9, 2013	The People's Bank of China issued "the notice on policies relevant to simplifying the cross-border RMB business"

Data source: Official website of the People's Bank of China at (http://www.pbc.gov.cn/), access on July 23, 2016

scale and types of bond issuance in Hong Kong by including treasury bonds and allowing more corporate bonds issued by mainland and HK enterprises.

3. The RMB settlement of bilateral trades. Up to now, the mainland is Hong Kong's largest trading partner and second largest source of foreign direct investment. At the same time, Hong Kong is the third largest trading partner and the largest source of overseas investment of the mainland. This economic partnership between Hong Kong and the mainland is getting increasingly closer. Denominating their trades by using RMB will save foreign exchange resources and reduce the risk caused by the fluctuation of exchange rates for both parties.
4. The stage of allowing HK banks to run loans in RMB. The current practice of Hong Kong RMB deposit business is very complex and causes high management cost and low desire for participating banks to attract deposits. So, with the improvement of interest rate liberalization and regulation, it is necessary to gradually allow HK banks to run their RMB lending business. That means that these banks can directly offer loans in RMB to local enterprises, and additionally, the branches of these HK banks can also offer loans in the mainland to mainland investors by using the money they have collected in Hong Kong.

But at this stage of development, China should realize that there are still associated risks owing to the interest rate spread between Hong Kong and the mainland. China therefore should take actions step by step by considering its pace of interest rate liberalization.

5. Allow security issuances denominated in RMB. At the beginning of 2004, Hong Kong Exchanges and Clearing Limited revised its listing rules of mainland enterprises in order to encourage more large companies of the mainland to list in Hong Kong's stock market. By the end of 2007, over 70 companies have listed in Hong Kong with total financing of 192 billion HK dollars, among which HK$158.4 billion was contributed by mainland companies. As of this writing, Hong Kong has become the most important platform of financing for mainland enterprises. With the development of Hong Kong offshore financial center, China should allow listed companies to issue RMB equities directly in Hong Kong. That will not only save the cost of currency exchange but also improve the stability of the RMB exchange rate by balancing stock prices in the two markets while reducing opportunities for speculative arbitrage.
6. Strengthening the corporation of anti-money laundering between the mainland and Hong Kong. At the same time, when the growing circulation magnitude and

increasing number of business varieties bring great financing convenience to companies, they also inevitably present more opportunities to money launderers. So, it is very important to strengthen the corporation of anti-money laundering between the mainland and Hong Kong during every stage specifically by sharing transaction information and establishing a registration system for large cash transactions.

III. Risk prevention in Hong Kong RMB offshore financial center

1. Take the mode of internal-external separation management. The offshore and onshore businesses may more or less influence each other, even though they are separated. So, at the initial stage of operation of RMB offshore market, it is necessary for China to take the IMF (International Monetary Fund) and JOM (Japanese Open Market) as references. With the development of interest rate and exchange rate liberalization, China could gradually relax the relevant management.
2. Standardize the access management of RMB offshore businesses. In the offshore market, the cost of credit investigation is rather high due to the complexity of the clients. So, the CBRC (China Banking Regulatory Commission) and HKMA should strengthen their approval procedures for applications of offshore businesses by issuing different licenses according to the credit status and capital strength of the applicants.
3. Set up a coordinative mechanism for the exchange rate between HKD and RMB. The difference between the exchange rates with the US dollar of Hong Kong and the mainland, respectively, may easily cause a speculative mania in RMB. So, the HKMA should either adjust the exchange rate between the HK dollar against the US dollar or turn its US dollar pegging into pegging a basket of currencies that centers around RMB at an appropriate time so that China, especially Hong Kong, would be able to keep its economy out of much of the constraint of North America and maintain an independent monetary system.

IV. Enlightenments from the Euro-money Market

1. The development of the Euro-money market. In the 1960s, foreign currency business began to rise in order to improve the efficiency of economy development and reduce systemic financial risk. Such a history brings forward great enlightenment to the development of Hong Kong RMB offshore financial market.

The Korean War was one of the first fuses of the formation of the Euro-money market. The former Soviet Union and some Eastern European countries placed their dollar deposits in commercial banks of northern Europe in order to stay away from the economic embargo imposed by the United States. In July 1963, the United States began to impose interest equalization tax for the purpose of curtailing capital outflow. But in reality, it was a tax that caused permanent, massive outflow of capital. A lot of financial institutions and enterprises, which had a desperate need for money, began to issue Eurodollar bonds in London. Later, energy issues caused a sharp rise in the oil price, which made a large quantity of oil dollar flood into the

Eurodollar market in the form of deposits. With the collapse of Bretton Woods System, the US dollar was decoupled with gold, making many countries diversify their foreign exchange reserves. At the same time, speculation became more common and began to create nonsystemic risks. In order to keep the stability of the financial environment, many European countries took steps to encourage foreign currency deposits. As a result, great amounts of hard currencies, such as the German mark, Swiss franc, and Japanese yen, flew outside their motherlands, and the Euro-money market of various currencies initially formed.

After World War II, the Euro-money market became the most popular platform for various countries to achieve economy recovery. Statistics shows (Bergsten 2012) that Japan had borrowed US$6.3 billion in the Euro-money market from 1974 to 1977. In recent years, the Euro-money market has become an important medium for countries with either surplus or deficit to finance their surplus or shortage of funds. In other words, the Euro-money market has greatly improved the equilibrium of the macroscopic economy of the world.

But most deposits in the Euro-money market are short-term capital (less than 1 year), while most loans are for long-term. So, maturity mismatches appear. Under this circumstance, liquidity risk has appeared frequently due to frequent ruptures of the capital chain. Moreover, the free flow of capital weakens the capital control of economies, which increases the instability of financial systems and creates more opportunities for international arbitrage.

2. The foundation and development of Hong Kong RMB offshore market. In 2009, China officially started its internationalization strategy. With the continuous rise of China's economic status, the scale of the RMB settlement business expands rapidly, which has led to a quick launch of the pilot project of RMB cross-border investment and finance; and China has signed a lot of bilateral currency swap agreements with multiple national trading partners. The establishment of Hong Kong offshore center moves forward smoothly. More and more developing countries, as well as some developed countries, are more likely than before to hold financial assets in RMB, especially after the European sovereign debt crisis.

With the RMB internationalization, Hong Kong should make full use of its congenital advantages and learn from the Euro-money market by expanding the RMB offshore market and increasing the liquidity of RMB in this market. It is also very important for Hong Kong to promote the internal competition of banks and seek further development by relaxing the existing limitations.

To summarize, two conclusions can be derived as follows: First, financial regulation plays an important role in the development of the offshore market in Hong Kong. In the short term, China should take the responsibility to measure the progress of the liberalization of its capital account and master the new tendency of financial innovation. Second, Chinese government should resolve its issues regarding the development of its offshore financial markets from the perspective of cultivating competition. Additionally, Chinese government should also pay attention to microscopic uncertainties, such as the aforementioned maturity mismatches.

And during the whole process, the government should take the responsibility of supervising and maintaining the stability of China's financial market.

20.3 Island Hopping Campaign: Currencies Swaps

What can offshore non-deliverable forward (NDF) market data tell about the prospect for further RMB appreciation, as well as the development of Chinese financial market since the band for RMB to fluctuate was widened in July 2005? How does the continuing volatility of the US dollar against the Japanese yen affect the development?

To comprehend the effects of the yen/dollar volatility on Chinese RMB, Gu and McNelis (2013) applied an established model to South Korea, whose currency and financial market are more open and flexible than those of China. They found that the volatility of yen/dollar has little effect on the NDF market for the won but has direct effects on the onshore Korean currency and financial markets. The NDF market plays a key role for RMB in transmitting pressures from yen/dollar volatility to the Chinese spot and financial markets. Many studies have attempted to measure pressures on volatility and thus the degree of RMB misalignment based on purchasing power parity (see, e.g., Frankel 2011a; Kurita 2014). More recently, Zhang et al. (2016) attempted to measure the misalignment of RMB by using relative prices and relative output levels. They found that when sampling uncertainty and serial correlation are taken into account, there is little statistical evidence that the RMB is undervalued, even though many point estimates usually indicate significant misalignment.

In fact, as an empirical proposition there is no reason to expect purchasing power parity to hold exactly, even in the long run, much less in the short run. Given the limited and fragile nature of empirical estimates of misalignment based on purchasing power parity, this section makes use of direct market information from the offshore non-deliverable forward market to measure pressures on RMB for appreciation. The NDF market for RMB is smaller and more restricted than the NDF market for Korean won, but it is still a market with traders taking positions either for or against RMB appreciation. There is no reason not to evaluate signals from this source of information.

The volatility of the yen against the dollar, of course, reflects differences in the macroeconomic fundamentals of the United States and Japan (particularly with respect to savings). Because RMB is linked to a bucket of foreign currencies, including the US dollar and the Japanese yen, and the weight of each currency is not revealed, let us assume that the influence of each currency in the basket on Chinese economy should be proportional to the country's importance to China's competitiveness in exports and imports. The United States takes the biggest share of China's exports (18% in 2010) and Japan takes the biggest share of China's imports (13% in 2010). Thus we may expect that the effects of the yen/dollar volatility will have different consequences in China than in the United States. Given these differences, there are strong pressures for Chinese to further appreciate their currency.

Prior to July 2005, RMB was pegged to the US dollar at ¥8.2777 = US$1.00. Fred Bergsten (2015), for example, noted that China continued to strengthen its "competitiveness" by "riding the dollar down," which in turn severely truncated the "adjustment process" because other Asian countries were afraid of losing competitiveness against China and thus blocked their appreciations against the dollar. Bergsten argued that further RMB revaluation would "help China cool its overheated economy" and help stop the inflow of speculative capital.

After July 2005, a new exchange rate regime was implemented. In the new system, RMB was pegged to a basket of currencies of China's main trading partners. Wang and Xie (2013) have shown that the weight of the dollar in Chinese currency basket has been reduced and sometimes has been less than one. However, they noted that "there is no evidence of systematic operation of a currency basket with discernible pattern of significant weights on other currencies." For this reason, let us concentrate on the volatility of the US dollar against the Japanese yen, since the dollar continues to dominate the Chinese currency basket, and, as noted above, both the United States and Japan have the largest shares in Chinese exports and imports, respectively.

On the other hand, although RMB did experience some appreciation against the US dollar, as Hu et al. (2016) noted, US critics have not considered the RMB appreciation sufficiently. The presumption of these critics, Cordon suggested, is that Chinese exchange rate intervention played an important role in causing the deficit in the US current account. Certainly, there are other views on this matter in the Pacific region. Before the July 2005 regime change, Hong Kong Monetary Authority argued that further RMB revaluation would not necessarily dampen speculative capital flows, but rather invite renewed speculative inflows on the expectation of further strengthening of the currency. They pointed out that job creation and financial stability are the key priorities and RMB revaluation may in fact do more harm than good (Sun and Ma 2005).

Of course, RMB revaluation has been tied, in both political discussions and policy analyses, to the continuing sustainability of the US current account deficit with respect to China. This deficit is seen not only sustainable but an integral feature of a sustainable international monetary system. Through the deficit, the United States supplies international collateral to China, which in turn supports two-way trade in financial assets, liberating the capital formation in China from the inefficient domestic market (Ying 2016).

Based on out-of-sample Granger causality tests, Ding et al. (2014) have shown that the volatility of yen/dollar exchange rate has strong direct effects on the NDF, which in turn affects the RMB exchange rate and interest differentials between the United States and China. These interest differentials significantly affect the share markets. These results are robust to the use of vector autoregressive (VAR) or Bayesian VAR specification. Furthermore, bootstrapped generalized impulse response paths, based on 95% confidence bands, are consistent with the conclusion that increase in yen/dollar volatility leads to discounts in the NDF market.

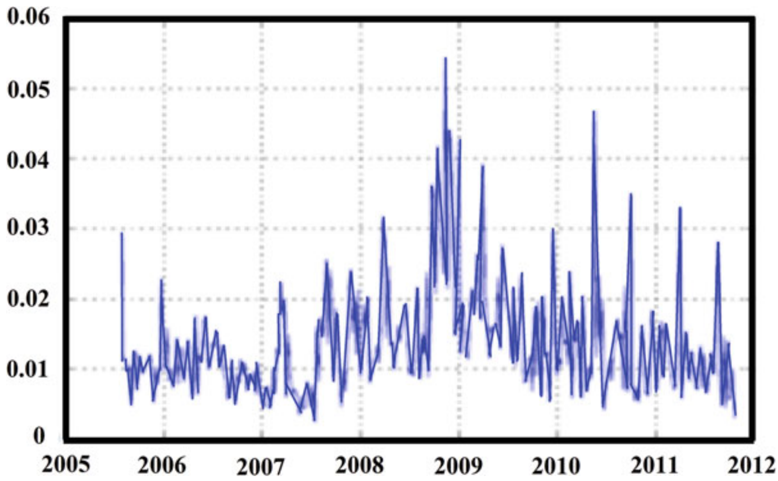


Fig. 20.4 Realized volatility of the daily yen/dollar spot rate (2005–2012)

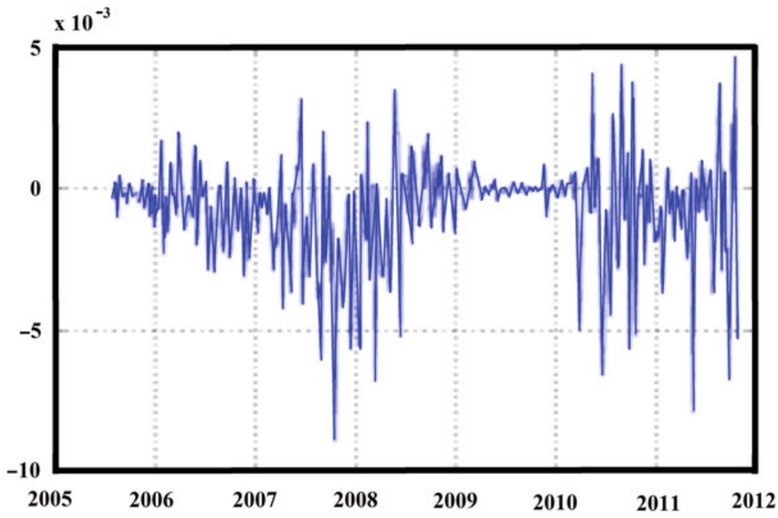


Fig. 20.5 Weekly rate of change of the RMB/USD exchange rate (2005.5–2012)

Figure 20.4 displays the weekly realized volatility, based on daily depreciation rates, of the yen with respect to the dollar from July 2005 to the beginning of 2012. This figure shows a marked jump in volatility following the worldwide financial crisis in late 2008.

Figure 20.5 shows the evolution of the weekly rate of change of the RMB/USD exchange rate for the same time frame. It can be seen that in the buildup to the financial crisis of October 2008, volatility in the weekly RMB increased. Between

2009 and 2010, the weekly RMB changes diminished but increased in volatility after that time period.

As of 2005, it is not well known that China had significantly increased its flexibility in foreign exchange operations from the early days of reform (1979–1993). In many ways, RMB's convertibility for current account transactions is similar to those that exist in OECD (Organization for Economic Cooperation and Development) countries. And, although RMB is not convertible for capital account transactions, a significant amount of flexibility has been introduced here as well (Ying 2016).

Early reforms had eliminated the existence of multiple exchange rates and unified the settlement and sale of foreign exchange (FX). A unified interbank market in FX was established. The China Foreign Exchange Trade Center (CFETC) in Shanghai is a nonprofit entity, based on membership and directed by People's Bank of China (PBoC). The members are made up of Chinese banks, foreign banks, and nonbank financial institutions. The CFETC deals only with cash trades and members cannot take proprietary positions. It plays the role of a unified, nationwide spot foreign exchange market in China. PBoC directly runs the operations and controls the movements of the RMB exchange rate at the Center (Zhang et al. 2006). NDF operations can be conducted in the RMB with existing RMB forward contracts. The Bank of China has been allowed from 1998 to 2006 to trade RMB forwards; local Chinese banks were given the right to trade such contracts as well. But this practice was stopped after December 2006. The Bank of China's dominating position in this market persists.

Although it appears easy, given these markets and the related reforms, for speculators to take positions in Chinese RMB, the high transaction costs, lower transparency, and limited liquidity of RMB NDFs make these instruments and the yuan forwards a less economical way of taking such positions than asset swaps, equity swaps, and currency swaps. It is likely that such over-the-counter (OTC) instruments are being used more for speculative purposes. However, to this end, it has been also difficult to obtain data regarding these OTC deals. The yuan NDFs, on the other hand, are quoted in Reuters with weekly data available. Although they are not the most cost-effective instruments, the NDF quotes are still an excellent proxy for the speculative sentiment that exists in the NDF market.

By using the Bayesian autoregressive system under several alternative specifications as well as those discussed above, the volatility of the euro/US dollar exchange rate can be employed in the place of the yen/dollar exchange rate. The results of such analysis are robust and straightforward. A very simple Bayesian vector autoregression (BVAR) model gives highly significant evidence for the hypotheses formulated in this section. The following summarizes the results obtained throughout the previous discussion and relevant data analysis:

(a) The Renminbi NDF is driven by its own dynamics and influenced by the volatility in the yen/dollar exchange rate. Neither interest rate differentials nor the spot exchange rate of RMB/US dollar movements affect the offshore Renminbi NDFs. This is in stark contrast to the situation with Korea, where the won NDF market is responsive to developments of the onshore financial market.

(b) As yen/dollar volatility increases, the Renminbi discount in the NDF market becomes more negative. This result is significant even at 5% level within one quarter.
(c) The US dollar/RMB has some predictability by using the information from the NDF markets.
(d) The statistical model becomes more accurate for the purpose of forecasting when the smoothing effect of the Bayesian priors is employed.

In this section, outlined is a hypothesis that the Chinese Renminbi NDF movements are driven by speculative psychology generated by the yen/dollar exchange rate. According to this hypothesis, as the yen/dollar exchange rate becomes more volatile, market players bet on further RMB appreciation making the NDF discount deepen. The evidence in support of this hypothesis outlined in this section is compelling in spite of the available sample of short weekly time series data.

The volatility of the US dollar has increased over the past decade, of course, not only with respect to the Japanese yen but also to the euro. The conclusions drawn in this section are robust with respect to the choice of the currency index for measuring volatility. By replacing the realized volatility of US dollar/Japanese yen by that of the US dollar/euro, the desired results are derived.

20.4 Without Match in Asia: Regionalization and Internationalization

China has been promoting the use of its currency, Renminbi (RMB), for international trade and investment, which, according to economic logic, means that this will eventually require full RMB convertibility, the ability to exchange RMB into another currency for any purpose and in any amount without restriction. RMB reserve currency status will further require that China establish an open capital account and more competitive capital markets. Thus, even though the internationalization of RMB has attractions for both China and the rest of the world, it also presents substantial challenges. In the short term, China's highly controlled exchange rate, capital account regime, and structural current account surplus complicate its efforts to generate outflows of RMB and manage returning inflows of RMB. Current inflationary pressures, which require relatively tight monetary policy, also make authorities reluctant to facilitate returning inflows of RMB.

In the longer term, opening the capital account would force China to make its exchange rate more flexible in order to retain control over the domestic interest rate. Given the reduced role this would imply for the government in the economy, political considerations might block the complete RMB convertibility for investment purposes for many years to come. A more flexible exchange rate would also reduce the need for the central bank to buy excess US dollars, leading to slower reserve accumulation and reduction in Chinese demand for US treasuries. That would put an upward pressure on the yield of the treasuries.

In 1993, China indicated that it was committed to achieving full currency convertibility by the end of the century and began removing capital account restrictions gradually and established current account convertibility (Ying 2016), as required by Article VIII of the International Monetary Fund's (IMF) Articles of Agreement, in December 1996. When the Asian financial crisis erupted the following year, however, China dropped its target for full convertibility. And, although senior financial officials still maintain full convertibility as an objective in private discussions, the government no longer provides any official commitments or timetables (Ying 2016). Nevertheless, since late 2008, China has accelerated its efforts to promote the RMB as an international currency. To this end, a natural question is *why*.

20.4.1 Internationalization of RMB, Why?

A primary motivation is for China to reduce its dependence on the US dollar. Public opinion, polled by a Chinese bestseller, entitled *Currency Wars*, inclined to believe that the United States is seeking to reduce its debt burden by depressing the value of its dollar and is concerned about the value of China's ample US dollar reserves (Ying 2016). Meanwhile, authorities worry that China's reliance on the dollar for invoicing and settling trades can hurt exports.

After Lehman Brothers collapsed in 2008, Chinese exports plummeted, not only because the final demand fell but also because of the credit freeze in many importing countries, which limited importers' access to trade finance. Hence, the authorities believed that turning RMB into a trade settlement currency will reduce China's risk of such shocks, will better protect Chinese exporters from currency risk, and will reduce or eliminate costs associated with hedging against that risk. Similarly, using RMB as an investment currency will help eliminate exchange rate risk for Chinese firms seeking to borrow for international investments. In addition, increasing RMB use would over time help lower China's excessive foreign exchange reserves (Ying 2016). In the short run, however, the opposite has happened and reserves have increased at a faster rate, which is surely not what was initially intended.

20.4.2 Implementation in the Short Run

Following the global financial crisis of 2008, China worked to better protect itself by intensifying efforts to internationalize RMB and to develop an offshore market. However, the country's capital account restrictions, current account surplus, and high economic growth have complicated its attempts to have foreigners outside of China to hold large amounts of RMB; traders want to use their RMB to buy Chinese goods, investors want to invest their RMB in Chinese assets, and corporations in China want to borrow RMB in the offshore market to circumvent domestic borrowing restrictions. In fact, given these pressures, only the widespread expectation of further RMB appreciation made China's push to create an offshore RMB market possible (Ying 2016).

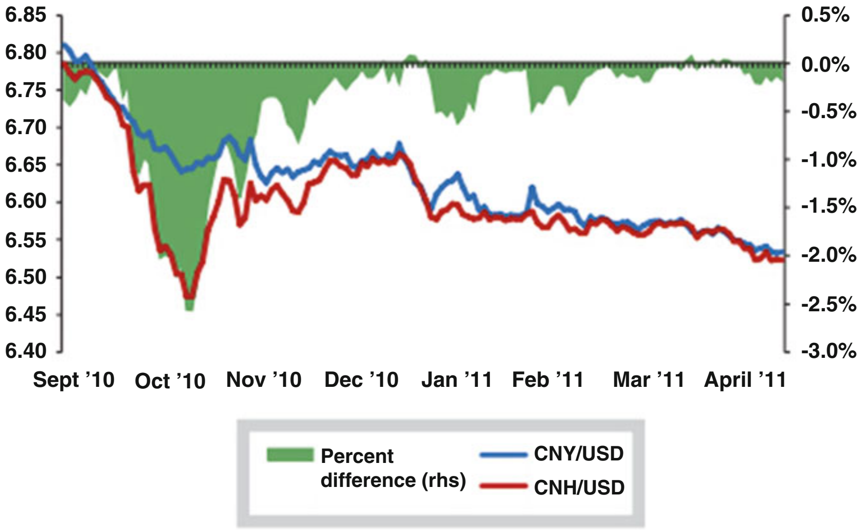
Motivated, in part, by liquidity concerns during the worst part of the 2008 financial crisis, China began its effort with a number of bilateral currency swap agreements with individual countries, such as South Korea, Malaysia, Belarus, Indonesia, Argentina, Iceland, and Singapore, and more recently Hong Kong (January 2009), New Zealand and Uzbekistan (April 2011), and Russia (June 2011). In July 2011, swap agreements were valued at ¥829.2 billion (about US $130 billion). China is also reportedly discussing the use of local currencies to settle trade with Brazil (Ying 2016).

In July 2009, China piloted an RMB trade settlement scheme. By the end of 2010, it had licensed more than 67,000 exporters in 20 provinces to invoice in RMB. Though further expansion is likely, concerns about inflation, mainly caused by China's excessive, stimulus-related credit expansion in 2009 and 2010, have put the licensing efforts on hold, as authorities' worry that invoicing in RMB could create additional liquidity. China is now focusing on encouraging importers to pay with RMB instead. Once the domestic monetary stability is reestablished, China would be able to promote the use of RMB for both imports and exports (Ying 2016).

As for offshore RMB markets, China has made considerable progress in Hong Kong, where residents were first permitted to open limited RMB accounts in 2004, well before the financial crisis. The amounts involved remained small until 2010 when deposits surged by almost 400% as RMB internationalization intensified. These deposits underpin Hong Kong's primary market for RMB-denominated financial instruments. The market has expanded rapidly since 2009 when China's Ministry of Finance issued a small amount of RMB-denominated bonds to help promote the market. Since then, several large multinational corporations, such as HSBC, McDonald's, and Caterpillar, have also issued so-called "dim sum" bonds. The first RMB-denominated initial public offering (IPO) took place in April 2011. However, a secondary market for RMB-denominated securities has yet to develop (Ying 2016).

Because of China's complex regulations to keep onshore and offshore RMB markets separate and to restrict cross-border arbitrage, interest rates and the dollar exchange rates can and do diverge in the two markets (Fig. 20.6). The arrangements are reminiscent of China's deliberate "dual-track" approach to domestic market reforms in the 1980s and early 1990s, though today's arrangements may be maintained longer (Ying 2016).

The People's Bank of China is currently in discussions with Singapore to create a second hub for offshore RMB trading. Kuala Lumpur, Jakarta, Manila, Seoul, and eventually perhaps even Taipei might be in line. Outside Asia, RMB is hardly traded, but that may change in the years ahead. In January 2011, the Bank of China,



Source: Conor Foley. MA student at Johns Hopkins SAIS. based on Bloomberg data.

Fig. 20.6 Offshore and onshore exchange rates

the third largest bank in China, began offering limited RMB deposit services in London, New York, and Canada (Ying 2016).

China announced significant additional initiatives for RMB internationalization in January 2011. Chinese firms are now permitted to transfer RMB offshore for investment abroad and Chinese banks are allowed to extend RMB loans for such purposes. Any profits from such investments can be repatriated in RMB. In addition, residents of Wenzhou, a prosperous, entrepreneurial city on China’s east coast, can now directly invest up to ¥200 million (about US$30 million at the current exchange rate) per year overseas. Shanghai’s municipal government has reportedly requested similar privileges for its residents (Ying 2016).

20.4.3 A Long-Term Outlook

Despite its proactive efforts to promote RMB internationalization, China may not approve all of the necessary measures to achieve full convertibility of RMB any time soon. Most significantly, full convertibility would require Beijing to remove its capital account restrictions and many domestic financial controls, which China relies on for various economic and political purposes, including maintaining a repressed financial system and an undervalued exchange rate.

If its leaders were to open the capital account, China would have to integrate its capital market into the world market with major implications for its state-owned banking system and privileged lending to state enterprises. It would also have to choose between a managed exchange rate and monetary autonomy, as the two are only possible together when capital controls are in place. In addition, China would have to develop a capacity to conduct monetary policy in ways that resemble those of other large economies. These changes would have to occur more or less simultaneously (Ying 2016).

Paradoxically, a decision by China to stop intervening in foreign exchange markets and float its currency now, a move that US politicians have been advocating for years, would create financial problems for the United States, because the reduced demand for US Treasuries and other debt securities would put pressures on the yields in the US bond market.

China's progress in promoting RMB as an international currency despite macroeconomic constraints and its apparent unwillingness to commit to full convertibility can be explained by the widespread expectations of rapid growth in China and of further RMB appreciation against the US dollar. China's large and growing presence in the global economy and concerns about the soundness of US macroeconomic policies add to the impetus toward RMB internationalization.

Even if China stops short of full convertibility, RMB can still gain some limited reserve currency status. In fact, Malaysia and other smaller countries in the region have announced that they have already invested, or plan to invest, a portion of their foreign exchange reserves in RMB-denominated financial instruments (Ying 2016). This might be done in part for political reasons, and whether or not such decisions are based on ad hoc convertibility agreements with China is unclear.

This very limited reserve role is a good first step, but the world should more fully embrace RMB as a reserve currency. An international monetary system based on multiple currencies, where RMB joins the US dollar with the euro as the third major reserve currency, offers a natural extension of the current monetary system and has the potential to alleviate present currency tensions while promoting systemic stability.

Turning RMB into a fully convertible international currency would also be good for China. It would, for example, require ending domestic financial repression. This would help China rebalance its economy, give its central bank greater independence, and win recognition as a real "market economy." It is neither possible nor prudent to make RMB fully convertible overnight, but the objective should be made clear and an approximate timetable would help all concerned parties.

20.4.4 RMB Undervaluation and China's Growth

Various studies have suggested that RMB is undervalued, with recent estimates ranging from 15% to 50% (Hu et al. 2016). China's large interventions in support of its currency lend credence to the view that its exchange rate is undervalued. Many economists (Zhang et al. 2006) believe that any RMB undervalued estimate should be taken with a grain of salt, because it requires many assumptions and China's current account surplus is not primarily caused by an undervalued RMB. Instead, factors, such as the rate of household savings, fiscal balance, tax, and other incentives offered to investors and exporters, play more significant roles.

From recognizing that an RMB revaluation increases the purchasing power of its consumers and is in China's own interest, leaders in Beijing allowed RMB to gradually appreciate, which amounted to 20% against the US dollar between July 2005 and July 2008. While the policy was suspended when the 2008 global economic crisis began, it resumed in June 2010. Over the following year, the currency appreciated by about 5.5% against the dollar (Ying 2016).

China's pre-crisis revaluation, combined with its massive demand stimulus, has served both the country and the world well. China's domestic demand has increased by 41% since 2006–2007, and its current account surplus has declined by 5% of its GDP. China has contributed greatly and disproportionately to the global growth over the time period 2000–2008 and since the outbreak of the financial crisis. And, global financial markets have become highly sensitive to developments in the Chinese economy (Ying 2016).

However, any RMB revaluation will not work for China and/or its trading partners if the revaluation disrupts China's export-dependent economy and undermines investor confidence in its continued growth. According to the IMF, net exports and fixed investments that were linked to the tradable sector accounted for more than 60% of China's GDP growth from 2001 to 2008, compared to 35% in the rest of Asia and 16% in the G7 economies (Ying 2016).

20.4.5 Who Will Gain from an RMB Revaluation?

The greatest beneficiary of a gradual RMB revaluation, accompanied by measures to stimulate demand, will be China itself. Revaluation will likely establish more balanced and resilient growth, which will have positive spillovers on the rest of the world, including reduced currency and trade tensions. RMB revaluation will be more beneficial for all countries if it comes with measures that accelerate China's domestic demand relative to its GDP. Indeed, without such measures, revaluation may fail to change China's current account surplus or may even widen it (Ying 2016). The direct effects of RMB revaluation on countries other than China are not straightforward, as their consumers will lose from higher import prices, but their producers will gain from improved competitiveness.

China's trading partners can be classified into three groups: low-income commodity exporters, middle-income manufacturing exporters, and high-income manufacturing exporters, and each will see a different impact from RMB revaluation. As a general rule, countries that import more from China than they export there will lose, while those that export more than they import from China will gain. Low-income commodity exporters increasingly look to China as an export market; it accounted for 7.2% of their total exports in 2009, up from 1.3% a decade before, and a supplier of cheap consumer goods and machinery (17% of their total machinery and transport equipment imports came from China in 2009). As a result, these countries are likely to be much more interested in China's continued growth than in RMB revaluation. In fact, according to a study of the Organization for Economic Cooperation and Development, a 1% slowdown in China's growth rate would result in a reduction of around 0.3% in growth of low-income economies (Ying 2016). In the very long run, RMB revaluation could help these countries diversify into basic manufactures. In the short run, however, RMB revaluation would likely have little effect on their exports, as global markets determine the price of their commodities (which are denominated in the US dollar). And countries that have the largest trade deficits with China, such as Ghana, will be most likely to lose as their terms of trade (the difference between the growth of export and import prices) deteriorate.

The same will hold true for middle-income manufacturing exporters, which have increased their imports from China in recent years (in 2009, nearly 12% of their imports came from China). Countries such as Vietnam and Hungary, which import much more from China than they export there (Ying 2016), will likely lose due to RMB revaluation, particularly in the short term. Generally, middle-income manufacturing exporters, such as South Korea and Malaysia, which compete directly with China in manufacturing exports, tend to have bilateral current account surpluses with the country. As a result, they are likely to gain the most from RMB revaluation. Like China, machinery and transport equipment account for some 45–50% of their exports. And, as an Oxford University study shows, China's average export prices (unit values) place substantial downward pressure on these countries' prices (but not on those of low-income countries) (Ding et al. 2014). As a result, middle-income manufacturing exporters will see their export volumes and prices expand with RMB revaluation, as they become more competitive with China in third markets and the price pressure relaxes a little.

In high-income countries, the effects of RMB revaluation will be mixed and will again depend on their bilateral trade positions with China. Generally, high-income countries have smaller deficits with China as a share of GDP than low- and middle-income countries do. Countries, such as Germany and Japan, will likely be able to increase prices on their large exports to China. The technology-intensive and differentiated nature of their exports makes their goods less price sensitive, and producers may choose to leave their RMB prices unchanged, taking increased profits instead. Since they generally do not compete with China directly, they are unlikely to see large gains in third markets or long-term volume gains. Table 20.4 provides the data of bilateral trades with China in 2009.

Other high-income countries, the United States and Italy, in particular, are in a less favorable position. Their imports from China are about three to four times larger than their exports to China. As a result, they are likely to be significant net losers from an RMB revaluation. They will also see a significant distributional impact, as their imports from China are consumed widely and disproportionately by low-income households. In both the United States and Italy, the wider bilateral trade deficit with China may be permanent, as neither import nor export volumes are likely to react enough to offset the large deterioration in terms of trade. Middle-income exporters may take some US and Italian market share away from China.

Table 20.4 Bilateral trade with China in 2009

	Exports to China	Imports from China		Exports to China	Imports from China
High-income countries					
United States	0.5	2.2	Italy	0.4	1.3
Japan	2.2	2.4	South Korea	10.4	6.5
Germany	1.5	1.9			
Middle-income manufacturing exporters					
India	0.8	2.3	Poland	0.3	1.8
Mexico	0.3	4.1	Sri Lanka	0.2	4.1
Philippines	1.9	2.5	Thailand	6.1	6.5
Hungary	1.0	5.2	Turkey	0.3	2.1
Indonesia	2.1	2.6	Vietnam	5.3	17.6
Malaysia	9.9	9.0			
Commodity exporters					
Nigeria	0.5	3.6	Ghana	0.5	11.0
Kenya	0.1	4.7			

Source: International Monetary Fund, Direction of Trade database

Intra-firm imports of US multinationals from affiliates in China, which accounted for nearly 30% of US imports from China in 2009 (Ying 2016), will probably be hurt unless they have diversified their sourcing to include competing middle-income manufacturer exporters.

This discussion does not imply a judgment that a large bilateral trade deficit with China is bad or that a big surplus is good. It only suggests that RMB revaluation will not erase a bilateral trade deficit. Instead, increasing national savings rates in Italy and the United States, and increasing consumption in China, would be more effective. Given China's high dependence on price-sensitive exports, a large one-time RMB revaluation may carry unacceptable risks to its growth and stability. In the event of a sharp slowdown in China, those countries that are likely to lose due to RMB revaluation anyway could suffer a proverbial double whammy.

20.4.6 Will Other Asian Currencies Follow China's RMB Revaluation?

RMB revaluation is often cited as a necessary solution to the problem of global imbalances. In part, the argument goes, an RMB revaluation will lead other Asian countries to revalue their currencies as well (Dobson and Masson 2009). Indeed, the exchange rates of some Asian economies have tracked RMB more closely in recent years (Ying 2016). However, such a widespread revaluation of Asian currencies is unlikely. While Asia's middle-income countries, which compete with China in export markets, may move with RMB, Asia's advanced countries, which account for 45% of the region's trade and whose exports complement those of China, are unlikely to follow RMB's path. In either case, any movement that occurs is unlikely to be large. As a result, the effect of Asian currency movement on countries, such as the United States, which competes more with advanced than with middle-income Asian economies, and on the most infamous global imbalances is likely to be limited.

20.4.7 RMB's Increasing Influence in Asia

Most Asian currencies have followed the US dollar for decades, including RMB, which was tightly pegged to the dollar until July 2005 when it began to liberalize. As China has allowed RMB to appreciate against the dollar, first from July 2005 to August 2008 (when the financial crisis erupted) and again from June 2010 to the present (as the recovery took hold), RMB appears to be exerting independent influence on some Asian currencies, notably those in middle-income Asian economies. For example, as shown in Table 20.5, during RMB's first period of reform (July 2005 to August 2008), the real effective exchange rates (REER) of Malaysia, the Philippines, and Thailand, all middle-income economies, moved with RMB. Their REER appreciated by 6–27%, compared to RMB's 13% real effective appreciation and in contrast to the dollar's 10% depreciation. However, the REER of the advanced Asian economies, such as Japan, Hong Kong, and South Korea, which have similar exports to and compete more with the United States than the middle-income Asian economies do, moved against RMB, depreciating by 12–17% over the period.

Although disentangling the factors behind such movements require much deepened research, policies had likely played an important role. For example, Asian central banks appear to be increasingly including RMB in the baskets of currencies

Table 20.5 Correlations between REER of Asian currencies and RMB and US dollar

	Before RMB reform (08/2003-07/2005)		After RMB reform (07/2005-08/2008)	
	RMB	USD	RMB	USD
Singapore	0.88	0.89	0.79	−0.91
Hong Kong	0.93	0.97	−0.81	0.98
Japan	0.12	0.02	−0.58	0.65
South Korea	-0.58	−0.51	−0.76	0.69
Malaysia	0.93	0.98	0.47	−0.52
Philippines	0.55	0.64	0.77	−0.90
Thailand	−0.04	−0.01	0.54	−0.75
Indonesia	0.34	0.39	−0.16	0.11
China	1.00	0.95	1.00	−0.84

Source: Bank for International Settlements

Table 20.6 Net export similarity index between China and Asian countries

	1996	2008	Exchange-rate regime
Thailand	43.6	35.3	Managed float
Malaysia	21.7	30.9	Managed float
Philippines	44.8	26.1	Float
Indonesia	31.6	19.0	Float
Singapore	10.1	15.8	Managed float
Japan	10.6	14.9	Float
South Korea	22.2	25.1	Float

Source: International Monetary Fund (2008)

their exchange rates track, partly because of China's rising weight in the region's trade. Pomfret (2014) estimated that Indonesia and Malaysia now give RMB a 45% weight in their baskets (with the US dollar, the euro, and the Japanese yen accounting for the other 55%). Market forces are likely also responsible for RMB's rising influence. Studies (Ying 2016) show that the speculation of rising RMB appreciation often leads Asian currencies to rise. And certain currencies, the Singapore dollar, for example, appear to serve as proxies for RMB in futures markets. Going forward, if RMB continues to appreciate, it could affect other Asian currencies through three channels: relative prices, demand, and foreign investment. We explore next each of these channels in turn.

First, let us look at prices. Any RMB revaluation against the US dollar will make Chinese goods more expensive abroad. As a result, countries that export close substitutes for Chinese goods, due to similar factor endowments, for example, will likely benefit from their increased market shares. Countries that export complements, for example, parts and components, for Chinese goods, on the other hand, will almost certainly feel an adverse effect. Middle-income Asian economies, such as Thailand, Malaysia, the Philippines, and Indonesia, appear to comprise the former group. Their export profiles, particularly those of countries with managed exchange rate regimes, show large similarities with China's (see chart below). And shifts in their shares of third markets suggest that their competition with China is growing. China's share of Asia's exports to the United States tripled from 14.5% in 2000 to 44% in 2008, while that of middle-income Asian economies fell from 15.2% to 11.5% over the same period, Table 20.6 where the index ranges from 0 to 100 with 0 representing completely dissimilar export profiles between two countries, while 100 identical export profiles. Similar export profiles suggest that the countries are competitors, while different export profiles suggest that they are complements to each other.

Those countries that export close substitutes for Chinese goods may gain market share if RMB revalues, which will eventually put pressure on them to appreciate their currencies as well. At the same time, some of these countries, including Indonesia and Vietnam, import more from China than they export there and will experience adverse effects from rising import prices. Therefore, the direction of the pressure on their currencies will depend on which effect is greater: the benefit from increased export market share or the cost of higher import prices from China.

As for China's advanced neighbors, such as Japan, Korea, Hong Kong (China), and Singapore, an RMB revaluation will likely hurt their trades. Their export structures (controlling for trade in components) have little in common with China's (see Table 20.6). Rather, the two complement each other: the advanced countries provide intermediate goods that China processes and reexports. About 60% of intermediate goods in China come from other Asian countries, particularly the advanced economies (Ying 2016). As a result, RMB revaluation could hurt the advanced Asian economies by slowing China's export growth and thus lowering its imports from them.

Secondly, let us look at the demand. RMB revaluation will also affect China's growth, which in turn will impact the rest of Asia's growth through reduced demand for consumer and intermediate goods exports. A recent study shows that a 1% slowdown in China's growth would lead to a 1.12% reduction in the growth rates of a sample of emerging economies, including Hong Kong, India, Indonesia, Malaysia, the Philippines, Singapore, and Thailand (Ying 2016). A large RMB revaluation that sharply slowed China's growth could therefore lead other Asian economies to suffer and put downward pressure on their real effective exchange rates.

Unless it were massive, however, a revaluation is unlikely to cause such a sharp slowdown. RMB appreciation against the US dollar from July 2005 to August 2008, nearly 7% annually, had little visible effect on China's double-digit growth, for example. Similarly, a 2010 study by Deutsche Bank found that a 10% RMB appreciation would reduce real GDP by only 0.6% from its baseline. More generally, studies found little evidence that countries that de-peg their currencies experience a durable growth slowdown as a result (Eichengreen and Rose 2014). Moreover, China may well adopt other policy measures that stimulate domestic demand, such as renewed fiscal stimulus, to offset the impact of RMB revaluation on growth. Thus, a gradual RMB revaluation would likely put little pressure on other Asian currencies through the demand linkage.

Thirdly, let us look at the diversion of foreign direct investment. An RMB appreciation could affect other Asian currencies through foreign direct investment (FDI). In recent years, China has not only become Asia's trading powerhouse but also emerged as the preferred destination for FDI in the region. Reflecting its attractiveness to outside investors, China's share of Asia's FDI inflows rose from about 25% in 1992 to 37% in 2008, while other Asian economies with similar income levels and relatively cheap labor, such as Malaysia, the Philippines, and Thailand, saw their share fall sharply over the same period (Ying 2016).

Since a revaluation of RMB may decrease China's attractiveness as an investment destination, FDI flows may go instead to developing Asian economies. However, the profit margin of multinationals in China is reported to be robust (Ying 2016), and given the large fixed and transaction costs and investors' tendency to reinvest profits, a shift in FDI is expected to be gradual.

In short, though RMB's influence in Asia is growing, a revaluation will affect the exchange rates of China's advanced and middle-income neighbors differently, reflecting their various trade and investment relationships. With regard to the United States, the high degree of complimentarity between its economy and those of China and Asian middle-income countries suggests that it will likely lose out from RMB revaluation as its import prices rise. As a result, the potential impact of RMB revaluation on the US current account deficit is smaller than often assumed.

Rasmus Fatum and Yohei Yamamoto (2016) concluded that for the first time in human history, the entire global economy relies on a paper currency, the US dollar, which is not linked or backed up by any reserve commodity (such as gold). Around the world, roughly 60% of all bank reserves are US dollars. Its standing as the world's reserve currency permits America's leaders to do what no other country in the world can do: legally print money to repay debts. If confidence in the dollar were to fail, what on Earth could be used to stop the panic? There are no reserves.

The world is increasingly unstable economically. Europe is technically bankrupt and can never repay the huge debts it is accumulating except by currency devaluation (i.e., inflation or hyperinflation), which in turn can have a domino effect on the United States. However, no nation threatens the United States as greatly as China. Even while China reels from its own debt problems, it is systematically attacking the United States through a currency war and undermining the US dollar as the world's reserve currency. Very few people understand that if China is successful, it will instantaneously make the US dollar worthless.

Sovereign entities as well as various terrorist groups have already seized the opportunity afforded by the current world economic situation to hit the United States at where the United States is most vulnerable. It is to be expected that nations will move for their own national security and interests first. Some do so with only slightly veiled belligerence. It is no secret that China has been aggressively and actively positioning itself to move to the top of the proverbial food chain.

20.5 Some Final Words

Based on analytical analyses and literature reviews, this chapter discusses what China has done and might need to further do in order to make its Renminbi a successful reserve currency of the world. By symbolically modeling the link between the offshore market and the onshore market, it is suggested that the proportion of pure offshore transactions needs to be improved and the impact of pure two-way trade need to be weakened, a full expansion of Hong Kong offshore RMB business by increasing the participation of nonresidents, and promotion of an orderly internationalization of RMB. By theoretically modeling how the development of RMB offshore market impacts China's domestic base currency and foreign exchange reserves, this chapter finds that China should take the responsibility to measure the progress of the liberalization of its capital account and master the new tendency of financial innovation; the government should resolve its issues regarding the development of its offshore financial markets from the perspective of cultivating competition. Additionally, the government should pay attention to microscopic uncertainties. And during the whole process, the government should take the responsibility of supervising and maintaining the stability of China's financial market.

In terms of the regionalization and internalization of Renminbi, the following hypothesis is established: Chinese Renminbi NDF movements are driven by speculative psychology generated by the yen/dollar exchange rate. And it is found that a revaluation of RMB will affect the exchange rates of China's advanced and middle-income neighbors differently, reflecting their various trade and investment relationships.

Chapter 21
A General Theory of International Money

Contents

The development history of the international monetary system can be divided into four stages as follows: gold standard, the interwar period, Bretton Woods, and the post-Bretton Woods system. In particular, during the gold standard (1879–1914), the standard economic unit of account is based on a fixed quantity of gold. It includes three types: specie, bullion, and exchange. The critical feature of the gold standard is its self-equilibrium nature. After a nation committed to an official gold price and convertibility with open current and capital accounts, the mechanisms producing "automatic adjustment" were classically described by the price-specie flow mechanism associated with David Hume. If a country suffered from trade deficit, this country would rather pay with gold as the currency depreciated (compared to the trade surplus country). This process would equilibrate the trade balance between the two countries as the prices in the previously deficit country became more attractive. This self-adjustment mechanism was determined by the supply and demand of gold in the world.

The disadvantage of gold standard was that it weakened the policy makers' functionality. The prices of goods and currencies between the two countries were subject to the supply of gold. And government cannot change prices by making monetary policies. After the outbreak of World War I, many countries suffered from fiscal problems, and they had to issue additional paper money to fill the hole in their finances. As a result, high inflation caused a great departure for the official parties to restore convertibility to the traditional gold price, while some countries endured painful deflation. This end illustrates the other flaw of gold standard: deficit

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countries would be vulnerable to deflation due to external constraints, while surplus countries were able to deflect the burden.

The subsequent interwar period captured a system in flux or an interregnum between systems. That a true system never evolved is evidenced in part by the fact that we cannot simplify its operation with reference to a few principles or mechanisms as with the classical Gold Standard or the later Bretton Woods. Eichengreen (1988), for example, considers three distinct exchange-rate regimes between 1922 and 1936; Van Dam (1977) divides the period into four sub-periods, while McKinnon (1995) is forced to omit the era in his analysis of monetary orders, maintaining instead that it defies "any such consistent characterization."

In 1919, the United States was in the uncharacteristic position of being firmly on gold with reserves so large and so well sterilized that they imposed no constraints on domestic policy. By 1928, with the dollar, pound, and franc all pegged to gold, and other economies on a gold-exchange standard, the Fed announced the "practical completion of the world's monetary reconstruction" (Van Dam 1977). However, the original parities resurrected proved unsupportable, and the system's inability to absorb shocks and the inherent conflict between domestic employment and the external constraint again became painfully evident. Within a year, the US economy was already showing signs of recession, reflecting the onset of financial crisis, exacerbated by the imposition of the Smoot-Hawley Tariff Act of 1930.

By 1931, and already suffering from a credit strain and heavy unemployment, Britain was facing tremendous pressure on the pound as people rapidly converted sterling into gold, prompted by a French sell-off of the pound. In response, British government suspended convertibility. Since unable to convert sterling into gold, investors and foreign governments rushed to trade sterling for the dollar and then dollar for gold, transmitting the pressure to the United States. In an effort to defend confidence in the US dollar, the Fed tightened credit conditions instead of providing emergency liquidity to banks. In 1933, the dollar was finally devalued with the franc following the suite 3 years later. However, the rigidities of adhering to gold had already exacerbated deflation, and with countries succumbing to reactive protectionism, the global economy collapsed (McKinnon 1995). For the remainder of the peacetime period, groups of countries remained divided into different monetary orders.

The lessons of the time are often cast as pedagogical for the Bretton Woods negotiations. And equally influential was that the US economy and the dollar would emerge from the next war with unrivaled dominance (Eichengreen 2012).

The Bretton Woods (1959–1971) is the US dollar-centered, rule-based system that was eventually materialized from the Bretton Woods negotiations. It varied substantially from the market-based, laissez-faire order of the gold standard. Exchange rates were fixed "but adjustable" with adjustment administered through the IMF if a country's balance of payments was in "fundamental disequilibrium." Capital controls were instituted to prevent the speculation and "hot money" flows that had contributed to the instability of the past.

Article IV of the articles permitted each country to define the par value of its currency in either gold or the US dollar. With virtually all participants choosing the latter option, the dollar became the only currency that was "as good as gold," fixed at $35 per ounce. In this arrangement, countries resolved international transactions and kept reserves in the dollar with the US monetary policy providing an anchor for the world price level.

Despite the agreement on how the system would operate, the number of adjustments in par values was in fact relatively limited (McKinnon 1995). Surplus countries could maintain persistent trade imbalances by sterilizing the effect of the foreign exchange interventions (required to maintain their par values) on domestic money supply and prices. From the viewpoint of these countries, surpluses were only temporary, not signs of fundamental disequilibria, and the associated accumulation of dollar reserves was viewed with "satisfaction or indifference" (Michaely 1981). On the other hand, deficit countries faced with decreasing reserves and could not defer adjustment indefinitely. The exception was the United States, which in its unique position as currency leader could run persistent deficits. Indeed, Triffin (1960) famously stated that this was a necessary condition for the provision of global liquidity. The other side of Triffin's dilemma suggested that this would ultimately undermine confidence in the link between the dollar and gold. The attempted resolution to the problem was the creation of special drawing rights (SDRs), which could be used to settle a country's imbalance in the balance of payments. The first SDRs were issued in 1970, valued at 1 SDR = $1 (Williamson 1985).

However, by this time, the world was no longer facing a shortage of liquidity. Instead, large US monetary and fiscal expansion and the enduring trade deficit had created a fear that the dollar was overvalued. With loosened capital controls allowing markets to place substantial downward pressure on the dollar, defending the gold link would have required the US authorities to raise interest rates and cut spending, sending the economy into recession. Because of the conflict between the domestic goals and international obligations, President Nixon took the dollar off gold in 1971. The nominal stability of Bretton Woods was eventually undone by the system's inability to absorb a devaluation of the dollar.

The post-Bretton Woods system (1971–present), also known as the Washington Consensus, stands for the economic system that spanned 1980–2009 with the latter half of the 1970s being a transitional period. The transition away from Bretton Woods was marked by a switch from a state-led to a market-led system. The Bretton Wood system was broken down in the 1970s, during which crucial events include Nixon suspending the dollar's convertibility into gold in 1971, the United States' abandonment of capital controls in 1974, and the United Kingdom's ending of capital controls in 1979 which was swiftly copied by most other major economies. And in some parts of the developing world, liberalization brought significant benefits for large sections of the population – most prominently with Deng Xiaoping's reforms in China since 1978 and the liberalization of India after its 1991 crisis.

Generally speaking, the industrial nations experienced much slower growth and higher unemployment than in the previous era, during which the 1950s and 1960s when the Bretton Woods system was operating were a golden age. Financial crises have been more intense and have increased in frequency by about 300% – with the damaging effects prior to 2008 being mostly felt in the emerging economies. On the positive side, at least until 2008, investors have frequently achieved very high rates of return, with salaries and bonuses in the financial sector reaching record levels.

And the present situation of the international monetary system has entered a new stage. As China's currency, RMB, enters into the SDR basket, the international monetary system is expected to experience a series of shocks.

As for the problem of broader global payment imbalances, the root cause is in the financial structure that the present international monetary system brings. Since the 1980s, the United States has become a net debtor nation, while the rest of the world has become its financier. As a matter of fact, the current international monetary system is on the US dollar standard and can be righteously seen as an extension of the Bretton Woods system. With the deepening of economic globalization, the demand for reserve currency increases. Countries besides the United States can only acquire the reserve currency, the US dollar, through trade surplus. As a result, the United States has a large current account deficit with emerging and developing countries' large current account surplus. The IMF estimates (Ying 2016) that the global foreign exchange reserves might amount to 690% of the United States' GDP.

The Triffin dilemma or Triffin paradox is the conflict between economic interests that arises between short-term domestic and long-term international objectives for countries whose currencies serve as global reserve currencies. This dilemma was first identified in 1960 by Robert Triffin, who pointed out that the country, whose currency, as the global reserve currency, foreign nations wish to hold, must be willing to supply the world with an extra supply of its currency to fulfill the world demand for these foreign exchange reserves, thus leading to a trade deficit. As the global reserve currency, the US dollar is now facing this dilemma. In order to meet the demand of global reserve, the United States has to supply more dollars through trade deficit. That makes the US net debt grow constantly. Once investors started to believe that the United States can no longer pay off its debts without creating inflation, they would dump the dollar and other dollar-denominated assets. That would eventually lead to the collapse of the present dollar standard system.

In terms of the present exchange rate system, it is mainly floating exchange rate system based. Though floating exchange rate system has been legitimate since Jamaica Agreement, it has suffered from problems itself. In fact, the alleged currency float is a kind of ideal; however, the vast majority of developing countries can only take pegged exchange rate system according to the reality of domestic economic development. That makes these countries' weighted average effective exchange rate fluctuate with the exchange rate of advanced countries and domestic economic imbalance created as a result of the pegged exchange rate regime. The characteristics of this system increase the risk of international hot money attack. Emerging and developing countries may more likely be casualties of the developed countries. Additionally, the coexistence of various exchange rate regimes adds the complexity of the exchange rate system; exchange rate fluctuates continuously; and disastrous currency flows appear frequently, causing weak states to constantly suffer from economic losses.

The rest of this chapter is organized as follows: Sect. 21.1 provides a descriptive presentation of the general theory of international money. Section 21.2 looks at the problem of how the euro will evolve from here onward into the future as an application of the general theory. And, the chapter is concluded in Sect. 21.3.

21.1 The Theory

There are several important generations of models developed for the study of currency crises, which could also be employed to understand the development and evolution of the international monetary system.

The first generation began with Paul Krugman's adaptation of Stephen Salant and Dale Henderson's model of speculative attacks in the gold market (Salant and Henderson 1978). In his article, Krugman (1979) argues that a sudden speculative attack on a fixed exchange rate, even though it appears to be an irrational change in expectations, can result from rational behavior by investors. This happens if investors foresee that a government is running an excessive deficit, causing it to run short of liquid assets or "harder" foreign currency which it can sell to support its currency at the fixed rate. Investors are willing to continue holding the currency as long as they expect the exchange rate to remain fixed, but they flee the currency en masse when they anticipate that the peg is about to end.

The second generation of models of currency crises starts with Obstfeld (1986). In these models, doubts about whether the government is willing to maintain its exchange rate peg lead to multiple equilibria, suggesting that self-fulfilling prophecies may be possible, in which the reason investors attack the currency is that they expect other investors to attack the currency.

Third-generation models of currency crises have explored how problems in the banking and financial system interact with currency crises and how crises can have real effects on the rest of the economy. McKinnon and Pill (1998), Krugman (1999), and Corsetti et al. (1999) suggested that excessive borrowing by banks to fund moral hazard lending was a form of hidden government debts (to the extent that governments would bail out failing banks). Radelet and Sachs (1998a, b) suggested that self-fulfilling panics that hit the financial intermediaries force liquidation of long run assets, which then "confirms" the panics. Chang and Velasco (1998) argue that a currency crisis may cause a banking crisis if local banks have debts denominated in foreign currency. Burnside et al. (2001, 2004) argue that a government guarantee of the banking system may give banks an incentive to take on foreign debt, making both the currency and the banking system vulnerable to attack.

In order to explain the Asian financial crisis of the 1990s, Krugman (1999) suggested two additional factors: (1) firms' balance sheets affect their ability to spend, and (2) capital flows affect the real exchange rate. Although he proposed his model as another candidate for the third-generation crisis modeling, the banking system does not play any role in his model. Out of this model, he provides the following policy prescription: Impose a curfew on capital flight, which was implemented by Malaysia during the Asian financial crisis.

21.1.1 A Descriptive Presentation of the Theory

It will take a long time for the international monetary system and international currency to evolve and to eventually appear. Although no one can make a detailed prediction on the trend of financial globalization, many scholars (Chen and Ying 2014) have paid their attention to the features and conditions of international currency and the evolution of international monetary system. In fact, financial globalization has become a major momentum of the economic globalization. Acting as both the inner demand and driving force of economic globalization, financial globalization promotes the development of world economy and international finance in general and leads the economic globalization toward an unprecedented width and depth.

According to the international monetary theory (Wang 2015), there are four major features for a hard currency or a hard international currency. First, it embodies the nature of or is closely associated with precious metals, such as gold. At the early stage of coinage in particular, a hard currency was always affected by the content and purity of the precious metal it contains. Second, it is acknowledged by the dominant powers or closely related to hegemony, even becoming a major channel for hegemony in some countries. Third, instead of being confined to certain regions, it is used in a wide range of areas and can be acknowledged and accepted by different countries. Fourth, it is able to maintain a relatively constant value.

If one country wants its currency to be internationalized, it must meet the following conditions:

- First and foremost, it must have a considerable economic size and an open environment, which is basic for the internationalization of its currency.
- Second, it must be capable of performing international payment in various ways. In other words, its government should have abundant gold and foreign exchange reserves as well as the capability of raising fund in overseas markets to satisfy remittance and fund transfer requirements at any time and maintain stability of both the exchange rate and foreign exchange market.
- Third, its macroscopic economy must be under effective control and remain stable. Its fiscal and monetary policies should be able to create a favorable macroeconomic environment for the internationalization of its currency, adapt itself for the exchanges of economic cycle both at home and abroad, and maintain a relatively constant value.
- Fourth, it must have a comprehensive market economy mechanism, which includes the establishment of and improvement on markets of commodity, human resources, capital, information, and finance, the establishment of price system that reflects the law of value, and the smooth operation of microenterprise management mechanism.
- Fifth, an appropriate exchange rate mechanism should be in place. The exchange rate should be able to objectively reflect the relationship between the supply and demand in the foreign exchange market and help to guide the rational allocation

of foreign exchanges. A managed floating exchange rate system should be adopted.
- Last but not the least, convertibility is the prerequisite and another character of currency internationalization. Without convertibility, a currency cannot be accepted widely.

When a currency is not made of gold or cannot be changed into gold freely, the entity credit, which insures the purchase power of the currency, is replaced by a superior credit – sovereign credit (Ying 2016). Such credit constitutes the fundamental basis of all currencies nowadays.

Looking back to the history of currency internationalization (Ying 2016), the following conditions need to be satisfied for the evolution of one country's currency toward internationalization:

- First is economic strength. The economic strength of the country is the fundamental requirement for its currency to evolve and to internationalize. However, one should notice that the economic strength of the country is not simply in proportion with the status of its currency in the international currency system, being an international currency is still a game of "winner-takes-all."
- Second is the importance of the country in global trade. Compared with economic strength, the importance of the country in global trade has a closer connection with the status of its currency in the international currency system. Whether the country's currency can be internationalized depends on whether this particular country can provide a big import market for other countries, diversify its foreign trade, as well as develop broad and close ties with major regions and countries.
- Third is the credibility of the monetary policy of the said country. The central bank of the country should have sufficient independence and should be able to resist pressures from sectors of the real economy, particularly export sectors, of depreciating the domestic currency for the purpose of selling more products.
- Fourth is the development stage and business variety of the financial sector. A mature financial market is required for the country to foster its own internationalized currency. A financial market of this kind should be basically released of strict controls to fully realize free currency convertibility and capital mobility while continuously develop in width and depth. Besides, the monetary policy should also be able to offer confidence for citizens and enterprises of other countries in the value of the currency of the said country, to maintain reasonable exchange rate fluctuation, and to reduce public anxiety on future inflation expectations in particular.

At the present, the US dollar plays a central role in the international monetary system. The 2006 Treasury, see Ying (2016) and references there, reports that nearly 60% of dollar banknotes are held abroad. Over the last half century, the dollar has also been the main currency used for trade invoicing, denominating international debt, and foreign exchange trades. Although this current arrangement is the joint outcome of choices made by private citizens and regulations by official bodies, much of the international macroeconomic literature (Ying 2016) treats payment arrangements as given by restricting agents to only using a particular currency. While this assumption prevents the exchange rate from being indeterminate (Kareken and Wallace 1981), such an approach is especially unsatisfactory for understanding the conditions under which a currency can achieve international status or how it might lose that status. Moreover, what are the implications of endogenous acceptance decisions for the choice of inflation in an open economy? And what are the welfare gains to having an international currency?

To answer these questions, let us develop a simple open-economy search model to analyze three central issues in international monetary economics:

(i) The conditions that allow for the emergence of an international medium of exchange
(ii) The choice of inflation by monetary authorities when currency acceptability is endogenous
(iii) The welfare benefits of having an international currency for both the issuing country and the rest of the world

Search-theoretical models are particularly useful at addressing international currency use because they explicitly formalize the essential role of money rather than assuming it exogenously. In this spirit, different from much of the international macroeconomic literature (Chen and Ying 2014), the simple model here lets private citizens choose which currencies to accept as means of payment instead of fixing the role of money by assumption. By integrating recent advances in monetary search theory (Chen and Ying 2014) with international monetary economics (Wang 2015), this model helps further the understanding of currency competition by providing microeconomic foundations for the internationalization of currencies. The model features two key ingredients that capture the fact that international monetary arrangements are the dual outcomes of choices made by private citizens and regulations by official bodies.

Firstly, payment patterns are pinned down by letting private citizens choose which currencies to accept. The basic idea dates back to (Jevons 1875) and has to do with the fact that an object that is widely recognizable, such as the dollar in the United States, is better at facilitating trade than alternatives such as foreign currency. For example, sellers in the United States are not as familiar with Mexican pesos, worrying that they might be counterfeits, so they will be reluctant to accept pesos as payment unless some costly information is acquired (Hadsell and MacDermott 2012). Secondly, government transaction policies are introduced to reflect choices of official bodies. Historically, a currency will not become international unless there is a centralized institution that favors its use. This is often achieved in practice by announcing legal tender status or only accepting domestic money for tax payments. The basic idea is that by simply accepting a particular currency in its own trades, governments may induce private agents to do the same (Wang 2015).

In the two-country, two-currency model, agents interact first in decentralized international trade markets and then in a Walrasian currency exchange market. The frictions in this environment are search frictions, private trading histories, and imperfect recognizability of assets. Each country issues one currency and satisfies two conditions: citizens in each country receive transfers of domestic currency and meet each other more frequently than they meet foreigners. Each trade entails exchanging local goods for a portfolio of currencies, with no restrictions on which currencies can be used between private citizens. Since what sellers accept depend on what buyers hold, and vice versa, complementarities in the trading environment lead to multiple equilibria where zero, one, or two international currencies can emerge. For instance, when information costs are sufficiently high, equilibrium with two national currencies arises endogenously, a result that is difficult to establish in previously developed dual-currency search models. Network externalities can lead to coordination failures with no guarantee that the world will end up with a socially efficient monetary system. By formalizing the role of currency in payments, the model provides a channel through which monetary policy can affect prices, trade, and welfare. For instance, currency substitution occurs as an endogenous response to local inflation. As it becomes more expensive to hold local currency, agents will start substituting the local currency with foreign currency, such as the US dollar. This end captures the phenomenon of dollarization commonly existing in many Latin American and Eastern European economies.

The theory also emphasizes on the important influence on the choice of money as an international medium of exchange. Fundamentals, as well as expectations regarding other agents' behavior, jointly make this decision and thereby determine the circulation patterns that arise. Due to inertia, it is difficult to extricate an incumbent currency from its international role, because of the associated low information costs. At the same time, a temporary disruption, such as a change in inflation, can permanently shift payment patterns. Therefore, international currency use reflects both fundamentals and history, consistent with what has been observed in practice.

By analyzing the strategic interaction among monetary authorities, insights on the choice of inflation in interdependent economies can be obtained. The dynamic policy game captures the trade-offs faced by policy makers and generates an inflation Laffer curve. While some inflation can benefit the issuing country through increased seigniorage from foreigners, too much inflation lowers the purchasing power of money and hence trade between countries. At the same time, the threat of losing international status puts an inflation discipline on the issuing country (Li and Matsui 2005), where these authors developed a model with indivisible monies. When monetary authorities interact in a simple policy game, the issuing country must therefore trade off the temptation to inflate with the threat of losing international status to set an inflation rate that will generally deviate from the Friedman rule, a result that is new and difficult to obtain in previous studies.

According to the theory, a country's welfare consists of seigniorage transfers across countries and the surplus due to liquidity provision to citizens' net of any information costs incurred. Depending on inflation rates and how information costs is standardized, the welfare benefit to the United States of having the dollar as the sole international currency ranges from 0.4% to 1% of GDP per year, of which approximately 0.1–0.2% of GDP is due to seigniorage. These estimates then serve as upper and lower bounds, respectively, on the welfare gains from international currency use. This can also be compared with 0.4% of GDP from Portes and Rey (1998), which only include seigniorage gains and the savings due to reduced transaction costs. This suggests that alternative studies may have underestimated the benefit of international liquidity provision since previous models do not account for the general equilibrium effects an international currency has at expanding trade opportunities abroad.

Regarding policies, a closely related work is Li and Matsui (2005), where the authors also study currency competition among welfare-maximizing monetary authorities but must proxy for inflation in a model with indivisible currencies. Because changes in the money supply imply different distributions of money holdings, it makes their policy implications not robust as one would desire. In addition, terms of trade cannot be adjusted with the "inflation tax," which is a key channel for the transmission of monetary policy. For instance, the model here explains how the emergence of an international currency, through changes in inflation, affects the terms of trade by expanding the set of trading opportunities. This generates important welfare gains from using the international currency, which have not been fully captured in previous models with indivisible money.

The model here renders the nominal exchange rate determinate in a setting where multiple currencies can coexist at potentially different rates of return. This is accomplished through assumptions on the economy's information frictions, namely, anonymity and imperfect recognizability of currencies. Formally, the model of asset liquidity by Hadsell and MacDermott (2012) is generalized to an open-economy setting. With the discussion of dollarization and exchange rates, the multi-country model presented here yields several additional contributions. For example, when interactions between countries are explicitly modeled, it becomes possible to link how structural differences and heterogeneities across countries affect the circulation patterns that arise. Incorporating these heterogeneities therefore brings the model closer to more mainstream open-economy macro models while still being explicit about the frictions that make money essential. Additionally, policy makers face trade-offs in an open economy that do not exist in a closed economy. For instance, it is shown that inflation can have redistributive effects across countries and some inflation can be welfare-improving. And so, the consequent policy implications differ from that of Hadsell and MacDermott (2012), where the Friedman rule is the unique optimal policy, so long as domestic currency is perfectly recognizable.

Liu and Shi (2010) also consider optimal monetary policy but focus on two symmetric currency areas. Additionally, agents in their model can hold either one of the two currencies, but not both. This restriction rules out such equilibria that some agents accept both domestic and foreign currencies, a key focus of the model here. And, since currency acceptability is not assumed to be endogenous, inflation is not disciplined by the potential loss of international currency status.

21.1.2 Consequences of the Theory

By generalizing the model of asset liquidity developed in Hadsell and MacDermott (2012) to an open-economy setting, the resultant information-based theory of international currency could help address some classical issues in international monetary economics, such as the emergence of an international currency, the choice of inflation when currency acceptability is endogenous, and the welfare benefits of international currency use. Instead of assuming the payments used in each country, the model allows private citizens to choose which currencies to accept. And, government transaction policies are introduced to examine how certain policies, which favor the use of the country's national money, affect private agents' acceptance decisions and hence the set of equilibria. Fairly innocuous policies of the kind considered imply the connections observed in practice between currencies and countries.

What is also explicitly modeled is the strategic interaction among money issuers in a dynamic policy game. An inflation Laffer curve emerges and captures the main trade-offs faced by the issuing country. While some inflation can be welfare-improving by increasing the amount of seigniorage extracted from foreigners, too much inflation lowers the purchasing power of money. Since sovereign policy makers are only responsible for the welfare of their own citizens, they are not penalized for any negative effects their policies might produce abroad. If, however, externalities can be internalized in a cooperative agreement, then all countries may benefit. Quantitatively, the welfare cost of losing international status is not inconsequential for the issuing country. For example, for the United States, this amounts to about 0.4–1.1% of consumption each year. This section thus provides a first step in examining the effects of transitioning across different types of payment regimes, where credit is imperfect and accepting foreign currency is costly.

Consistent with the evidence from Eichengreen (2012), the general theory in this section questions the conventional wisdom that competition for international currency status is a winner-takes-all game. Just as history shows that several international currencies have often shared this role in the past, the theory of this section implies that a likely situation for the future monetary system is one where several international currencies will compete and coexist.

21.2 Where Will Euro Go?

As an application of the general theory presented in the previous section, this section looks at on the development and the potential future of the euro.

21.2.1 An Offspring of Noble Ancestors: Franc and Mark

The two key motives for the adoption of the euro were:

1. To enhance the role of Europe in the world monetary system
2. To turn the European Union into a truly unified market (Krugman et al. 2012)

In terms of the second motive, a number of prior studies have examined the question of whether the euro has actually contributed to the integration of the European market (see, e.g., Rose 2000; Rose and van Wincoop 2001; Micco et al. 2003; Engel and Rogers 2004; Dominguez 2006; Lane 2006; Abad 2009; European Central Bank 2013, 2014). In terms of the first motive, however, there is little evidence regarding the extent to which the euro (EUR), relative to the US dollar (USD), has influenced the exchange rate behaviors of other currencies. There have been numerous studies that have examined such questions as how the world monetary system will evolve over time and whether the euro will surpass the USD as the leading vehicle currency (see, e.g., Fratianni and Hauskrecht 1998; Portes and Rey 1998; Mundell 2000; Bergsten 2012; Kenen 2002; Chinn and Frankel 2005; Eichengreen 2005; Cohen 2007; Norrlof 2009; Norrlof 2014; Pisani-Ferry and Posen 2009; Fields and Vernengo 2013). However, most of these studies have focused on power analyses of the dollar against the euro with regard to the reserve position of the two currencies in the central bank holdings and to the use of the two currencies in international transactions.

This section, which is mainly based on Eun et al. (2015), and for more details, please consult with this source and references listed there, discusses the currency competition between the dollar and euro by directly focusing on the influence of the dollar and euro on the exchange rate behaviors of other currencies and by examining how their relative influence has evolved during the period since the introduction of the euro (1999–2013). In doing so, introduced is a simple distance metric that is independent of the choice of the numeraire currency in expressing bilateral exchange rates. Using this distance metric, examined is the temporal variation of the natural logarithm value of the ratio of a currency's distance from the euro to its distance from the dollar, hereafter called the currency distance ratio. For a given currency, if the influence of the euro relative to that of the dollar on this currency increases over time, the movement of the currency will more closely track the movement of the euro than that of the dollar; thus, the currency distance ratio will decrease over time. After that we examine the temporal variation of foreign exchange risk for dollar-based and euro-based agents. If the influence of the euro relative to the dollar on other currencies increases over time, the exchange risk is likely to increase for dollar-based agents and decrease for euro-based agents.

The results from the sample period of 1999–2013 indicate that, for most of the 25 floating currencies sampled, excluding USD and EUR, there has been a noticeable decrease in the currency distance ratio. Furthermore, the finding remained robust when subjected to several sensitivity tests. In particular, the influences of other major currencies, such as the Japanese yen, British pound, and Swiss franc, relative to the USD on lesser currencies, are demonstrated to be significantly less than that of EUR. Jointly, the findings indicate that the influence of the euro relative to the dollar on the exchange rate behaviors of other currencies has increased over time.

The sample used spans the 15-year period from January 1, 1999 (Friday), to December 27, 2013 (Friday), and includes 27 currencies of the following countries: Australia, Brazil, Canada, Chile, Colombia, Czech Republic, Euro area, India, Indonesia, Israel, Japan, South Korea, Malaysia, Mexico, New Zealand, Norway, the Philippines, Poland, Russian Federation, Singapore, South Africa, Sweden, Switzerland, Thailand, Turkey, the United Kingdom, and the United States.

These sample currencies are selected based on the following procedure. First, start with the 33 currencies that are consistently ranked in the top 35 in terms of their foreign exchange (FX) turnover share according to Triennial Central Bank Survey reports from the times of April 2001, 2004, 2007, 2010, and 2013 of the Bank for International Settlements (BIS). On the average, the 33 currencies selected comprise 97.3% of the total FX turnover. Secondly, examine the history of the exchange rate arrangements and monetary policy frameworks conducted annually by the International Monetary Fund (IMF) in order to only focus on currencies that were identified as independently floating or managed floating. For the purpose of this section, these five currencies, Hong Kong dollar, Danish krone, Taiwanese dollar, Chinese renminbi, and Saudi riyal, are excluded from the sample, because they were not classified as floating throughout the sample period. Thirdly, Hungarian forint is excluded from the sample because it was not classified as floating until 2008. Therefore, only 27 currencies remained in the final sample.

Used are the bilateral exchange rates against the USD sampled weekly on Fridays, which were obtained from Data Stream. In particular, employed are the closing spot rates of the World Market Reuters (WMR), which report the mid-quote of the daily closing bid and ask, and these are recorded at 4:00 p.m. London time. The weekly exchange rates are used in order to reduce the noise in the data and to mitigate the problems associated with time zone differences in simultaneously examining the exchange rate behaviors of many currencies while maintaining a reasonably high frequency. In addition, for each sample currency, we use its exchange rate data starting from the date when the currency was first classified as floating during the sample period according to the IMF classification. The sampling began on January 1, 1999, for 21 currencies, but began later for 6 currencies. The sample start date of each currency is reported in Table 21.1. The currency distance ratio is defined by the natural logarithm value of the currency's distance from the euro divided by its distance from the dollar.

Following Evans and Archer (1968), Wagner and Lau (1971), and Solnik (1974), the relationship between the riskiness of a currency portfolio and the number of currencies included in the portfolio can be examined. From the perspective of USD-based agents, for example, for given natural number N, randomly select N currencies from the 26 other sample currencies, i.e., excluding USD, without replacement. Then, for the equally weighted portfolio of the N sampled currencies, compute the variance of the changes in the weekly bilateral USD exchange rate.

Table 21.1 Time trends of currency distance ratios

Currency	Start date	(1) Currency distance ratio		(2) Difference	(3) Time trend of currency distance ratios computed annually	
		1999/01-2006/06	2006/07-2013/12		Coefficient	t-Stat
Australian dollar	1999/01/01	−0.059	−0.177	−0.118	−0.010	−0.87
Brazilian real	1999/02/01	0.130	−0.108	−0.238	−0.028	−2.50
Canadian dollar	1999/01/01	0.350	−0.003	−0.355	−0.039	−3.19
Chilean peso	1999/01/01	0.339	−0.016	−0.355	−0.039	−3.19
Colombian peso	1999/09/25	0.558	0.038	−0.520	−0.054	−3.45
Czech koruna	1999/01/01	−0.745	−0.643	0.103	0.005	0.44
Euro	1999/01/01	n.a.	n.a.	n.a.	n.a.	n.a.
Indian rupee	1999/01/01	1.254	0.214	−1.040	−0.148	−8.41
Indonesian rupiah	1999/01/01	0.113	0.316	0.204	0.046	2.40
Israeli shekel	2004/01/01	0.597	0.016	−0.581	−0.073	−2.70
Japanese yen	1999/01/01	0.113	0.241	0.128	0.011	0.70
Korean won	1999/01/01	0.439	0.009	−0.430	−0.023	−1.56
Malaysian ringgit	2005/07/21	1.003	0.355	−0.648	−0.100	−2.15
Mexican peso	1999/01/01	0.498	0.008	−0.490	−0.050	−5.99
New Zealand dollar	1999/01/01	−0.050	−0.160	−0.110	−0.010	−0.99
Norwegian krone	1999/01/01	−0.578	−0.432	0.147	0.010	1.10
Philippine peso	1999/01/01	0.660	0.453	−0.207	−0.020	−1.02
Polish zloty	2000/04/12	−0.282	−0.450	−0.168	−0.040	−4.31
Russian ruble	1999/01/01	0.487	−0.142	−0.629	−0.116	−3.40
Singapore dollar	1999/01/01	0.682	0.320	−0.362	−0.037	−3.70
South African rand	1999/01/01	−0.018	0.110	−0.092	−0.016	−3.40
Swedish krona	1999/01/01	−0.666	−0.507	0.159	0.006	0.39
Swiss franc	1999/01/01	−1.101	−0.405	0.695	0.032	1.14
Thai baht	1999/01/01	0.507	0.478	−0.030	0.010	0.55
Turkish	2001/02/22	−0.011	−0.092	−0.081	−0.004	−0.37
UK pound	1999/01/01	−0.170	−0.125	0.045	−0.000	−0.02
US dollar	1999/01/01	n.a.	n.a.	n.a.	n.a.	n.a.
Average		0.162	−0.037	−0.199		

Repeat this procedure 1000 times; compute their average variance, denoted by Var (P_N). As a measure of the effect of the diversification on the reduction of the foreign exchange risk, then compute the ratio Var(P_N)/Var(P_1). This ratio illustrates the relationship between the number of currencies in the portfolio and the risk of the portfolio relative to that of a typical one-currency portfolio. As a method of investigating the temporal variation of the effect of diversification on foreign

Table 21.2 Number of constructed portfolios of size N

Number of currency, N	1	2	3–23	24	25	26
Number of constructed portfolios of size N	26	325	1000	325	26	1

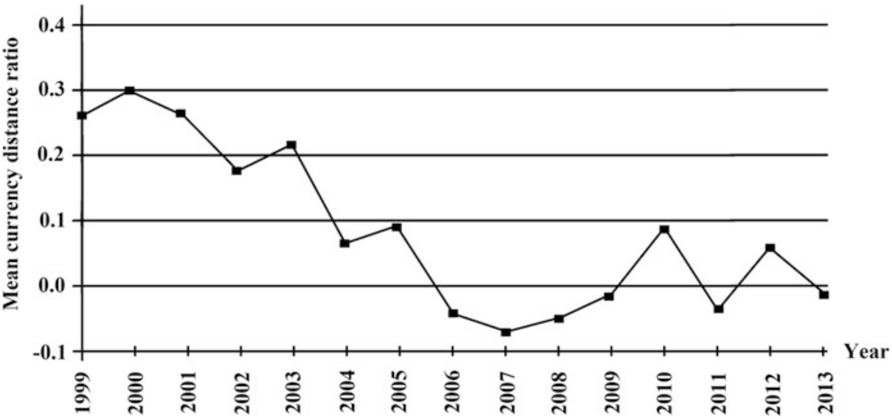

Fig. 21.1 The time trend of the average currency distance ratio

exchange risk, divide the sample period into two equal sub-periods and examine how the ratio $\mathrm{Var}(P_N)/\mathrm{Var}(P_1)$ changes over time.

Because the total number of possible combinations of selecting N out of 26 currencies is not too large for $N = 1$, 2, 24, 25, or 26, the relevant $\mathrm{Var}(P_N)$'s are computed by using all possible combinations. Table 21.2 provides the number of portfolios generated for the portfolio of size N.

Table 21.1 illustrates that, for the majority of 25 floating sample currencies (excluding USD and EUR), the currency distance ratio decreased over the sample period. In particular, the columns labeled (1) and (2) demonstrate that over the two equal length sub-periods, the ratio decreased for 18 out of 25 currencies. The ratio increased for seven currencies, but only the Swiss franc exhibited a notable increase (Eun et al. 2015). On average, the ratio decreased from 0.162 to −0.037 (a difference of −0.199) over the two sub-periods, and the difference of −0.199 is significant at the 5% level based on both the paired sample t-test ($p = 0.011$) and Wilcoxon signed rank sum test ($p = 0.010$). Next, the column labeled (3) reports the coefficient estimates on yearly basis and the associated t-statistics from the ordinary least squares (OLS) regression of the currency distance ratio, computed annually, on the intercept and year. This demonstrates that the time trend coefficients were negative for 18 out of 25 currencies. Despite the sample size being very small (ranging from 9 to 15), the t-statistics for the negative time trend coefficients were greater than the two in absolute value terms for 11 currencies.

Figure 21.1 presents the time trend of the average currency distance ratio. It confirms the overall negative time trend of the currency distance ratio. Although the

Table 21.3 Changes in currency distance ratio among major currencies

	X = EUR	X = USD	X = JPY	X = GBP	X = CHF
Change in the cross-currency average of the log ratio of a currency's distance from X to its distance from USD between two equal sub-periods	−0.199	0.000	0.036	−0.105	−0.0070
	(0.011)		(0.453)	(0.083)	(0.340)
	[0.010]		[0.175]	[0.146]	[0.323]
Change in the cross-currency average of the log ratio of a currency's distance from X to its distance from EUR between two equal sub-periods	0.000	0.199	0.235	0.094	0.128
		(0.011)	(<0.001)	(0.002)	(<0.001)
		[0.010]	[<0.001]	[<0.001]	[<0.001]

average currency distance ratio increased from 2010, which was when the Eurozone crisis intensified, the average ratio was far smaller during the second sub-period compared with the first sub-period.

Although USD and EUR are two dominant currencies, other major currencies, such as the Japanese yen (JPY), British pound (GBP), and Swiss franc (CHF), might have also affected the currency exchange rate behaviors of many lesser currencies. Thus, as a robustness test of the previous results, the influences of JPY, GBP, and CHF, relative to USD and EUR, on the exchange rate behaviors of other lesser currencies are also evaluated, where Table 21.3 reports the results. The number in each cell represents the difference of the currency distance ratio between the two equal sub-periods. The numbers in parentheses and brackets are the p-values based on the paired sample *t*-test and the Wilcoxon signed rank sum test, respectively.

The results of the currency distance ratio measured against USD indicate that:

(i) The average currency distance from EUR relative to USD decreased significantly (at the 5% level) over the two sub-periods.
(ii) The average currency distance from JPY, GBP, and CHF relative to USD exhibited no significant difference (at the 5% level) over the two sub-periods.

Additionally, the results of the currency distance ratio measured against EUR indicated that the average currency distance from USD, JPY, GBP, and CHF relative to EUR increased significantly (at the 5% level) over the two sub-periods. This observation indicates that the behaviors of other currencies were more tightly linked to EUR than they were to USD, JPY, GBP, and CHF during the second sub-period compared with the first sub-period.

In short, Table 21.3 indicates that the influence of EUR, relative to USD, on other lesser currencies increased significantly over the two sub-periods, which cannot be explained by the influences of other hard currencies, such as JPY, GBP, and CHF.

In terms of foreign exchange risk, Fig. 21.2 illustrates the relationship between the number of currencies in a currency portfolio and the risk of the portfolio relative to that of a typical one-currency portfolio for two equal sub-periods for dollar-based

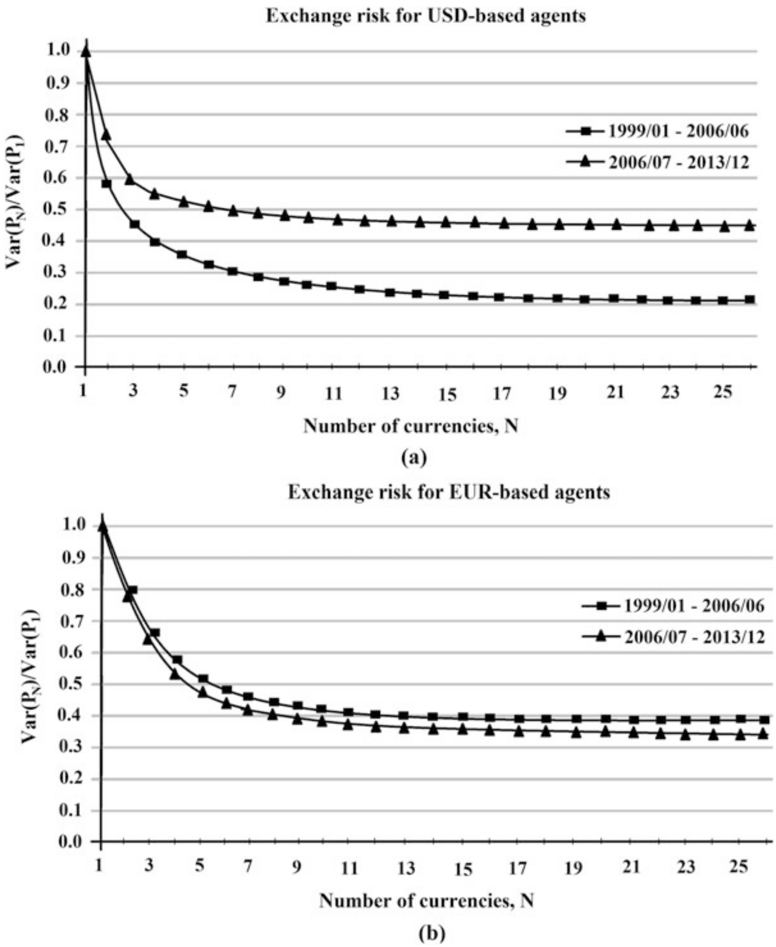

Fig. 21.2 The relationship between the number of currencies and portfolio risk

and euro-based agents. In particular, Fig. 21.2a presents the relationship from the perspective of a dollar-based agent. Because the ratio $Var(P26)/Var(P1)$ increases from 21.1% to 44.4%, it means that the exchange risk increased substantially over the two sub-periods. In comparison, Fig. 21.2b illustrates the relationship from the perspective of a euro-based agent. Because the ratio $Var(P26)/Var(P1)$ decreased from 39.3% to 34.8%, it implies that the exchange risk decreased, although not substantially, over the two sub-periods. In short, Fig. 21.2 indicates that for the first sub-period, the exchange risk was much higher for euro-based agents than for dollar-based agents, and for the second sub-period, the situation is reversed.

The previous discussions indicate that by using a simple distance metric between currencies, one can establish the fact that the majority of floating currencies behave more similarly to the euro relative to the dollar than they did earlier, for the period from 1999 to 2013. And, the exchange risk increased substantially over this period for dollar-based agents, whereas it decreased somewhat for euro-based agents. In short, the discussion in this subsection indicates that the influence of the euro relative to the dollar on the exchange rate behaviors of other currencies has increased since its inception. And as of December 2013, the euro has appeared to have established its status as another leading global currency as the European Union intended with the launch of the euro.

Generally speaking, the gap in the economic strength between the United States and Europe, arising from the difference in science and technology levels, will continue to exist for a long while (Chen and Ying 2014). Here, economic strength is a term different from that of economic size with the former emphasizing more on the ability and potentiality of development. Nowadays, the level of science and technology represents the competitive edge of a country. In this sense, the United States has an unparalleled economic strength and vitality, and its edge of science and technology keeps the United States ahead of Europe in terms of economic strength. However, the European inheritance and the fusion of Germany, France, and other countries' currencies would potentially provide a prominent status for Europe. For example, in the time period from 1999 to 2013, the proportion of euro used in global foreign exchange reserves increased from 17.9% to 24.4% (Hanish 2013). People have been concerned about the euro's international status: whether it will grow stronger with each passing day to eventually match that of the US dollar or it will be like Japanese yen, experiencing roller coaster ups and downs (Hanish 2013).

In brief, the outlook for the euro as an international currency could be considered from various angles:

1. Economic strength: In 1999, the European Union's gross GDP is 6.87 trillion dollars, equivalent to 74% of that of the United States. By 2013, the EU's gross GDP is 17.37 trillion, equivalent to 103% of that of the United States (Ying 2016). The number of member countries in the European Union grew from 11 at the beginning to the current 28, which is the main reason why the gross economic output of EU has become greater than that of the United States. However, with the strong recovery of the US economy, the Eurozone will not continue to hold obvious advantages over the United States in the long run.
2. Financial markets: Here are the statistics – The aggregate 2003 value of the stock market, bonds, and bank assets of the Eurozone amounts to 25.7% of that of the world and that of the United States was equal to 33.1%. By the year of 2013, the proportion of the Eurozone rose to 30.8% while that of the United States fell to 24.1% (Hanish 2013). Although the scale of the Eurozone financial market is larger than that of the United States, the respective financial markets have great differences in terms of their structures. For example, the large bank asset size of the Eurozone declined from 41% in 2003 to 30.9% in 2013, while the US securities market was huge in 2003 and 2013, and jointly the US stock and bond markets accounted for 86% of the world in 2013 (Hanish 2013). And in comparison, the development of the securities markets creates greater and

deeper impact on the status of international currency than that of the bank credit market.

3. Currency qualities: The quality of a currency depends on the domestic inflation and the fluctuation of exchange rate. The Eurozone inflation has been relatively stable in recent years for the main reason that the Eurozone has a unified independent European Central Bank, and the Eurozone has a legal system to guarantee price stability (Ying 2016). In addition, the fluctuation of the exchange rate of the euro also affects the quality and credibility of the euro and in turn influences the process of the euro's internationalization.
4. Policy coordination: The United States is a unified country so that its policies could be naturally coordinated, while policy coordination is still an unsolved problem for the Eurozone. That is mainly because it has been difficult, if not impossible, for the individual Eurozone countries to align their decentralized fiscal policies to the unified monetary policy, where individual fiscal policies are introduced based on country-specific, wide-changing situations.
5. The subjective intention: The European Central Bank keeps a neutral attitude toward the internationalization of the euro; the bankers believe the main responsibility and policy objective of the European Central Bank is to maintain price stability, not deliberately pursue the internationalization of the euro; relying on the market's needs and power to promote the internationalization of the euro is their choice. On the other hand, the United States insists on maintaining the dollar hegemony (Hanish 2013).
6. The historical inertia: The first inertia is the strong international currency status of the US dollar, which is currently the most commonly used in international trades. The economic scale and the network of economic interests of the dollar are incomparable by any other international currency. There will be a process for the euro to be acquainted, understood, and accepted by the international community. The second inertia is the impact of the historical and cultural origin. Europe is a veteran of the capitalist countries and used to have many colonies in the world. So the euro is not only readily accepted in Europe but also quite easily accepted by many countries and regions in the world. On the other hand, the United States is a young nation consisting of mainly immigrants. Other than the fact that the special population components have significant impact on the international reach for the dollar, the American culture also enjoys very strong global permeability. That also exerts indirect but strong influence on the dominance of the dollar as the international currency.

21.2.2 Born in a Wrong Time: The European Sovereign Debt Crisis

In the past decades, the euro seems to have met many challenges and overcome great difficulties, such as credit interactions for the Eurozone countries over the January 1, 2007, to October 1, 2010, period. During November 2009, shortly after the election of the new Greek government, the deficit of the Greek public sector was revised from 6% of GDP to 12.7%. This event initiated a sovereign debt crisis that led to large financial interventions in Greece, Ireland, and Portugal. The resultant fluctuations in financial markets and sudden impacts on the fiscal policies in the affected states are often referred to as the "Eurozone sovereign debt crisis" (Ying 2016).

The deterioration in government finances, after the credit crisis of 2008, led to a sudden loss of confidence in sovereign debt markets, which revealed itself in the form of widening credit spreads between several euro area members and the Eurozone's largest economy, Germany. The response by Eurozone member states and international bodies, such as the International Monetary Fund (IMF) and the European Union (EU), has been a suite of interventions led by the European Central Bank (ECB).

Throughout 2010 the focus of the crisis had been on Greece, Ireland, and Portugal, where there was concern about the rising cost of financing government debt and the possibility of default on a sovereign debt issuance. On May 2, 2010, the Eurozone countries and the IMF agreed to a EUR 110 billion loan for Greece, conditional on the implementation of a package of severe austerity measures. On May 9, 2010, Europe's Finance Ministers approved the creation of the European Financial Stability Facility (EFSF) aimed at preserving financial stability in Europe by providing financial assistance to Eurozone states that fell into economic difficulty. The objective of the EFSF is to collect funds and provide loans in conjunction with the IMF to cover the financing needs of Eurozone member states in difficulty subject to strict policy conditionality. The Greek bailout was followed by a €85 billion rescue package for Ireland in November 2010 and a €78 billion bailout for Portugal in May 2011; see Table 21.4.

During the crisis, several commentators expressed concern that manipulation of the CDS market by speculators was playing a crucial role in exacerbating the liquidity dry up in the market for Greek, Irish, Portuguese, and Spanish sovereign debt. In particular, "naked" CDS positions were blamed for driving bond yields on these countries' sovereign debt higher during the first half of 2010. In this context, Greece was suggested to have been a victim of short-term speculative short-selling practices on its national debt and naked-shorting practices in the CDS market (Ying 2016).

The primary risk mechanism involved in triggering the Eurozone sovereign debt crisis is that each individual country, upon joining the Eurozone, effectively gave up the right to inflate (and hence depreciate their currency) their way out of financial distress, should the amount and cost of borrowing suddenly rise to unsustainable levels. That implies that countries, in an identical manner to firms, could in theory completely default on sovereign debt issuances. Indeed, the collapse of Lehman Brothers in 2008 revealed that the so-called too-big-to-fail institutions could default on their debt and as a consequence credit spreads on corporate debt increased rapidly during the period from 2007 to 2010 (Ying 2016).

Prior sovereign defaults, for instance, Argentina in 2001, were caused by a similar ceding of seigniorage revenue and a hard constraint on the expansion of

Table 21.4 Time line of events during the Eurozone debt crisis

Date	Event
August 2007	BNP Paribas liquidates two funds heavily invested in mortgage back securities; subprime crisis effectively begins
March 2008	Bear Stearns bought by JP Morgan with support from US Federal Reserve
August 2008	Lehman Brothers enters Chapter 11 bankruptcy; global financial panic begins
October 2008	Icelandic banking system nationalized, UK assets seized under anti-terrorism laws
Jan./Feb. 2009	Icelandic government collapses, first sovereign victim; Iceland applies to join the European Union (EU)
November 2009	Greek government revises public sector deficit to 12.7% GDP from 6% originally stated
December 2009	Greek credit rating cut by Fitch from A- to BBB
April 2010	Greece applies for help from the EU and the International Monetary Fund (IMF)
May 2010	European Financial Stability Facility (EFSF) is set up with €440 billion
September 2010	Ireland announces it will need €46 billion to bail out its crippled financial sector
October 2010	End of CDS data provision by CMA for the sample used in this presentation
April 2011	Portugal files for support from EFSF and IMF
May 2011	Predicted total public debt for Greece, Ireland, and Portugal forecast to be 166.1%, 117.9%, and 107.4% of GDP, respectively

Data resource: (Calice et al. 2013a, pp. 124)

the monetary base. In the case of Argentina, a currency board with the United States was fixed with supposedly 100% US dollar reserves. When the currency board was broken and the Argentinian peso devalued, several US dollar backed sovereign debt issuances defaulted with low recovery rates (Hanish 2013).

The reasons for the high levels of borrowing for certain members of the Eurozone in the aftermath of the financial crisis are not the same. Countries, such as Greece and Italy, have consistently recorded high levels of government borrowing to ensure the continuation of provision of public services and public sector pay and condition settlements (Ying 2016). The major issue for Ireland has been in the form of providing assurances for a large financial sector that has suffered great losses during the financial crisis (Ying 2016).

During the crisis period, one can observe major changes in many macroeconomic indicators for the Eurozone members. The most striking statistic is annual GDP growth. In fact, during 2009 every single country recorded a contraction in output. The Eurozone as a whole, which had seen 2.16% growth trend during the period from 1999 to 2006, suffered a 4.10% contraction during 2009. Output growth in 2008 was virtually stagnant with Ireland and Italy exhibiting a contraction 1 year before the rest of the Eurozone members. For default risk, the most obvious indicator is the size of the government deficit and the direction of growth in government revenue. The conditions for both of these indicators deteriorated markedly during the period from 2007 to 2010. Revenue has dropped for the

Eurozone as a whole and particularly for certain countries, such as Ireland, Portugal, and Spain. Over approximately the same period, the total government deficit for the Eurozone had increased to around €0.5 trillion (Calice et al. 2013a).

Treating CDSs simply as short positions in a defaultable bond is an entirely consistent argument because once protection equivalent to the par value of the underlying bond has been purchased, then the portfolio of underlying asset and derivatives should replicate the risk-free rate (it is indeed a synthetic risk-free rate). So, the spread on the yield of the defaultable bond over the risk-free rate should in effect be replicated by the cost of holding the protection (i.e., there is a risk premium in holding bonds, and under arbitrage-free pricing, the cost of protection should fully offset this premium). However, recent studies (Calice et al. 2013b) suggest that trading strategies in corporate CDSs generate far higher returns than the equivalent cost of the premium. The ability to construct replicating positions by combinations of short and long positions in the defaultable bond, risk-free rate, and CDS markets is complicated by variations in the underlying liquidity of each market and the nonaligned incentives created by holding one of the three instruments exclusively, for example, a short naked CDS position. The incentive structure is easy to understand if an investor is able to create a highly leveraged speculative bet on default (by using a naked CDS position, for instance, which often requires no initial margin). In this situation, it would then be highly desirable to alter the liquidity of the alternative markets to suit the speculator's purposes (e.g., by withdrawing liquidity from the defaultable bond market and driving up required yields and complicating the restructuring of distressed debt).

Manipulating market liquidity is often the primary strategy speculative attacks are designed and implemented, and in this case, the object of interest is the bilateral liquidity structure of the sovereign debt market and the sovereign CDS market. To this end, there has not been any direct evidence from regulatory investigations to suggest that this type of strategy has been implemented by certain market participants. However, a natural question arises at this juncture: Does the basis point difference in the yield (spread) bid-ask capture the true liquidity of the bond (CDS) market? The bid-ask spread is one of a suite of liquidity proxies commonly used in the academic literature. Unfortunately for bond and CDS markets, the volume information is not as readily available as it is in the equity market. Therefore, robustness checks with alternative measures are not easily implementable.

In particular, Roll and Solnik (1979) present an early assessment of the information content of the bid-ask spread, identifying the components of the transaction costs of trade. A number of recent studies have addressed the synchronizing movement of CDS markets, bond markets, and equity markets. Byström (2004) finds a linkage between stock indices return volatilities and CDS spreads for a set of subindices of the European iTraxx index. Byström shows that CDS spreads have a negative relation with stock prices, whereas they are positively related to stock price volatility. Calice et al. (2013a, b) investigates the potential spillover effects between the credit and liquidity spreads in the Eurozone sovereign bond market and the sovereign credit default swap (CDS) market during the 2010 European sovereign debt crisis. He defines two credit spreads, denoted by the suffix CS: first, the difference in the required discount rate on Eurozone members' benchmark sovereign debt issuance against a benchmark (in this case equivalent German benchmark bonds) and, second, the difference between the CDS spread on benchmark sovereign debt against the CDS spread on equivalent German sovereign debt. In equilibrium, these should move correlatively almost precisely. Then, the bid-ask spread on the bond and CDS markets is used to proxy for market depth and transaction costs and hence market liquidity by entering these four variables into a vector model. This is denoted by the suffix LS for liquidity spread. For convenience, the commonly understood equity/foreign exchange parlance bid-ask spread is utilized to denote the difference between the yield (spread) bid and the yield (spread) ask for the sovereign bond (CDS) market. Calice (2013) documents three noteworthy findings:

- Explosive trends did appear during the sovereign crisis, and the CDS market did appear to have been a driver in most cases.
- There is a positive and significant lagged transmission from the liquidity spread of the CDS market (proxied by the bid-ask spread) to the credit spread in the bond market.
- Several variance breaks appeared in the time-varying models, indicating that the noise structure inundating the VAR model has changed markedly over the 2007–2010 period.

These findings indicate that (a) static models would be uninformative and indeed biased when estimated over such a dataset and (b) the information structure of the sovereign credit market has undergone substantial and dramatic adjustments throughout the time of the crisis.

The implications of these results for policy makers and practitioners are significant. For example, it is clear that, in the absence of coordinated EU-wide actions, the explosive trend would have resulted in a complete market failure for the trade in sovereign debt instruments for several Eurozone countries. The evolution with time of the coefficients of the constructed model leads to a multitude of structural breaks in the slope coefficients, which illustrates the difficulty of why band market participants had faced in correctly pricing these instruments.

21.2.3 The Sun Sets: Flowers Fall Off Helplessly

Since the bursting of the NASDAQ bubble in 2000, the global economy has entered a regime of recurring instability. In the early 2000s, the widespread prudence that pervaded the financial markets in the wake of the crash of the equity bubble and the almighty collapse of major public corporations on both sides of the Atlantic quickly subsided due to several powerful global trends and domestic fiscal and monetary policies. These global trends and policies, however, kindled a bubble in real estate in many developed and developing countries. The bubble climaxed in early 2007. The weakest links in the speculation chain that inflated the bubble in the United

States were the subprime mortgage loans and the securities they backed. The essence of this bubble's inflation was the extreme leveraging attained through many layers of structured investment vehicles (SIV) and especially collateralized debt obligations (CDOs) comprising asset-backed securities (ABS). The compound layering structure led to a false perception of low risk, as supported by rating agencies, in the senior tranches. When the eventual crisis erupted in September 2008, financial markets were confronted with systemic uncertainty as to both the size and the complexity of the asset and the role they played in the balance sheet of major institutions (Ying 2016). For many years, the markets had trusted the framework and agencies government had put in place, such as the Fed in the United States, in the wake of major crises with their ability to protect the value of mainstream assets. However, as the fall of 2008 approached, this sense of security was shown to be grossly incorrect.

The ensuing crisis forced the Fed and the US Treasury to implement extreme measures, setting in motion a new phase of the crisis: governments began absorbing private debt in unprecedented fashion (Ying 2016). In 2009, the financial markets hailed such sweeping action as the only way in which a floor could be placed under the insolvency of major banks. The market panic subsided, and the price of financial assets rebounded. However, what turned out is that the bulk of the risk had simply been shifted. For example, the decision of the Irish government to bail out the country's major bank merely tamed the national debt unmanageable (Ying 2016).

In early 2010, it became apparent that the fiscal conditions of the peripheral economies in the Eurozone were much more precarious than previously estimated. The market perception was that the sovereign debt of these countries was unmanageable and default was increasingly likely. And, although the debt of smaller peripheral economies, such as Greece, Portugal, and Ireland, was deemed salvageable, Italian public debt was far beyond the arsenal of bailout funds available to the ECB and other monetary institutions (Hanish 2013).

The main reason why the international credit market focused on the Eurozone problems is that the monetary union does not correspond to conventional nation state, and individual member countries have a very indirect and weak control of monetary policy while are still responsible for their economies. And even the ECB is heavily constrained in how it manages the money supply in its mandate. On the other hand, the regulation on risk capital encouraged investing in sovereign debt by considering it virtually riskless regardless of issuance. Banks and other institutions chased the higher yields of PIIGS' debt, leading to the accumulation of unprecedented leverage. In the fall of 2011, after spreading from Greece to the other small peripheral economies, such as Portugal and Ireland, the contagion pushed Italian 10-year yields above the threshold of sustainability of 7%. The emergency lending implemented by the ECB stanched the liquidity hemorrhage. However, just as the US banking system in the spring of 2009, this is much more an issue of solvency. However, austerity alone is unlikely to allow debtor nations to satisfy their creditors. Greece, which has endured the longest recession in economic history, is most emblematic in this regard (Hanish 2013).

The field of dynamical systems is relatively new in mathematics; it studies the evolution of time-dependent systems. Regardless of the system under consideration, the predominant goal of the field is to investigate the stability of the state at a given time and its asymptotic behavior, which is often realized by studying the trajectory of a point in the system (Chen and Ying 2014). Although the laws, be physical or not, that govern the system remain unaltered over time, the dynamical system itself can be perturbed to yield a desirable behavior that is totally different from the original one. This is why we believe that the systems science in general and the theory of dynamical systems in particular can be fruitfully applied to the investigation of financial crises from the analysis of the etiology to containment to prevention. For example, Hoque et al. (2015) used the concept of multi-agent dynamical systems to model first the 2007–2009+ US financial crisis and then financial crises in a single economy in general. An economic system is divided into aggregates called "agent," and a dynamical system is constructed to track the wealth of the agents. High leverage and borrowing capacity constraints of the agents induce a bifurcation and subsequent change of the stability type of economic equilibria. Near an unstable equilibrium, a negative shock on wealth can propagate through the system via the feedback loop created by interagent cash flows, and due to the nonlinearity of the system, the shock can intensify while propagating, causing the wealth of all affected agents to drop. If banks are among the affected agents, due to the interconnected of the banking system and extremely high leverage from the esoteric financial tools widely used these days, not only their wealth would drop with acceleration but also would follow bank runs and mass bankruptcies. The entire economy would be severely hit and very likely a financial crisis would break out. The incorporation of bifurcation mechanism and theories on stability to explain financial crises is the major difference between (Hoque et al. 2015) and other multi-agent based models (Chen and Ying 2014).

21.3 Some Concluding Remarks

The international monetary system faces the challenge of globalization. In the long term, the challenge is about how to cope with the integration of a financial powerhouse into the world economy, which is in no position to absorb another big deflationary shock. The possibility of such a shock from China over the next several years is real. Through the analysis of the above two sections, we have revealed the future development trends of the international monetary system.

The special drawing rights (SDRs) represent a class of supplementary foreign exchange reserve assets defined and maintained by the International Monetary Fund (IMF). The SDR was created by the IMF in 1969 and was intended to be an asset held in foreign exchange reserves under the Bretton Woods system of fixed exchange rates. Each SDR was initially defined to be equivalent to US$1 and equal to 0.888671 g of gold. The SDRs come to prominence every time when the US dollar is weak or otherwise unsuitable to be a foreign exchange reserve asset.

Table 21.5 The SDR currency basket during 1981–1998

Period	Dollar (%)	Deutsche mark (%)	Franc (%)	Japanese yen (%)	British pounds (%)
1981–1985	42	19	13	13	13
1986–1990	42	19	12	15	12
1991–1995	40	21	11	17	11
1996–1998	39	21	11	18	11

Table 21.6 The SDR currency basket during 1999–2020

Period	Dollar (%)	Euro (%)	Japanese yen (%)	British pounds (%)	RMB
1999–2000	39	32	18	11	–
2001–2005	44	31	14	11	–
2006–2010	44	34	11	11	–
2011–2015	41.90	37.40	9.40	11.30	–
2016–2020	41.73	30.93	8.33	8.09	10.92%

The value of the SDR is determined by the value of a basket of several currencies important to the world's trades and financial systems. This basket is reevaluated every 5 years, and the currencies included, as well as the weights given to them, can then be changed. See Tables 21.5 and 21.6 for the changes of the SDR currency basket, where the tables are based on the following work: Antweiler, W. (2011), "Special Drawing Rights: The SDR Fact Sheet," University of British Columbia, Sauder School of Business, at http://fx.sauder.ubc.ca/SDR.html, accessed on June 19, 2011.

In the future, the international monetary system is expected to see more diversification of reserve currencies. From Tables 21.5 and 21.6, it can be readily seen that the US dollar's prominence in the world economy declines gradually. During 1981–1985, US dollar took up 42% of the SDRs, while after 2016, the proportion slightly declined to 41.73%. In addition, with more use of the euro, the ongoing internationalization of the Chinese yuan, and the development of financial cooperation among East Asian countries, the global monetary system is expected to establish a more diversified basket of reserve currencies.

Chapter 22
Where Will the US Dollar Go?

Contents

In the eighteenth century, Britain was the largest economy of the Western world; London was the center of international trade and finance; the currency was convertible so that sterling became the world's reserve currency. After World War II, the US dollar dethroned the British sterling to become the world's leading reserve currency. The dollar accounts for about two-thirds of the global reserves and 88% of daily foreign exchange trades. By the 1960s, the dollar had usurped sterling and was the world's new reserve currency with 60% of total central bank reserves being held in dollars, twice the level of sterling reserves.

However, time continues its march forward. By the mid-twenty-first century, the United States will no longer be the world's largest economy. By then, China and India will have overtaken the United States, Western Europe, and Japan, on purchasing power parity terms at least. That should represent where exchange rates are likely to be in the long run. Indeed, optimistic measures of sustainable growth in China and India suggest this will be the case in 20 years (Ying 2016). The dollar will start to lose its leading reserve currency status, not to the euro but to the renminbi. According to the latest Treasury data (US Department of the Treasury 2016), China holds US$1120 billion worth of US Treasury securities as of October 2016. China is the largest creditor nation in the world, while the United States is the largest debtor nation. Renminbi (RMB), the Chinese currency, may become the global leading reserve currency by 2050 since its economy in terms of purchasing power parity is projected to outstrip the US economy. Renminbi is on its way to be more flexible and international.

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Instead of pegging Chinese yuan to the US dollar, China is currently watching on the sideline and preparing to float its yuan. It has struck bilateral currency agreements with several countries, such as Russia, Iran, Chile, and Brazil, thereby bypassing the dollar in business transactions (Ying 2016). The BRICS countries have also agreed to form their own currency arrangement to bypass the dollar (Ying 2016). If the demand for the dollar decreases drastically, the United States will potentially lose its status as the global superpower. When the yuan starts to floated, it will become another global currency, constituting a challenge to the dollar's supremacy.

A great movement in internationalizing the RMB was signaled by the opening of the Shanghai-Hong Kong Stock Connect in the latter part of 2014, allowing foreign investors to freely invest in eligible Chinese A shares previously restricted to only Chinese citizens or foreigners with special permits. Additionally, Shenzhen-Hong Kong Stock Connect was opened on December 5, 2016. These progresses are reflective of the People's Bank of China's target to offer fully managed convertibility of RMB proposed in 2015.

Another major movement in internationalizing the RMB was that China has successfully made its currency, officially called the renminbi but also known as the yuan, included in the composition of the International Monetary Fund's (IMF's) special drawing rights (SDRs). This will bring forward potential benefits for China, such as lowered borrowing costs, more convenient overseas expansion by Chinese companies, and cross-border contracts with major commodities, such as iron ore, to be priced in RMB, thereby easing foreign exchange risks arising from relevant assets priced in the US dollar. And above all, this will open the way for a portion of China's enormous foreign exchange reserves to be redeployed in more economically productive directions.

In the last century, the US dollar has been the key currency for international settlements. The hegemony of the dollar declined after the proportion of the dollar in global foreign exchange reserves peaked at 71% when the Eurozone was formed. And, the proportion fell to 62.9% in 2014 (Hoholik 2016). Nowadays, more and more countries and institutions choose not to use the dollar to settle their international trades, which weakens the status of the dollar as the most prominent global currency reserve. In bilateral trades, some countries are giving up the dollar while considering using other currencies instead (Ying 2016). China is becoming important in the world and promoting its yuan as a trade settlement currency instead of the dollar. Asian Infrastructure Investment Bank, led by China, was initiated and founded in 2015. The institution has US$100 billion capital and 57 nation members with its headquarter located in Beijing, China, while the United States is not a member. Additionally, China and Russia signed a 30-year energy contract worth US$400 billion on the agreement that they will use own currencies for bilateral trade settlements (Ying 2016).

The rest of this chapter is organized as follows: Sect. 22.1 looks at the relationship between globalization and need for international currency. Section 22.2 details the data used in the presentation of results and conclusions. Section 22.3 discusses the important insights revealed by the data. Section 22.4 presents empirical results implied by the data. Section 22.5 checks how robust the developed results are. Section 22.6 establishes the whole story on how the US dollar became the leading international currency. Section 22.7 discusses where the US dollar will go. And Sect. 22.8 concludes the presentation of this chapter.

At this junction, we like to emphasize the fact that this chapter is mainly based on the excellent work of Chitu et al. (2012).

22.1 Globalization and Need for International Currency

The recent economic globalization and frequent appearance of financial crises have lent new drive to discussions of the future of the international monetary and financial system. Policy makers in countries like China and Russia have openly questioned the viability of the current dollar-based global system. Some advocate moving to a multipolar system in which the dollar shares its international currency role with the euro, the Chinese yuan, and/or the IMF's special drawing rights (SDRs). At the Cannes Summit of November 2011, G20 Leaders committed to taking concrete steps to ensure that the international monetary system can reflect the changing equilibrium and the emergence of new international currencies. For this end, see the G20 Leaders' final declaration at the Cannes Summit, November 3–4, 2011.

Others expect this change to develop more spontaneously; they see it as a natural result of the declining economic and financial dominance of the United States and the increasingly multipolar nature of the global economy, together with the advent of the euro and rapid internationalization of the yuan (Angeloni et al. 2011; Bini Smaghi 2011a, b; Constâncio 2011; Dorrucci and McKay 2011; Eichengreen 2011; Fratzscher and Mehl 2011; Subramanian 2011).

Sceptics object that the prospect of a shift to a multipolar monetary and financial system is in fact remote; if it occurs, such a transition will take many decades to complete (Frankel 2011a). The view that a shift to a multipolar system is unlikely to occur rapidly is rooted in theoretical models where international currency status is characterized by network externalities giving rise to lock-in and inertia, which benefit the incumbent (see, e.g., Hartmann 1998; Krugman 1980, 1984; Matsuyama et al. 1993; Rey 2001; Zhou 1997).

These models rest, in turn, on a conventional historical narrative (Triffin 1960), which it claims that between 30 and 70 years, depending on the aspects of economic and international currency status considered, from when the United States overtook Britain as the leading economic and commercial power and when the dollar overtook sterling as the dominant international currency. The United States, as it is observed, surpassed Britain in terms of absolute economic size already in the 1870s. It became the leading commercial power, gauged by the value of foreign trade, already in 1913. It was the leading creditor nation by the conclusion of World War I. And yet sterling remained the dominant international currency, not simply during this period, but also throughout the interwar years, and even for a brief period after World War II (Triffin 1960).

Recent studies, referred to as the "new view" by Frankel (2011a, b), have challenged this conventional account. Eichengreen and Flandreau (2009), relying on new data on the currency composition of global foreign exchange reserves, show that the dollar in fact overtook sterling as the leading reserve currency already in the mid-1920s. That is to say, more than two decades prior to the date assumed by previous scholars.

Eichengreen and Flandreau's work also challenges broader implications of the conventional narrative:

- Inertia and the advantages of incumbency are not as important as claimed.
- There is room for only one international currency in the global system. In fact, Eichengreen and Flandreau (2009) show that sterling and the dollar accounted for roughly equal shares of global foreign exchange reserves throughout the 1920s.
- The dominance, once lost, is gone forever. In fact, Eichengreen and Flandreau's data indicate that sterling retook the lead from the dollar for a brief period after 1931.

Later, Eichengreen and Flandreau (2010) show that what held true for reserve currencies was also true for currencies used in financing international trade. The dollar overtook sterling as the leading form of trade credit, as the currency of denomination for trade acceptances or bankers' acceptances, already in the mid-1920s, instead of after World War II, despite the fact that dollar-denominated trade credits had been virtually unknown as recently as 1914. Both market forces, such as financial market development, and policy support, with the Fed as a market maker in the New York market for bankers' acceptances, were instrumental in helping the dollar rival and overtake sterling. As a result, both New York and London, and both the dollar and sterling, remained as sources of trade credit in the 1920s. That fact indicates that there might be multiple international currencies that coexist simultaneously, instead of what was believed that in the international currency competition the winner takes all.

At the same time, some critics have questioned the new view. For example, Ghosh et al. (2011) suggest that the interwar gold standard was special in that gold, not foreign exchange, was the dominant reserve asset, accounting for some two-thirds of international reserves. In other words, the fact that gold played a large monetary role then while plays only a small role today may limit the inferences about prospective changes in international currency status that can be drawn from this earlier experience. Forbes (2012) suggests that, compared to the past, international financial transactions may play a larger role in driving the decision of which monetary unit or units to use internationally. Merchandise transactions, and the importance of a currency and market as a source of trade credit, play a correspondingly smaller role. Therefore, inferences about the future are less convincing insofar as they are drawn from the past behavior of trade credits and not from the use of currencies in international financial transactions.

To this end, this chapter addresses these objections and completes the story by providing new evidence from the interwar years on the use of the leading international currencies, sterling and the dollar, in international financial transactions. This sheds new light on the international currency status from a third dimension, the use of currencies as vehicles for international finance. This chapter focuses on the international bond market, where bonds had been employed as the principal instrument for foreign lending and borrowing in this earlier era prior to the advent of syndicated bank lending.

Looking at yet an additional aspect of international currency competition is useful for establishing the general theory of international currency competition. Additionally, because international bonds were typically denominated in national currencies and not gold, the earlier objection that evidence from reserve data is not insightful for today no longer applies. (The reluctance of foreign investors to purchase bonds denominated in the currency of the issuer in more recent periods is emphasized in Eichengreen and Hausmann (2005).) Lastly, this chapter provides further deepened understanding of the factors that helped the dollar surpass sterling by empirically analyzing the determinants of currency choice in international bond markets during the interwar years.

The data employed are the currency denomination of foreign public debt for 33 countries in the period 1914–1946 by focusing bonds issued in foreign markets, also known as international bonds. The reason for doing so is because they were only rarely denominated in the issuer's own currency. Instead, these were denominated in international currencies so as to appeal to international investors. It is thus the denomination of these foreign bonds that shed light on international currency use.

The analysis supports the new view in that the dollar already enjoyed a nearly equal share with sterling as a currency of denomination for international bonds in the interwar years. And if the Commonwealth countries are excluded, because they heavily inclined toward using sterling issuance due to their dominion status, the dollar overtook sterling as early as 1929. And the results in this chapter further call two other views of the conventional narrative into question. While sterling lost its preeminence in 1929 if the Commonwealth countries were excluded, it subsequently ran neck to neck with the dollar as the dominant currency of denomination for international bonds at least for a brief period. That contradicts the conventional view that dominance, once lost, is gone forever. Secondly, much of the 1920s and the 1930s saw the use of both sterling and the dollar as currencies of denomination in international debt markets, which implies a two-currency system. That fact goes against the presumption that there is room for only one dominant international currency in the market. And finally, the results of this chapter suggest that inertia effects in international currency use, which might be strong, are not insurmountable, while financial development in the United States was an important macroeconomic determinant for the dollar to ultimately overcome sterling's initial advantage. The impact of financial development in the United States dwarfed that of country size or that of monetary policy and the exchange rate regime.

Because the interwar years were the only time period since the start of the industrial revolution when one incumbent monetary unit was dethroned by a competitor as the world's currency, findings presented in this chapter will be relevant to discussions on the future development of the international monetary system. For example, one of the indications is that a shift from the current dollar-based system to a multipolar system is not impossible. Although it takes time, the shift could occur sooner than commonly believed; and the results in this chapter point to financial deepening and market liquidity as key determinants of how and when additional monetary units strengthen their international currency status.

Contemporary data on the currency of denomination of international bonds are consistent with the existence of this kind of shift. For example, the share of the euro in the stock of international debt securities increased to some 30% in the 2000s from approximately 20% in the 1990s (Detken and Hartmann 2000, 2002). This end, once again is inconsistent with the presumption that there is room for only one international currency in the financial domain.

22.2 The Data Employed

The data on the currency composition of foreign debt came from United Nations (1948). They were gathered by statisticians employed by the League of Nations, the UN's predecessor, and by the UN itself, by using official national sources, such as national accounts and/or budgetary accounts prepared by ministries of finance, annual or special reports of central banks or national statistical institutes, national statistical yearbooks, and so forth.

As the same with modern debt data, there is always the possibility that the UN data are not strictly comparable across countries. Some debts floated in foreign financial centers may in fact be purchased by domestic residents. Some national statistical agencies may include with foreign debt domestically issued securities purchased by foreign investors. The authors of the UN compendium attempted to adjust for these problems as much as possible.

For the purpose of this chapter of gauging the importance of sterling, the dollar, and other currencies as vehicles for international financial transactions, the key is that the public debt categorized as foreign by the United Nations is distinguished by currency of denomination. And when it categorized countries' foreign debts, the UN did apply consistent criteria by their currency of denomination, where each foreign debt issue was categorized by "the original currencies in which it was raised." Chitu et al. (2012) distinguish the currency of issuance from the currency of the country in which the bonds were issued while accounting for the facts that not every foreign bond issued in London was denominated in sterling, that the currency in which the bond was issued was not always the same as the currency in which it was redeemed, and that both the currency of issuance and currency of redemption could differ from the currency of the country where it was issued. For example, a bond issued in French francs in London might be payable in the US dollars.

The UN data on foreign public debt of the following 33 countries in three continents (Asia, Europe, and America) are digitized: Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Denmark, Dominican Republic, Finland, France, Guatemala, Haiti, Honduras, India, Japan, New Zealand, Nicaragua, Norway, Panama, Peru, Poland, Portugal, Romania, Siam, South Africa, Switzerland, Turkey, and Uruguay. And a few countries, such as Italy, that provide data on their overall stock of foreign debt but not on its currency composition were necessarily excluded from the sample.

Data are annual and available from 1914 to 1946 subject to missing observations (typically during World War I and its immediate aftermath and during World War II). Between 14 and 24 countries reported data between 1914 and 1927; approximately 30 countries reported data between 1928 and 1939; and 19–27 countries reported data between 1940 and 1945. The statisticians of the League of Nations/United Nations gathered data on stocks of foreign public bonds measured at book value, which is also the internationally agreed methodology today (Gruić and Wooldridge 2012). That implies that shares of the dollar and sterling did not change merely as a result of external defaults.

Along with sterling, the dollar, the French franc, the Swiss franc, and the German mark, foreign public debt was also issued in 16 other currencies, including the Austrian schilling, Belgian franc, Canadian dollar, Czechoslovak crown, Danish crown, Dutch florin, Dutch gulden, Italian lira, Norwegian crown, Scandinavian crown, Spanish peseta, Swedish crown, Argentinean peso, and Romanian lei. (Note: Names could change over time. For instance, the Austro-Hungarian "gulden" was replaced by the crown ("krone") in 1892 as part of the introduction of the gold standard. However, the name "florin" was used on Austrian coins, while "forint" was used on post-1867 Hungarian banknotes and coins. And around one-third of the countries in our sample, such as Cuba, Dominican Republic, Haiti, India, New Zealand, Panama, Portugal, South Africa, Switzerland, and Siam, had foreign debt in only one currency (either sterling or dollars); others had foreign debt in ten or more currencies.)

Debt denominated in some of these minor currencies was occasionally denominated in currency units of constant gold content. Thus, the data set includes foreign debt denominated in Argentine gold pesos, Austrian gold crowns, Austrian gold florins, French gold francs, Italian gold lire, and Romanian gold lei. Because Argentina, Austria, France, and Romania had been off the gold standard for extended periods and/or suffered high inflation, these countries' data provided opportunities for us to understand the practice. However, the value of foreign bonds denominated in currencies of constant gold content was relatively small, namely, in the order of about 3% of the global total stock, and almost no dollar or sterling loans of constant gold content existed. Turkey issued such bonds between 1933–1934 and 1938–1939 but in negligible amounts (about US$6–9 million).

The book value of outstanding amounts in different currencies is taken and converted to US dollars by using end-of-year market exchange rates. Debt in gold currency is converted to US dollars by using the exchange rate under the gold standard that is nearest to the year when such debt was issued. For example, Brazil's debt in gold francs, issued in 1914, is converted to its equivalent US dollar amount by using the Franc Germinal 1914 parity (5.095 gold francs per US dollar).

Following standard practice in the literature, the established empirical model by Chitu et al. (2012) uses currency shares at current exchange rates, which allows us to compare our results with those of earlier studies. To take into account the impact of devaluations, such as that of sterling in 1931 and that of the dollar in 1933, and valuation effects, calculated are also currency shares at constant exchange rates, which is considered in robustness checks. Another issue is how to treat the war-related debts. To this end, France is the most notable case: Between 80% and 90% of its foreign public debt was owed to allied governments and incurred during World War I. Moreover, France's foreign public debt, at around US$6–7 billion, is by far the largest in the sample and equivalent to over a third of the 33 countries' total stock of foreign public debt. That leads to the need to check for the sensitivity of the established results to the exclusion of France from or inclusion of France into the sample.

Another distinction is between the fiscal and calendar years, which are not always the same. A few countries have fiscal years that start on April 1st of year t and end on March 31st of year $t + 1$. There are even some countries, such as Brazil, France, Romania, and Poland, that changed from calendar to fiscal year at some points in the sample. Following the UN statisticians' convention, this chapter assigns data for fiscal year April 1st t to March 31st $t + 1$ to calendar year $t + 1$.

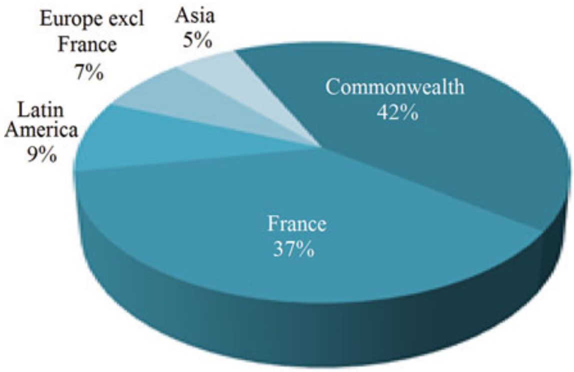
22.3 New Insights Revealed

Let us start with an overview of the evidence that can be immediately gained from the data. The 33 countries in the sample accounted on average for about 37% of world's GDP over the time period from 1914 to 1946. By 1929, roughly the midpoint of the sample, these countries owed more than $17 billion of foreign public debt, which is about twice the amount owed in both 1920 and 1939. That is a little bit higher than the amount of global reserves (in gold and foreign exchange, with 24 countries) estimated by Eichengreen and Flandreau (2009) for that year. It corresponded to about 4% of the world's GDP at that time. By comparison, the stock of international debt securities accounted for 17% of the world's GDP as of the end of 2010.

Of the debt of these US$17 billion, about US$10 billion was sterling debt, which is equivalent to almost 50% of the United Kingdom's GDP, and another US$7 billion was the US dollar debt, which is equivalent to roughly 7% of the United States' GDP. The shares of both currencies were substantial. This confirms the insight of the new view that there is room for more than one international financing currency at any point in time.

Sterling and the dollar jointly accounted for about 97% of global foreign public debt, while other currencies, such as the French franc, the Swiss franc, the German mark, and the Dutch guilder, were largely irrelevant, despite the fact that the French

Fig. 22.1 Global foreign public debt in sterling – main debtors for 1929 (as a % of total at current exchange rates). (**a**) Full sample of 33 countries, (**b**) excluding the Commonwealth countries



and German economies were substantial in size. The absence of the French franc is notable, given the efforts of French officials to elevate Paris to the status of an international financial center and secure an international role for the franc (Meyers 1936). This end reinforces Eichengreen and Flandreau's finding using data on the currency composition of foreign exchange reserves, which were heavily dominated by sterling and dollars and where the French franc similarly did not provide a meaningful alternative. As mentioned above, securities indexed to gold accounted for a very small share of international bonds, about 1% in 1929, for example.

There are also clear differences in the regional origin of foreign public debt denominated in either sterling or dollars (Figs. 22.1 and 22.2). (Note: Fig. 22.2 shows the shares' evolution over time of sterling, US dollar, gold, and other currencies in the global stock of foreign public debt (in % and at current exchange rates) based on the full sample of 33 countries. Data for Australia, Canada, New Zealand, and South Africa refer to the location (London or New York) where debt was "payable," "redeemable," or "due" and are not strictly comparable with those of the remaining 29 countries whose data refer to actual foreign currency debt denomination.)

In particular, almost 80% of the dollar-denominated debt was owed by Europe. Of that amount, the main debtor was, by a large margin, France, which alone accounted for almost 60% of global foreign public debt owed in US dollars. This reflected France's heavy involvement in World War I since the largest share of its debt was held by allied governments. US loans to the French government, first through US banks and then by the US government itself, amounted to just over US $4 billion when converted into long-term bonds in the early 1920s, while the amounts borrowed from the United Kingdom by the French government were slightly smaller (Moulton and Pasvolsky 1926). Most of the remainder was owed by Latin America, where four countries, Cuba, Dominican Republic, Haiti, and Panama, issued foreign public debt exclusively in US dollars. This observation reflected the strong economic and financial ties that the United States developed with the region since the turn of the century and, especially, during and after World War I; see Mitchener and Weidenmeier (2005) for more details. The rest was owed

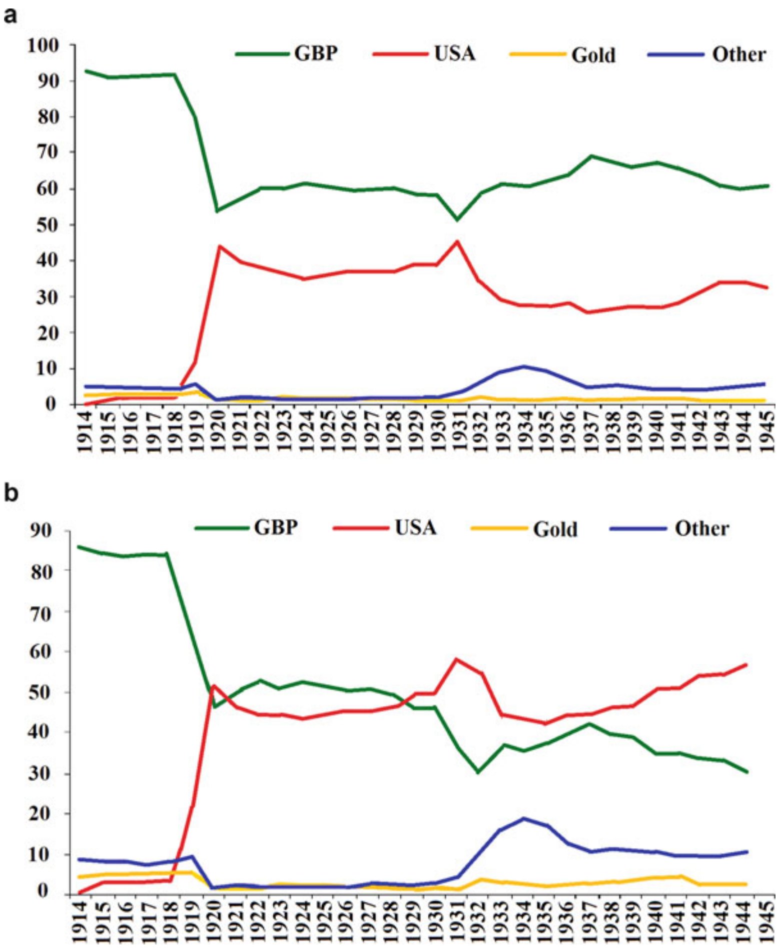


Fig. 22.2 Global foreign public debt (% of total, at current exchange rates)

by two Commonwealth countries, Australia and especially Canada and Japan, which borrowed from the United States as early as 1904 and 1905 to finance its war with Russia and returned to the market in the 1920s.

About 40% of sterling-denominated debt was owed by the Commonwealth countries. That was in line with their strong political as well as economic ties to the United Kingdom. Another 40% was owed by Europe, where France was again the main European originator, accounting for a third of global foreign public debt denominated in sterling. Asia, such as Japan and Siam, accounted for around 5% of global foreign public debt in sterling, while Latin America, including Argentina, Brazil, Chile, Bolivia, Costa Rica, Honduras, Guatemala, Nicaragua, Peru, and Uruguay, accounted for a further 9%.

As for when the dollar surpassed sterling as the leading currency of denomination of international bonds, from Fig. 22.2a, it follows that by 1931, the share of the dollar amounted to 45%, which was almost equal to that of sterling (51%). Here the figure shows the breakdown of global foreign public debt at market exchange rates when the sample includes all 33 countries.

However, due to their strong political links with the United Kingdom, including the five Commonwealth countries in the aggregates may bias the results. So, by taking out the five Commonwealth countries, the evolution over time of the shares of sterling, US dollar, gold, and other currencies in the global stock of foreign public debt is given in Fig. 22.3 (except Fig. 22.3c). Now, the crossover date for sterling and the US dollar is 1929, with sterling's lead the largest in 1924, although the dollar's share of the market is already substantial. The dollar closed the gap in the second half of the 1920s. That was the period marked by the scramble for investment opportunities (Lewis 1938) and when British authorities, concerned with the weakness of the balance of payments, used moral suasion and controls in an effort to restrain long-term foreign lending (Moggridge 1971). (Note: Fig. 22.2b is inconsistent with the conventional wisdom that sterling remained the dominant currency throughout the interwar period despite the fact that the United States had long since overtaken the United Kingdom as the main economic, commercial, and financial global power.)

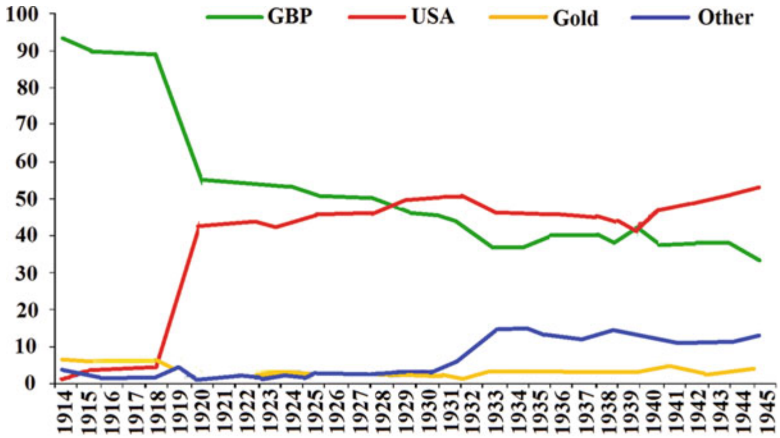
Although sterling regained market share after 1933 and again ran neck and neck with the dollar at the end of the decade, the US dollar became dominant ever since. During the 1930s, the US experience with foreign public debt was troublesome: About two-thirds of outstanding issues lapsed into default roughly double the share of sterling-denominated debt (Winkler 1933). That was the consequence of various factors:

- Bonds issued in dollars appear to have been more marginal credits.
- US underwriters were less experienced.
- Sterling-denominated bonds issued by members of the British Commonwealth and Empire were faithfully serviced all through the 1930s (Eichengreen and Portes 1990; Mintz 1951).

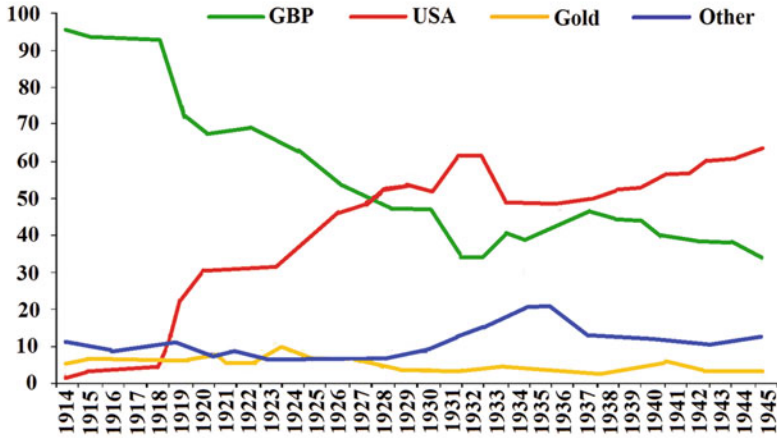
For whatever the reason behind the trouble, the relatively widespread defaults on dollar-denominated debts demoralized the New York market and limited foreign issuance there. Then the Johnson Act of 1934 prohibited governments in default on their sovereign debts from marketing new loans in the United States.

No matter what the mess the US dollar was in the 1930s, the greenback had emerged as a major vehicle for long-term foreign lending already in the 1920s. This history in fact reinforces the empirical knowledge that fortunes can change quickly and that the advantages of incumbency tend to be overstated.

Other than World War I, the sharp rise in the dollar after 1914 is also a consequence of the Federal Reserve Act of 1913 that lifted the ban on foreign branching by US banks. That stimulated international financial markets and transactions in dollars and set the stage for the first wave of expansion of US banks abroad (Chiţu et al. 2012). In the following years, US banks set up foreign branches,

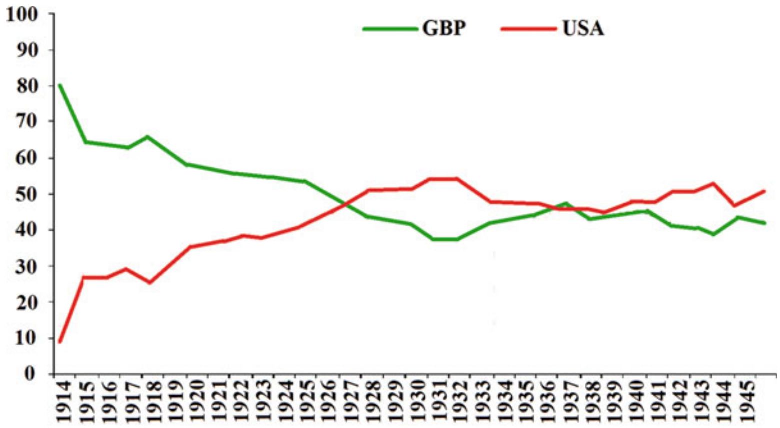


a) At constant (end of 1930) exchange rates (including Frnace)

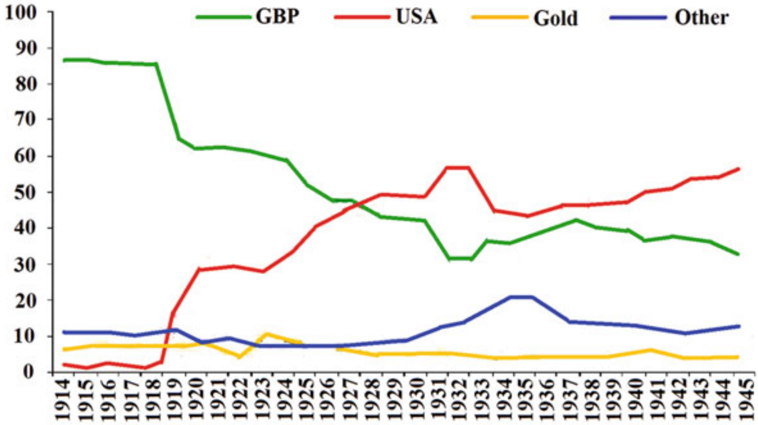


b) At current exchange rates (excluding France)

Fig. 22.3 Currency shares of global foreign public debt (as a % of total)



c) At current exchange rates, average across 33 countries



d) At current exchange rates excluding France & countries issuing only in U.S. dollar or sterling

Fig. 22.3 (continued)

underwrote foreign bonds, and strived to sell these to domestic customers for the first time.

The dramatic rise in the share of the dollar in the early 1920s (Fig. 22.2b) is possibly caused the weighted averages employed, where weights are proportional to the sizes of debt. For example, the largest debtors, including America's wartime allies, such as France, might therefore have a disproportionate influence on aggregate changes. To confirm that end, calculating shares as unweighted averages, as in Fig. 22.3c, does alter the finding, although the share of the dollar still rose swiftly and the greenback overtook sterling in the mid-1920s.

In three countries, Austria, Colombia, and Finland, did the share of the dollar decline markedly in the interwar years. In terms of Austria, this was caused by the growing dependence of the government on Paris, the one market that remained open during the early-1930's financial crisis. As for Finland, it borrowed in Swedish kronor in the 1930s and during World War II. For Colombia, it engaged in a borrowing binge in New York in 1927–1928 in dollars. Afterward, its relatively modest borrowings were both in sterling and dollars as well as in French francs in the case of a substantial 1931 loan floated in Paris. That brought down the dollar share of the total. There was similarly some movement by central banks into subsidiary currencies like the French franc and Swedish kronor in the 1930s. However, the effect on the markets in dollars and sterling was limited in incidence and magnitude (Eichengreen 2011).

Building on the literature on the macroeconomic determinants of currency shares (Chinn and Frankel 2007, 2008; Frankel 2011a, b), let us focus on the following four categories of explanatory variables:

- Network externalities, as is widely emphasized in the literature. An international currency, like a domestic currency, is more useful when others use it. That is to say, a currency used in international debt markets is more likely to be used in international trade transactions and in foreign exchange trading, as an anchor currency or as a reserve currency, etc. which gives rise to economies of scope (Krugman 1980, 1984; Matsuyama et al. 1993; Zhou 1997; Rey 2001; Flandreau and Jobst 2009). This network effect gives rise to inertia or incumbency effects.
- Country size. The currency of an economy with a large share in global output, trade, and finance has a greater natural advantage (Chinn and Frankel 2007). To approximate such size effects, the time-varying shares of US and UK output in global output are used.
- Confidence in a currency's value. As a store of value, investors would want to know that its value of the international currency is stable and will not be inflated away. To approximate such confidence of currency shares, contemporaneous inflation, calculated by using annual CPI data, is used.
- Financial depth. Liquidity is an important attribute of the attractiveness of investing in a particular security, similarly, in a security denominated in a particular currency. And financial development is an important determinant of market liquidity (Eichengreen and Flandreau 2010). To measure financial development, bank assets relative to GDP, as measured by Schularick and Taylor (2012), are used.

For the robustness of the results presented in this chapter, determinants of currency choice are additionally considered, as highlighted in literature using firm-level data. For example, firms issue debt in the currencies of countries in which they operate as a way of hedging their exposure to foreign exchange risk (Kedia and Mozumdar 2003). Specifically, there is evidence that the probability of issuing foreign currency debt is positively correlated with foreign-exchange exposure metrics such as foreign sales in total sales or earnings and cash in foreign currency as a share of firm value (Allayanis and Ofek 2001). So, to proxy for the aggregate country exposure to foreign exchange risk in dollar and sterling, this chapter uses the share of the United States and the United Kingdom in a country's trade.

Another potential determinant is funding cost. McBrady and Schill (2007) suggest that deviations from uncovered or covered interest parity may present opportunities for borrowers to lower borrowing costs by issuing in a foreign currency. Habib and Joy (2010) found that interest rate differentials matter, suggesting that bond issuers choose their issuance currency to exploit arbitrage opportunities between funding currencies. As a proxy for this effect, this chapter uses the differential between the short-term interest rates in country *i* and that in the United States (respectively, the United Kingdom).

Finally, previous studies have shown that market liquidity matters particularly for currency choice at the firm level. Firms facing domestic credit constraints have an incentive to broaden their investor base by issuing in foreign currency (Allayanis and Ofek 2001; Kedia and Mozumdar 2003). The larger the pool of potential investors is in a market, the greater the incentive to issue in their currency. As a complement to the previously chosen financial development proxy, a specific metric of relative market liquidity is considered. Following Flandreau and Jobst (2009), who argue that the short-term interest differential is a good measure of relative market liquidity in a credible gold standard, the short-term dollar-sterling interest differential is used to capture this effect. In particular, the US market liquidity is defined as the differential between the US short-term interest rate and the corresponding sterling rate (the lower the spread, the higher the liquidity) and UK market liquidity as the same spread but with an opposite sign.

22.4 Empirical Results Implied by the Data

To facilitate comparison with the estimates of the determinants of the currency composition of foreign exchange reserves in recent periods, the persistence, credibility, and country size are considered first without considering financial deepening. Table 22.1 presents these benchmark results, where the three variables are entered first one by one and then together. Moreover, to facilitate comparison between the alternative (nested) specifications, the sample size is kept constant. The estimation is carried out on the baseline sample of 28 countries excluding the Commonwealth countries (whose strong political links with the UK constrained their ability to issue debt in currencies other than sterling) and over the full-time period from 1914 to 1946. The full sample of 33 countries is considered in robustness checks.

A first pattern, which is clearly seen in Table 22.1, is the importance of the inertia effects. The point estimate on lagged currency share of 0.90 suggests that these are strong, albeit not insurmountable. Specifically, 10% of the adjustment to the long run in international currency shares in global debt markets is estimated to occur in a single year when all other variables are held constant. This corresponds to

Table 22.1 Baseline model estimates

	(1)	(2)	(3)	(4)	(5)	(6)
Inertia	0.978*** (0.007)			0.978*** (0.007)		0.980*** (0.006)
Credibility	0.013 (0.107)			−0.073* (0.040)		−0.068 (0.052)
Size			0.685*** (0.144)	0.124** (0.053)		1.069*** (0.172)
Financial depth					0.370*** (0.122)	0.280*** (0.074)
Observations	1493	1563	1563	1493	1284	1214
No. of groups	66	66	66	66	66	66
Log likelihood	−4651	−6656	−6645	−4647	−5452	−3837

Note: The specification in column (6) is the benchmark model established by Chitu et al. (2012) with standard errors reported in parentheses
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

a half-life of about 6 years. This estimate is similar in magnitude to the estimates of Chinn and Frankel (2007) of 0.90–0.96 using reserve data for 1973–1998. It suggests that to adequately understand the evolution of currency shares, it is important to consider medium-term evolutions, as what is done here. But the estimate also indicates that the share of a currency in global bond markets can be halved in less than a decade (when all other variables are held constant), which is essentially what happened to sterling between 1914 and the mid-1920s.

Credibility also matters, although its effect is smaller. Lower inflation significantly raises the share of the dollar or sterling in countries' foreign public debt, although the impact is small in magnitude. Column (4) of Table 22.1 stands for the full model estimate, which suggests that the short-run (1 year) effect of reducing the inflation rate by 10% points (a large amount by US and UK standards in the 1920s) is associated with an increase in the share of the US dollar (respectively, sterling) of about one-and-a-half percentage point.

Country size is also important. The full model estimate suggests that the short-run effect (1 year) of an increase in the share of the US (respectively, UK) economy in global output of 10% points corresponds to an increase in the share of the US dollar (respectively, sterling) by roughly 4% points.

Columns (5) and (6) report the results for financial deepening. The point estimates for the persistence and credibility effects change somewhat, with the size effect being larger than before (with an estimated elasticity close to unity) and credibility losing statistical significance. Importantly, financial deepening also exerts a significant effect on the share of the US dollar (respectively, sterling) in global foreign public debt markets. The full model estimate suggests that, in the short run (over 1 year), an increase in the ratio of banking assets to GDP by 10% points is associated with an increase in the share of the US dollar (respectively, sterling) of about 3% points.

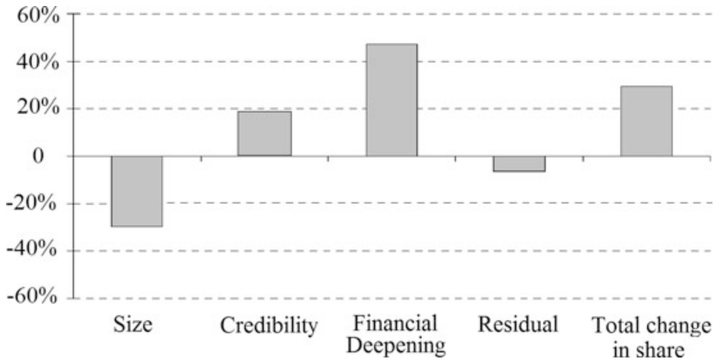


Fig. 22.4 Individual factors' contributions to changes in the share of the US dollar in global foreign public debt (1918–1932)

Figure 22.4 shows the contributions of such variables as size, credibility, and financial deepening to the change in the average share of the US dollar in foreign public debt during the time from 1918 to 1932. The contributions are calculated by using the estimated parameters of the benchmark model (Chitu et al. 2012), column (6) in Table 22.1. They explicitly take into account the effects of inertia arising from the persistence introduced by the lagged values of currency shares in the specification. Those dynamics imply that changes in credibility, size, and financial depth have an impact on currency shares not just contemporaneously but also in the future. For each year t between 1919 and 1932, the contribution of variable z, be it either size, credibility, or financial deepening, to the change in the average share of the US dollar (respectively, sterling) in global foreign public debt y is calculated as

$$\frac{\left(\sum_{i=0}^{\infty} \rho^i \theta dz_{t-i}\right)}{dy_t}$$

where θ is the estimated parameter for z, ρ the estimated parameter for the lag of y, and $dy_t = y_t - y_{t-1}$. The overall contribution of z to the change in y is then obtained by summing the 14 annual contributions between 1919 and 1932.

From Fig. 22.4, it can be seen that that financial deepening is by far the most important contributor to the increase in the share of the dollar as a currency of denomination for international bonds between the time periods from 1918 to 1932, which is consistent with the findings of Eichengreen and Flandreau (2010) for the market in trade acceptances. With the ratio of US banking assets to GDP rising from 70% to 100% of GDP over the period, the share of the dollar in global foreign public debt would have risen by over 40% points if all other conditions are held constant. Next in importance is greater credibility due to lower US inflation, although this impact is not statistically significant.

Interestingly, country size contributed negatively to the rise of the dollar, since the share of the United States in global output fell from 30% in 1918 to 22% in 1932, contributing to a 20% decline in the share of the US dollar if all other conditions are held constant.

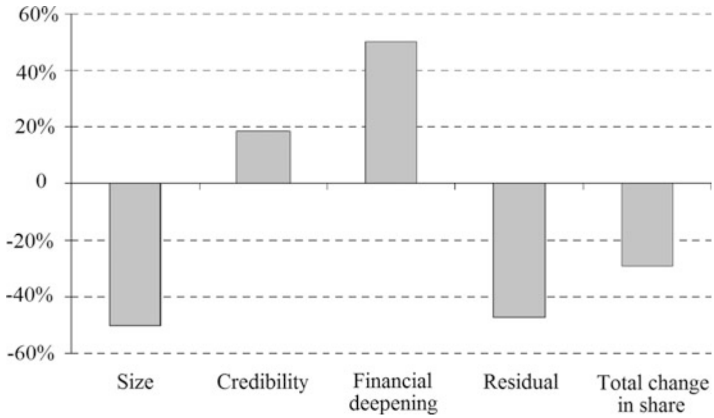


Fig. 22.5 Individual factors' contributions to changes in the share of sterling in global foreign public debt (1918–1932)

Figure 22.5 shows similarly estimated contributions for sterling. Here too financial deepening had a positive impact. But country size is the most important factor explaining the fall in the average share of sterling between 1918 and 1932, with the share of the United Kingdom in global output falling from 13% in 1918 to 8% in 1932. In particular, financial deepening is the single most important *identified* contributor to the decline in the share of sterling, given that the contribution of the residual is even larger in absolute magnitude. This end is consistent with the literature emphasizing how slow growth and high unemployment handicapped Britain's efforts to maintain its financial preeminence and undermined the role of sterling in the 1920s (Chandler 1958; Sayers 1976).

When a similar exercise for the period 1932–1939 is conducted, during which the average share of the US dollar in foreign public debt declined by about 10% points, it is again financial depth that contributes most; see Fig. 22.6. Over this time period, the ratio of bank assets to United States' GDP fell by nearly 20% of GDP as a result of the bank failures of the Great Depression.

In sum, results in this chapter can explain a significant portion of the change in currency shares in global bond markets in the 1920s and 1930s. Along with inertia, financial development in the United States is the most important determinant of the dollar's rise in the 1920s, while economic stagnation leading to a decline in relative country size is the most important factor in sterling's decline.

22.5 Robustness of the Results

Table 22.2 examines the robustness of the previously developed results to the use of alternative estimators, including a linear group-fixed effect estimator without time effects (column 1), a linear group random effect estimator (column 2), and a panel tobit estimator (column 3). These results are close to the previous baseline estimates

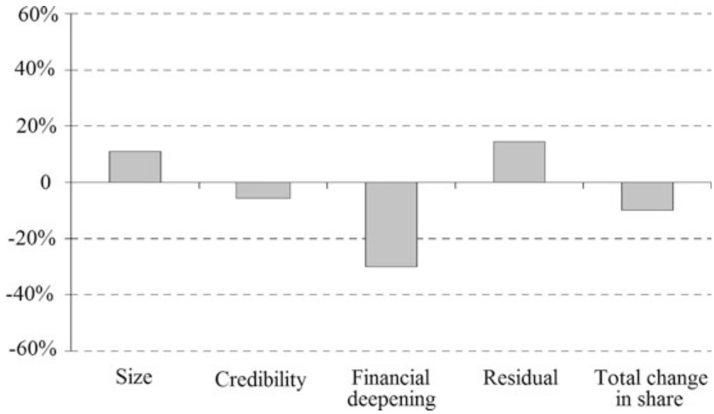


Fig. 22.6 Individual factors' contributions to changes in the share of the US dollar in global foreign public debt (1932–1939)

both in terms of statistical significance and economic magnitude. Once again, the effect of credibility is statistically insignificant and that of financial depth is smaller in magnitude when time effects are excluded.

It is potentially problematic if one interprets the lagged dependent variable in terms of inertia because inertia might be simply picking up persistent error terms. The combination of serially correlated errors and the lagged dependent variable could also introduce the possibility of biased coefficient estimates due to correlation between the lagged variable and the error term.

One way to deal with this problem is to instrument the lagged dependent variable with its second lag and the first lags of the independent variables (Griliches 1961; Liviatan 1963). This will yield consistent, although inefficient, estimates. Intuitively, including only the predicted component of lagged currency shares enhances the plausibility that the lag is picking up genuine inertia effects, rather than merely persistent random errors. A second approach is that of Hatanaka (1974), which includes both the fitted value and the residual from the first-stage regression in the second stage and yields estimates that are both consistent and efficient.

Columns 4 and 5 of Table 22.2 report the results for the two suggested approaches. The estimates are strikingly close to those obtained with the baseline specification in terms of sign, statistical significance, and economic magnitude, where the effect of credibility regains its previous statistical significance. Overall, these results are consistent with the idea that we are picking up genuine inertia effects and not merely persistence in the error term.

In Table 22.3, column 1, France, the single largest debtor in both US dollar and sterling, is excluded. In column 2 controlled is the fact that the number of countries reporting data varies over time, which could distort the baseline results if large outliers start (or discontinue) reporting data, thereby creating significant breaks in the series. This is done by including as additional control variable the number of

Table 22.2 Estimates using alternative estimation methods

	(1)	(2)	(3)	(4)	(5)
Inertia	0.979***	0.985***	0.902***		
Credibility	−0.018 (0.022)	−0.069 (0.063)	−0.073 (0.052)	−0.158** (0.077)	−0.086 (0.058)
Size	0.503*** (0.121)	1.087*** (0.164)	0.867*** (0.174)	0.844*** (0.241)	1.048*** (0.178)
Financial depth	0.087** (0.036)	0.276*** (0.062)	0.293*** (0.069)	0.249** (0.100)	0.274*** (0.076)
Fitted inertia				0.907*** (0.020)	0.978*** (0.007)
First stage residual					0.964*** (0.032)
Observations	1214	1214	1214	1146	1146
No. of groups	66	66	66	64	64
Log likelihood	−3850		−3770	−3999	−3641

Note: This table reports panel tobit estimates for the benchmark model (Chitu et al. 2012), where (1) are the results using a panel tobit estimator without time effects, (2) a linear random effect estimator, (3) a linear fixed effect estimator (with errors robust to heteroskedasticity and clustered heterogeneity), (4) the Griliches (1961)-Liviatan (1963) estimator, and (5) the Hatanaka (1974) estimator. Standard errors are reported in parentheses
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 22.3 Other sensitivity tests

	(1)	(2)	(3)	(4)	(5)
Inertia	0.980*** (0.006)	0.980*** (0.006)	0.978*** (0.006)	0.982*** (0.007)	0.975*** (0.007)
Credibility	−0.089* (0.052)	−0.068 (0.052)	0.014 (0.048)	0.060 (0.061)	−0.039 (0.043)
Size	1.063*** (0.175)	1.069*** (0.172)	0.623*** (0.160)	1.075*** (0.193)	0.094* (0.055)
Financial depth	0.281*** (0.076)	0.280*** (0.074)	0.107* (0.069)	0.321*** (0.083)	
# Reporting countries		−0.033 (0.104)			
Bilateral trade with the United States/ United Kingdom				0.028*** (0.010)	
Market liquidity					−0.399** (0.188)
Observations	1177	1214	1214	882	1493
No. of groups	64	66	66	49	66
Log likelihood	−3719	−3837	−3748	−2754	−4645

Note: This report reports panel tobit estimates for the benchmark model (Chitu et al. 2012), where (1) excludes France (largest debtor) from the estimation, (2) controls for the number of countries reporting data, (3) uses currency shares calculated at constant exchange rates, and (4) controls for economic proximity. Standard errors are reported in parentheses
***$p < 0.01$, **$p < 0.05$, *$p < 0.13$

countries reporting data on foreign currency debt composition per year. The results again remain largely unaffected.

Used can also be the currency shares calculated at constant exchange rates rather than current rates, where using current rates is the established practice in the literature, in order to take into account possible valuation effects arising from, e.g., devaluations. The effect of persistence remains broadly unchanged, while that of size declines markedly in magnitude and that of credibility is again insignificant (column 3). What is important is that the estimate for financial deepening remains significantly positive, although it is now smaller in magnitude.

The possible endogeneity of financial development is also considered. In the previous section, evidence is provided to support that financial development, as proxied by the ratio of bank assets to GDP, is an important determinant of the attractions of a currency as a unit of denomination for international bonds. To this end, one concern might be the reverse causality, where the issuance of bonds in a market may be followed by the deposit, at least temporarily, of the receipts accruing to the issuer in the banks of that same market. Causality, in other words, may run from the value of bond floatation to the level of bank deposits as well as the other way around.

To counter this concern, one should notice that the dependent variable of focus here is the share of bonds denominated in a particular currency and not the share floated in a particular national market. These are not always the same, as noted above. Another counterargument is that even if issuers did temporarily deposit the receipts from bond issuance in the banks of the country where the issue was floated, the money to buy the bonds would have come, in part, from the same place. That is, investors would have withdrawn money from those same banks in order to finance their purchases.

To address this concern, instrumented is bank deposits as a share of GDP by using other dimensions of financial development less plausibly affected by bond issuance in the same country: broad money to GDP, private credit to GDP, and narrow money to GDP. This is further supported by the estimates obtained using the Arellano-Bond (1991) two-step generalized method of moments (GMM) estimator. Similar results are again obtained, including for financial depth. System GMM estimates, in which instrument proliferation bias is explicitly controlled for, once again support the point. Again the models successfully pass standard specification tests. What is important is that the estimates for the coefficient on financial depth remain largely unchanged relative to the baseline specification in terms of sign, significance, and economic magnitude.

As a further robustness check, the five Commonwealth countries are added back to the sample. The results again are similar; details are omitted. This end confirms the fact that the findings listed previously are not biased by the exclusion of countries heavily oriented to sterling for institutional and political reasons, underscoring the generality of the conclusions.

In terms of the potential concern that the regression results on the importance of financial development are a figment of a persistent – albeit stationary – process, given that financial depth could be trending, this is not the case. Although financial depth increased significantly in the United States in the 1920s, it collapsed in the Great Depression of the 1930s. Formal Fisher-Phillips-Perron tests for unbalanced panels also reject the presence of a unit root in financial depth, both with and without a time trend. Estimates in first differences rather than in levels, i.e., unlike the conventional specification used in the literature, which models inertia explicitly, confirm that financial development matters. Not surprisingly, the effect of inertia vanishes virtually, while that of size turns negative in two specifications, although becoming insignificant in the full model. But the results for credibility and financial depth remain unchanged, which supports again the presumed emphasis on financial development.

22.6 How the Dollar Became the Leading International Currency

This chapter provides new evidence on the emergence of the US dollar as the leading international currency by focusing on its role as a financial currency in global debt markets. This evidence challenges the three central tenets of the conventional wisdom on international currencies:

- Network externalities, first-mover advantages, and inertia matter. But they cannot indefinitely delay the transfer of leadership in the international monetary sphere relative to that in the economic, commercial, and financial spheres. They do not dominate to the extent as previously thought. The evidence in this chapter shows that when the Commonwealth countries are excluded, the dollar overtook sterling already in 1929. That is at least 15 years prior to the date cited in other accounts. Even including the Commonwealth countries, which were wedded to sterling for political and institutional reasons, the dollar was already within hailing distance of sterling as a currency of denomination for international bonds by the later part of the 1920s.
- The evidence here challenges the presumption that once international monetary leadership is lost, it is gone forever. For example, although sterling lost its leadership in the 1920s, it recovered after 1933 and again ran neck and neck with the dollar at the end of the decade.
- The finding presented in this chapter challenges the presumption that there is room for only one dominant international currency due to strong network externalities and economies of scope. For example, international debt markets in the 1920s and the 1930s were characterized by a bipolar currency system, not a unipolar one. That is true even if one takes into account the Commonwealth countries, which were heavily oriented toward sterling for very institutional and political reasons.

What is presented in this chapter points to the development of US financial markets as the main factor that helped the US dollar overcome sterling's incumbency advantage. It is found that financial deepening was the most important contributor to the increase in the share of the US dollar in global foreign public debt during time from 1918 to 1932. In the case of the Unite Kingdom, economic stagnation (declining relative economic size) was the most important factor accounting for sterling's declining share over the period.

These findings have implications for the future of the international monetary system. They suggest that a shift from a unipolar dollar-based system to a multipolar system is not impossible, that it could occur sooner than often believed, and that financial deepening and market liquidity will be key determinants of the ability of currencies other than the dollar to strengthen their international currency status. They point to addressing financial market fragmentation and deepening financial integration in the euro area as important to the evolution of the euro's international profile in the years ahead and to the opening up of the capital account, along with further exchange rate reform, and the building up of liquid domestic financial markets, as of key importance to that of the Chinese yuan.

The international status of a currency rests on solid foundations, where financial deepening in the issuing country is sustainable, and the financial innovation and liberalization do not lead to bust other than cause booms.

The impact of finance on international currency shares in global debt markets worked both ways during the interwar period. In particular, the collapse of the US banking system and subsequent financial retrenchment were the most important factor contributing to the decline in the share of the US dollar in global foreign public debt between 1932 and 1939.

Japanese yen's experience is another cautionary tale. Attempts by Japan's authorities to develop the international role of their currency suffered from the bursting of Japan's equity and real estate bubbles in the late 1980s and the banking and economic crisis of the 1990s. This underscores that the compass guiding the pace and scope of finance sector reform should always point to the direction of medium-term sustainability. In turn, that highlights the important role that macroprudential policies and tools will play in shaping the international status of currencies in the new millennium.

22.7 Where Will the US Dollar Go?

Looking into the future, the US dollar will be in an overall decline process, while Chinese yuan in a growing up process. The decline and the growth are full of uncertainties and will experience a long and tortuous process. However, the US dollar will not willingly relinquish its dominant position. Being the biggest economy in size, the United States is still the single superpower in the world with unparalleled comprehensive strength. Its most advanced financial technology and innovation capacity will surely help serve the purpose of maintaining the dominant status of the US dollar.

Factors affecting the decline of the dollar and logical sequence are:

- The relative decline of American economic strength
- A decline of America international financial status
- The decline of the dollar's international status

The decline of the dollar and the evolution of the pound are expected to be parallel and comparable. And what can be said about the pound in the past reflects the evolution of the dollar in the future.

Compared with the US dollar, Chinese yuan will be a growing currency on its way to become internationally important and will also follow the logical order of interlinked nature:

- The first is the rise of China's economic strength.
- Then is to improve the Chinese international financial status.
- Finally Chinese yuan rises in its international status.

To this end, let us look at the following two comparisons: First, let us consider the totality of China's economy. Since World War II, of the scale of the world economy, the United States amounted to more than 20% in the long term or even more than 30% occasionally, while China accounted for only about 1%. After the reform and opening up, which were initiated in the 1980s, China's economy continued to grow rapidly and reached the size of 7.14% of the world economy in 2008 and 12.1% in 2013. Based on economic growth forecasts, Chinese economy in 2025 will reach the scale of the present economy of the United States (Ying 2016). That is, the overall trend is that the scale of Chinese economy has been and is rising, while America's in decline. That means that in around the year of 2025, China and the US economy will experience a major reversal, which will bring about great uncertainties.

Secondly, let us look at the situation of financial development of these two countries. The current American financial market has grown to an unprecedented degree, while China is still in its infancy. In particular, there is a big gap between the two countries. For example, from the ratio of the total market capitalization over GDP, there is a clear gap between China and the United States. The ratio in 1992 was about 20 times (3.89–68.4%). The ratio in 2000 was about ten times (18–163%). That is, the level of China's financial development is still low. There is also a large gap between Chinese financial market and that of the United States. That clearly indicates that the financial market in China is obviously insufficient for China, where the financial structure is dominated by indirect financing and the capital market is still under developed.

Therefore, in the whole, there is a very big disparity between China's economic strength and the United States' strength; at the same time, the gap between the two nations' financial markets is much greater. Although the speed of Chinese economic development may be faster than that of the United States', the overall sizes are still far different. So, over an extended period of time, Chinese yuan will not be a realistic rival to the dollar, although the United States may consider Chinese yuan as its real adversary.

22.8 Some Final Remarks

The global leading currency has started a Trump Tornado since the US election in 2016. The dollar index recently reached its highest level in the past 13 years, and RMB was falling to a record low continuously. With more than 6% depreciation on the RMB-USD exchange rate in 2016, the currency game among the United States, China, and Europe, three major economies in the world, has been the most concerned focus in the entire world market. Whether the dollar can continue to be strong, whether the RMB can be steady, whether the euro can stop being weakened, and what will be the fate of the relationship of these three currencies mainly depend on the market economic expectations and policies adopted by the three economies.

In the short term, the key point is on the current economic situation and the political landscape. Due to the start of a new presidential era in the United States, currencies will more than any other times reflect the prospective factors and market expectations of whether or not the fiscal policy of Trump's new deal will be more expansionary. Based on the indications shown in December 2016, the dollar continues to strengthen with the dollar index reaching to its highest level in 14 years. However, the economic goal of the new president who hopes to improve the US export by weakening the dollar has made the markets have disagreeing expectations on the dollar over the long term (Ying and Ye 2016).

From the perspective of China, in the short term, the economy continues to slide, the ongoing reform achieves successes, and the inflation remains benign. Although the RMB/US dollar exchange rate has slightly depreciated, the rate of RMB against a basket of currencies has risen, and the effective exchange rate continues to rise steadily. So the general trend shows a stable and strong characteristic.

Eurozone is in a political unrest recently. Its economy has been continuously weakening, and inflation expectations have declined. It is hard for euro to stage a meaningful rally after its continuous sharp decline.

Looking backward, in recent years, the recovery of the global economy is disappointing and full of accidents. Especially last year (2016), the fluctuation of global financial markets at the beginning of the year, the British referendum of leaving the EU at the middle of the year, and the US presidential election at the end of the year, together with European refugee crisis, the coup attempt in Turkey, and other geopolitical conflicts, frequently disturb the global economic and financial system. With an unprecedented number of countries approaching to their limits of debt, the economic growth problem is inevitable and should be addressed and resolved quickly. The difficulty facing global economic growth is not only due to the impact of short-term risks but also deeply rooted in the deficiency of long-term motivation. And policy measures and market situations have constantly broken the conventional boundaries.

Looking to the future, within the weak global economy, United States wants to grow abruptly and retain a dominant position in world affairs (Ying 2016). To slow down the decline of the dollar, there are two important things the United States should consider doing: Merge itself into the big family of the world as a regular member and a constructive leader and avoid as many as possible wars, no matter how local or minor they could be. Otherwise, a not very strong dollar and a not very weak RMB might well devastate the potentials of the US economy and alter the landscape of the world economy and politics. Additionally, by restraining itself consciously, the United States will also strengthen its controlling ability in the Asia-Pacific region while placing restrictions on the development of China so that RMB will be under a serious revaluation pressure over a long period of time.

However, an excessively strong RMB will likely make the composite of international currencies give more weight to RMB while reducing the importance of the US dollar. And strengthening RMB will weaken the growth potential of China as the world factory and exert a great negative effect on the stability of the global economy, which is definitely harmful to the US interest. So, there is a need to reach a subtle balance between the dollar and the RMB on the standpoint of United States. Having occupied an important position in the global economy, China is so far highly successful in its economic development and financial reform. Therefore, with the advancement of RMB's internationalization, it is necessary for China to maintain the stability of the exchange rate of its RMB. But, the current strong US dollar leads to rapid depreciation of RMB, and the Chinese government does not like to see an increased risk of capital flight. The history has well shown that China's central bank would intervene in the foreign exchange market when RMB depreciates beyond expectation. So, present economic fundamentals, import-export fundamentals, and the conditions of currency reserves of China will determine the increasing level of short-term fluctuation of RMB. However, there is no clear reason for RMB to experience long-term depreciation. To maintain the basic stability of RMB's value at a reasonable, balanced level will bring forward benefits to the growth of both China's economy and that of the world.

In the process of globalization, nothing is eternal except the need to gain benefits. The currency game between China and the United States is the core of current global economic game. To conform the trend of world economic and political development, both the United States and China should carefully prepare politically and economically and theoretically and realistically on how to face the long-term complexity existing in the dual game between RMB and the dollar. They should also carry out policy coordination in the multilateral global stage. Only in the premise of maintaining the growth of individual economies can a steady growth of the global economy be maintained, creating benefits of globalization for all.

Chapter 23
Where Will Chinese Yuan Go?

Contents

The Triffin dilemma is the inherent contradictions existing in the international monetary system. Whether it is gold-standard system or the Bretton Woods system or the current Jamaica system, this dilemma cannot be resolved. This dilemma represents the conflict of economic interests that arises between short-term domestic and long-term international objectives for countries whose currencies serve as global reserve currencies. It was first identified in the 1960s by Yale University Professor Robert Triffin, who pointed out that the country whose currency, as a global reserve currency, foreign nations wish to hold must be willing to supply the world with an extra supply of its currency to fulfill the world demand for foreign exchange reserves, thus leading to a trade deficit.

In the last two decades, with the relaxation of capital control and the acceleration of financial market integration, cross-border currency competition has intensified. The motive force behind changes of the international monetary system is to seize dominance in the international finance. Under the influence of such force, the system has shown competitive patterns with a few strong currencies emerging as the core. Hence, considering the relationship between international capital flows

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and the development of East Asia, if the current account deficit of the United States is no longer unsustainable, then the financial center status the United States has enjoyed will be threatened, which means a new Triffin dilemma.

As far as China is concerned, its enhanced economic strength and large international reserves enable its currency, Renminbi (RMB), to be used in an increasingly much greater scale of international transactions day by day. At the same time, the conditions for the internationalization of RMB are bounded to deeply challenge China's economic structure and financial order. To analyze the power struggle between China and the United States within the international monetary system in the post financial-crisis era, it is practically important for policy makers to know where Chinese yuan will potentially go.

The rest of this chapter is organized as follows: Sect. 23.1 looks at how Renminbi started to grow from a humble beginning. Section 23.2 considers the evolution and development of the Chinese currency. Section 23.3 shows how offshore financial centers of the Chinese currency gradually appeared. Section 23.4 studies the ongoing pace of regionalizing Renminbi. And Sect. 23.5 concludes the presentation of this chapter.

23.1 The Growth of Renminbi from a Humble Beginning

Laozi, a recluse who lived during the Spring and Autumn period of time, 571–471 B.C., summarized a profound truth of life: *The highest level of ethics is like water, which is beneficial for all things, without striving for fame and gain* (Laozi 2012).

The Chinese currency internationalization has been one of the most important aspects of debates in global economic and political forums (Orăştean 2013; He et al. 2016). China is the second largest economy and the biggest exporter worldwide, but its currency, yuan or Renminbi, does not have the reserve currency status. Moreover the short- and medium-term prospects for the Chinese economy are favorable, despite its current slowdown.

With a population of over 1344 billion people, China is the largest economic entity in the world with 19.3% of the entire human population, far exceeding the euro area's population (333 million, 4.8%), the United States' (311.6 million, 4.5%), and Japan's (127.8 million, 1.8%) (Yang and Zhang 2016). In 2011, China's share of the global GDP was 10.5%, compared with 21.6% for the United States, 18.7% for the euro, and 8.4% for Japan (Cross and Nguyen 2017).

China's share in world merchandise exports reached 10.43% in 2011, consolidating its top position that China has occupied since 2009 (Xu 2016). Regarding imports of goods, a 2011 ranking puts the United States in the first position (12.33%), followed by China (9.48%), Germany (6.81%), and Japan (4.65%) (Xu 2016).

China is a country with a persistent surplus of current account balance, with a peak reached in 2007 (10.2% of GDP) followed by a decreasing trend in recent years, reaching 2.8% of GDP in 2011 (Ma and McCauley 2013).

This surplus is unexplained to some extent, and the question that arises is about the role of exchange rates and the willingness of some countries to accumulate huge international reserves after the Asian crisis of the 1990s.

The value of the official reserves was doubled in 2011 compared to that of 2007, reaching US$3.2 trillion in 2011. So, China held the first position in the ranking of countries with the largest foreign reserves, followed by Japan and then the Russian Federation. According to World Gold Council, China doubled its gold reserves between 2007 and 2012 with holdings of 1054 tons in October 2012, representing 1.7% of total Chinese foreign reserves. For the same period, China is the world's fifth largest holder of monetary gold, but the share of gold in total foreign reserves remains low (1.7%) compared with that of the United States (75.4%).

In other words, China ranks first in terms of exports and imports of goods and services in terms of their shares in China's GDP, population, and international reserves.

23.2 Evolution and Development of Renminbi

Theoretically, an international currency is a currency that is used both within and outside the issuing country. The international role of a currency is related to the three basic functions of money: medium of exchange, store of value, and unit of account. Internationalization of China's currency means that Chinese yuan, or also known as Renminbi (RMB), will be used internationally for fulfilling all these functions.

This section looks at the link between regional cooperation and currency regionalization and specifically analyzes Inner-Asia currency cooperation after the Asian financial crisis of the 1990s. Through analysis on the correlation of China's macroeconomy and that of other Asian countries, remaining factors that hinder RMB's regionalization are investigated with the following conclusions:

- It will take a long time for any of the Asia's currencies to evolve into an age of Chinese dollar, an imagined common currency for Asia. There are huge differences in the development stages among Asian countries and regions. That creates many obstacles for these countries to reach a cooperation consensus. Meanwhile, many outstanding historical issues weaken the cooperation willingness of peoples and governments within the region.
- Historical data has shown that China shares high similarity with other Asian countries and regions in terms of economic growth and inflation. Therefore, it is feasible for RMB to expand its influence over the surrounding areas and develop part of functions as an international currency. With quantitative analysis of 21 Asian countries and regions, the statistic data indicate that there are

17 countries and regions whose economic growth cycles share position correlation coefficients with China, among which 10 have correlation coefficients over 0.5, demonstrating that these countries and regions have similar economic growth cycles with China and other countries and regions within the region. In terms of the correlation coefficient of inflation, there are 19 of the 21 countries and regions that show high correlation with China, among which 16 have correlation coefficients over 0.7. This shows that if RMB is regionalized in Asia, the macroeconomic costs will be relatively low for other countries within the region to give up their independent monetary policies. Therefore, in the path toward RMB internationalization, it is possible and feasible to first expand the influence of RMB in the surrounding areas and develop part of its functions as an international currency.

International currency status of the yuan (Renminbi) can be earned through Chinese currency internationalization, which includes ensuring its convertibility and keeping up the government's initiatives to promote settlement of international trades in China's currency, through enhancing exchange rate flexibility, developing domestic financial market, removing restrictions on capital movements, and increasing the central bank's independence.

Although the yuan's (Renminbi's) internationalization has made some positive progress in recent years, the Chinese currency still plays a minimum role in the global economy (Meng 2016).

In the global foreign exchange market, according to the Bank for International Settlements, the Chinese currency is among the emerging market currencies that recorded significant increases in their trading volumes. The yuan (Renminbi) accounted 0.9% of global turnover in 2010, on a par with the Indian rupee and the Russian ruble, compared with 0.5% in 2007 and 0.1% in 2004.

Although China records 11.4% of world trade, the share of the yuan (Renminbi) in international payments was merely 0.24% in 2010. But there is no doubt that in the medium and long term, the yuan (Renminbi) will become an important currency in international trade settlements. For China, the main benefits of having an internationalized yuan (Renminbi) include:

- Chinese companies are able to make cross-border settlements in their domestic currency and will gain from the elimination of the additional costs and exchange rate risk.
- Chinese banks are able to do international transactions in their national currency and will have access to global financial markets, taking into account that in the future China aims to become a global financial power.
- Chinese financial markets will become deeper and more liquid.
- Chinese government and private financial institutions will benefit from lower cost of funding.
- Chinese authorities will gain seigniorage.

At the same time, the potential costs of the yuan's (Renminbi's) internationalization are as follows:

- Increasing risks to monetary and financial stability
- Growing vulnerability to speculative attacks by opening the capital account

For the relevant literature that analyzes in details the benefits and costs of the Chinese moving toward multicurrency international monetary system, including the yuan (Renminbi), it requires first the Chinese currency to become an international currency. China wants a balanced international monetary system with the US dollar, euro, and the yuan (Renminbi) as the core currencies (Ponsot 2016).

In 2005, China adopted a more flexible exchange rate regime against the US dollar. Since then the yuan (Renminbi) has seen its increasing use in the region. And in June 2010, the People's Bank of China announced that it would abandon its currency peg to the US dollar and manage the yuan (Renminbi) more flexibly against a basket of currencies, defined according to their share in world trade. Although the Chinese currency flexibility increased to some extent, the yuan (Renminbi) remains strongly managed and recorded a slight appreciation against the US dollar (around 5% annually).

On the other hand, although China is now the largest trading nation in the world, its currency has just recently become a part of the SDR basket. Currently, the SDR basket comprises five key international currencies, US dollar (41.73%), euro (30.93%), Renminbi (10.92%), Japanese yen (8.33%), and pound sterling (8.09%) (IMF 2015), selected based on the size of the export sector and whether the currency is freely usable. The basket composition is reviewed every 5 years by the Executive Board of IMF to ensure that it reflects the relative importance of currencies in the world's trading and financial systems, based on the share of each currency in world exports of goods and services and international reserves.

Benassy-Quere and Capelle (2014) studied the impact of a broadening of the SDR basket to include the Chinese currency on the composition and volatility of the basket. Alexei Kudrin, Russian Minister of Finance, said at the International Economic Forum in St. Petersburg (June 2009) that the Chinese currency could be included in world currency reserves within 10 years with the liberalization of the Chinese economy and ensuring convertibility of the yuan (Renminbi). This statement could be interpreted as Moscow authorities' desire to reduce the US dollar's dominance. China and Russia, which occupy the first and third place in terms of reserves, expressed their concern about the instability of the US dollar and called for discussions to diversify the reserve holdings. On the other hand, Joaquin Almunia, EU Commissioner for Economy, downplayed the prospects that the US dollar be dethroned from the world currency position in the near future (Bénassy-Quéré and Capelle 2014).

In the last decade, China has taken a number of initiatives to promote its yuan (Renminbi) as an international currency. In 2002 it allowed foreign investors to participate in its stock exchange, in 2004 launched offshore Renminbi market in Hong Kong, and in 2007 began bond issuance denominated in Renminbi (dim sum bonds). Since July 2009, the Chinese authorities began to promote international use of the yuan (Renminbi) in international trade settlements with major partners (the pilot project included Hong Kong, Macau, and ASEAN countries; and after 1 year the scheme was extended to 20 Chinese provinces) and the development of Hong Kong as an offshore center for trade and investment in Renminbi. Agreement between the People's Bank of China and the Hong Kong Monetary Authority in July 2010 allowed all companies to open accounts in Renminbi in Hong Kong not only for commercial purposes but also for financial institutions to offer more sophisticated financial products denominated in Renminbi. Central banks in Malaysia, Nigeria, Chile, Thailand, Brazil, and Venezuela have begun to include the yuan (Renminbi) in their foreign exchange reserves.

According to the European Central Bank, in the first quarter of 2011, total value of trade settlements in Renminbi was RMB 360 billion, representing 7% of China's total trade in that period. Offshore deposits in Renminbi amounted RMB 451 billion in March 2011, equivalent to 7.6% and 0.6% of total deposits in Hong Kong and China, respectively. Renminbi bond market in Hong Kong is small with a transaction value of RMB 80 billion in March 2011.

Considering all these actions, it can be readily seen that the internationalization of the Chinese currency has progressed and expanded, covering many dimensions of private use of an international currency: trade invoicing and settlement currency and investment currency. International use of China's currency remains limited as denomination currency in financial transactions, investment currency for cross-border deposits and securities, reserve currency, and currency anchor. There are important steps, beyond which China must focus its efforts to convince local and foreign companies to make business in the yuan (Renminbi) and encourage central banks around the world begin to hold reserve assets denominated in Chinese currency.

In the last several years, there have been a number of international agreements assigned that are likely to weaken the strength of the US dollar. According to Forbes, China dropped the US dollar in trade with BRICS countries, Brazil, Russia, India, China, and South Africa, and signed agreements with the UAE to only use local currencies in their bilateral trades. In particular:

- Brazil approved Chinese strategy to impose its currency, accepting the yuan (Renminbi) direct exchanges, instead of the US dollar.
- China and Russia initiated in November 2010 an agreement to use their own currencies in bilateral trade without making use of the US dollar. The yuan (Renminbi) trading against the Russian ruble began immediately in the Chinese bank market in Shanghai and in December on the Moscow Interbank Currency Exchange.
- China and South Africa have agreed to use the yuan (Renminbi) in their transactions, and a number of African central banks included the yuan (Renminbi) in reserve currencies, while the US dollar was the dominant currency in Africa in the past. China is by far the strongest economic partner in Africa.
- China and UAE have decided to abandon the US dollar and to use their own currencies in trading oil products.

On the other hand, the People's Bank of China has signed in recent years swap agreements in local currencies with central banks in Hong Kong, South Korea, Singapore, Indonesia, Malaysia, Argentina, Belarus, Iceland, New Zealand, Uzbekistan, UAE, Turkey, Australia, and Brazil, in order to provide liquidity in the case of liquidity shortage of the dollar to finance bilateral trade. Some of such agreements include:

- January 2012 – currency swap agreement between China and UAE over 3 years, for the bilateral exchange of their currency in the value of ¥35 billion. The agreement should lead to significant growth of trade and investments between the two countries.
- February 2012 – currency swap agreement between China and Turkey in the amount of US$1.6 billion.
- March 2012 – currency swap agreement between China and Australia to exchange currencies between central banks worth up to 30 billion Australian dollars over a period of 3 years.
- June 2012 – currency swap agreement between China and Brazil, which allows central banks of the two countries to exchange currencies for values up to 60 billion Real or ¥190 billion. The amount can be used to strengthen reserves in times of crisis and to boost bilateral trade.
- March 2013 – China and Brazil signed a currency swap deal. The pact will allow their central banks to swap local currencies worth up to 190 billion yuan.
- July 2014 – China's central bank signed a bilateral currency swap agreement with the Swiss National Bank (SNB) worth 150 billion yuan or 21 billion Swiss francs.
- October 2015 – China increased the size of a bilateral local currency swap agreement with Britain to 350 billion yuan from the previous agreement of 200 billion yuan.

As of the end of May, 2015, China's central bank had signed 32 bilateral currency swap agreements with the central banks or monetary authorities of different countries and regions, reaching the total size of the agreements to about 3 trillion and 100 billion yuan. That substantially increased the effect of employing currency swaps. And, China had set up RMB clearing arrangements in 15 countries and regions, covering Southeast Asia, Western Europe, the Middle East, North America, South America, and Oceania.

In addition, in early 2012, many oil-producing countries decided to carry out transactions in other currencies, which make the US dollar to lose in some of its international domination (Mohaddes and Pesaran 2016).

Since June 1, 2012, China and Japan use only the yen and yuan (Renminbi) in bilateral trade at an exchange rate parity of 7.9480 yuan for 100 yen to stimulate trade cooperation, reducing currency risk and transaction costs. China is the largest trading partner of Japan with trade flows representing US$360 billion in 2011 and over 60% of trade transactions between the two countries until mid-2012 being denominated in the US dollar. The reason for not using Chinese currency in trade with most important trading partners is the presence of capital control, reflecting lack of liquidity in Chinese financial market (Jiang et al. 2017).

However, the yuan (Renminbi) is still far from being an international currency. The year 2020 is the target date that Chinese authorities have set it for currency internationalization. According to the IMF (IMF 2011), this is the date predicted for China to exceed the United States in the economic dimension.

In the literature there are different views about the prospect for the Chinese currency to attain international currency status, which is seen to happen in the short term (Subramanian et al. 2015) or medium to long term (Dobson and Masson 2009).

A number of other measures are required in order for the yuan (Renminbi) to be fully internationalized:

- Promote commodity prices in yuan/Renminbi.
- Eliminate restrictions on capital movements, which must be preceded by the financial deregulation and liberalization of interest rate, to provide the Chinese currency convertibility.
- Increase the flexibility of the exchange rate.
- Enhance the central bank's independence.

Although China benefited greatly from capital controls during both the Asian financial crisis of the 1990s and the global crisis of the late 2000s, which allowed China to protect itself from external shocks, the 12th Five-Year Plan of China (2011–2015) still targeted to liberalize its capital account (Ying 2016). In June 2012, China announced the creation of a special business zone in the city of Shenzhen, a pilot area where the convertibility of the yuan (Renminbi) has been tested, planning on transforming the area into a financial center by 2020. For how the Chinese financial market remains underdeveloped, please see (Huang et al. 2017).

The introduction of the euro has somewhat changed international monetary system configuration, causing a slight decrease in the US dollar's position. Given the growth of China as a world economic power, it remains to see how such growth of China will reshape the international monetary system and what role the yuan (Renminbi) will play.

Theoretically, the development of Chinese dollar will contribute a lot to solving a series of problems confronting Asia, such as removing exchange rate uncertainty, reducing the cost of currency exchange, and so on. And in practice, the success of the euro has provided a good example. So to successfully internationalize the Chinese currency, the following barriers must be overcome:

1. Enhance the mobility factor within Asia. Regional economic integration is an important premise for the construction of the optimal currency area, among which the factor mobility is the most important. Compared with the euro area, the level of economic integration in Asia is much lower, even though the situation is gradually improving.

   (a) The disparity in economic developments among Asian countries is getting smaller.

   According to World Bank statistics, in 2013 Japan's national income per capita was US$38,491, while China's was US$6747 and India's US$1504.

The coefficient of variance of the national income per capita of the three countries is 1.8, comparing with that of 2.1 in 2008. With the rapid development of economy in both China and India recently, the variance has been getting smaller. That means that adopting a same currency within Asia has become more feasible. However, in 2013 German's national income per head was US$44,999 and France's US$42,999. Hence, the degree of economic integration, as well as economy development, in Asia is far behind that in the euro area.

(b) The mobility factor within Asia is becoming stronger.

Due to the tradition in most regions of Asia, cross-border employment, marriage, and family migration happen much less than that in Europe. That somewhat reduces the mobility factor. But with the development of economy and open policies in Asia in recent years, cross-border travel and study have become more common. That has greatly improved the regional mobility factor, especially the mobility of the capital and labor forces. Therefore, the traditional factors, as mentioned above, can no longer hinder the emergence of Chinese dollar anymore.

2. Reduce the international objective and policy intention gaps among major Asian countries.

   Policy is also an important factor. The common international objective and policy intention made great contribution to the success of the euro. That indicates that the policy gap between Asian countries has to be shrunk in order to successfully issue a common currency for the Asian region. China and India have always been in good relationship, while in modern times there appeared some confrontations between China and Japan, although historically these two countries were quite friendly to each other. Under such circumstances, it is possible to realize the common goals of the Asian countries through joint efforts of all the parties involved.
3. Stabilize the comprehensive national strength of Asian countries.

   It is very important to the issuance of a common currency that every participant has its accurate position in the common currency area. In Asia, China and India, as well as Japan, play the leading role in both economy and policy just like that played by German and France in the Eurozone area. So, the comprehensive national strength of these countries has to be stabilized in order to provide the Chinese dollar a better environment to circulate in.
4. Weaken the difference in the scales of Asian countries.

   Unlike European states, Asian countries have a great difference in their scales. That obstructs the development of a common currency area. So, there is a need to reduce the economy gap and to adopt an open policy for the purpose of reducing the inhibitory effects brought forward by the difference of scales.
5. Shorten the geographical and cultural distances.

   Nowadays, geographical distance can no longer hinder the circulation of currency. Aircrafts, ships, and railways have conveniently joined Asian countries together. It only takes 3 h at most to travel from Shanghai or Beijing to other main cities in Asia, such as Tokyo, Soul, New Delhi, and others, while it takes no more than 1 day of travel by ships. Moreover, large quantities of international railroad lines are being built, such as the lines from Kunming to Bangkok, Vientiane, and Yangon. As for cultural distance, many Asian countries do have a lot in common both traditionally and linguistically. That brings great convenience to the development of Chinese dollar.

23.3 Offshore Financial Centers of Renminbi

Financial services belong to the tertiary sector and facilitate the transfer of monetary assets. In the current global economy, banks, stock brokerages, investment funds together with credit card, insurance, and consumer financial companies are the main providers of financial services (Wojcik 2009). In our modern time, finance has become a booming industry, fueled by an explosive combination of economic growth, globalization, advancement of technology, and mushrooming innovation.

Financial services usually cluster in cities or financial centers (Tschoegl 2009). Measured by the geographic scope of services offered, financial centers can be classified as national, regional, or international. A national center, such as Athens and Jakarta, acts as the main area for financial services within a single country (Poon 2009). Regional centers, such as Frankfurt and Toronto, conduct a large proportion of cross-border transactions among countries in a region (Tsuyuguchi and Wooldridge 2008). International financial centers (IFCs), such as London and New York, participate in cross-border asset trade on a global level. Historically, an international financial center with a truly global reach develops in a large, stable economy where the national currency is an international reserve currency widely used in global invoicing and settlement (Krugman 1988). In the seventeenth century, Dutch guilder was accepted worldwide, and Amsterdam was the top IFC in the world. In the nineteenth century, however, the British pound sterling replaced Dutch guilder as an international currency when London became the world's most important financial center. And when the British pound was gradually replaced by the US dollar as a world reserve currency, New York City emerged as the paramount international financial center since the early twentieth century (Chen and Chen 2015). All these international financial centers grew and their currencies strengthened when their national economies took a predominant role in the world. Therefore, it is argued that the competitiveness of an international financial center lies in the size and power of the domestic market (Chen and Chen 2015).

In the modern economy, IFCs often have a large share of foreign exchange markets and are usually home to world famous banks and/or a stock exchange (Jun et al. 2003). For instance, New York City hosts the New York Stock Exchange as well as world-leading banks, such as Goldman Sacks, JP Morgan, and Citigroup. Similarly, London hosts the London Stock Exchange as well as world-leading banks, such as HSBC, Standard Chartered, and Barclays. The growing power of these IFCs may penetrate the national space of capital to reshape international political and economic relations.

Localization of these financial institutions produces a strong agglomeration effect. Given the fact that today's complicated global economic network relies on exhaustive division of labor, spatial agglomeration of financial services reduces firms' transaction costs for gathering and interpreting information (Storper and Scott 1995). And, an economy of this nature facilitates technology spillover and innovation in financial services (Fosfuri and Rønde 2004).

Aside from a localization economy, an urbanization economy serves as an important factor in the formation of IFCs as well. First of all, large cities enable financial services to take advantage of economies of scale in terms of information and communication industries so that financial intermediation can be provided to large volumes of trade at a low cost. World City and Global City theories also offer explanations for the formation of IFCs (Sassen 2015). Both theories argue that by hosting multinational corporation (MNC) headquarters, large cities have control and management power in the international economy and in international politics. In a complicated global market, MNC headquarters rely extensively on advanced producer services in a volatile world economy, including financial services (Zhu 2002; Sassen 2015). Due to the complexity of these businesses, only a small number of large cities are capable of providing services that are sophisticated enough to allow an MNC's headquarter to operate globally. Such cities are most likely to grow into IFCs that provide cross-border transactions on a global level.

In conjunction with the effect of an agglomeration economy, path dependence offers an important explanation for the continued growth of financial centers (Chen and Chen 2015). According to the concept of path dependence, whether accumulation is derived from increasing returns to scale, the benefits of tacit knowledge, or information externalities, the pathways to accumulation can be reinforced and taken into the future (Meyer 2009). A financial center gains initial advantages by attracting commercial and investment banks and/or a capital market. Such an initial advantage produces a positive spillover effect over time, including the accumulation of capital flows, specific knowledge and expertise, skilled financial professionals, and access to information and markets. In the long run, these advantages may become self-reinforcing so that they continue to exist and function well into the future. As a result, a financial center may keep growing and become more competitive.

However, path dependence may be interrupted when conditions that favor the growth of IFCs disappear and new cities replace existing ones. For example, New York City replaced Philadelphia as the primary financial center in the United States due to the former's concentration of investment banks and the dominance of the US stock market located in New York City. Similarly, Sydney gained on Melbourne, Toronto surpassed Montreal, and Sao Paulo overtook Rio de Janeiro (Sassen 2015). Given the global nature of the contemporary economy and the advanced, widely available telecommunication technology, some scholars argue that some financial centers will thrive at the expense of others and that predominantly national financial centers of the present will be replaced by just a handful of IFCs (Chen and Chen 2015).

One important way for new financial centers to become more competitive is through institutional support (Lee et al. 2016). Generally, a business-friendly environment is viewed as essential for a financial center to grow: a legal system that protects the rights of investors and creditors is important to the development of capital markets. Financial deregulation and low taxes are also often cited as factors that attract financial businesses (Mitchell 2006).

Economic systems are shaped by institutional forces so that they vary from one form to other. In the United Kingdom and the United States, for example, free entrepreneurship is a fundamental way in which innovation arises in business activities in the market economy, despite government regulations on the market or policies to foster certain industries (Chen and Chen 2015). In contrast, some transitional economies are characterized by state-directed capitalism or state capitalism, where the state acts as the dominant economic player with enormous power to allocate and mobilize resources, credit, and investment and where government intervenes in the economy for the benefit of large-scale, state-owned enterprises (Xu and Su 2016). Such a state capitalist system exerts paramount influence on the spatial configuration of national financial centers. For example, Singapore represents a state-directed capitalism, where the city grew rapidly in terms of its financial sector and became a competitive IFC in a relatively short period of time, all with strong government support designed to attract international financial firms. In addition to providing a business-friendly environment, including such factors as tax breaks and trust laws for the financial industry, Singapore's government began its own special government school to train private bankers and helped to develop the asset management industry and foreign exchange market, all of which have made the city appealing for wealth management firms worldwide (Li and Kwok 2009). To some extent, Singapore's approach is the antithesis of laissez-faire, but the state-directed IFC growth has been very successful.

To summarize what has been discussed above, a strong domestic market, a localization economy driven by a concentration of financial institutions, an urbanization economy characterized by high-end service demand from MNC headquarters, path dependence, and institutional forces are all possible reasons for a rising international financial center. Given the growing influence of emerging markets, such as that of China, the question is how institutional powers interact with each other and with markets and geographical and historical forces in the formation of IFCs.

23.3.1 Debates on Emerging Financial Centers in China

China's economy took off in the late 1970s with the opening-up policies. The country's GDP rose to second place worldwide at around 2010. A large domestic market, a huge impact on the global commodity market, and significant foreign direct investment flows all demand an efficient financial industry, causing domestic financial centers to grow. However, compared to developed countries and some emerging economies, the modern financial industry in China has made a late start. It was not until the mid-1980s that China began to slowly reform its financial industry by commercializing banks, introducing insurance businesses, and opening equity markets (Liu et al. 2013). Accompanying these steady reforms, the nation has been slowly opening up financial markets since the mid-1990s, accelerating the pace after joining the World Trade Organization (WTO) in 2001 (Ying 2016).

However, the country's banking market is not fully liberalized yet. Once plagued by large nonperforming loans, major Chinese banks received tremendous financial and managerial help from the central government on their balance sheets after the Asian financial crisis of the late 1900s. In fact, China's banks transformed from almost insolvent institutions into profitable companies in the following decade (Clemens 1999). In contrast, international banks face stringent regulations in their business operations and have only a limited influence on China's financial industry. By 2012, foreign financial institutions accounted for less than 2% of the assets in China, the lowest share among major emerging markets, lower even than those in the Brazilian and Indian markets. Under China's currently incomplete market system, four large state-owned banks dominate the nation's highly regulated financial system (Yee 2012; Liu et al. 2014).

Against such a background, financial centers in mainland China gradually opened up and took shape. The current debate is mainly centered at comparing Shanghai and Beijing to determine which will achieve IFC status (Chen and Chen 2015). Overall, it is argued that Shanghai's prosperity is driven by market-related forces and favorable policy support from the Chinese government in the context of a rising national economy in the global market. Studies that emphasize Shanghai's primacy stress the importance of urban economy, capital markets, international reach, and path dependency. In comparison, Beijing amassed tremendous fiscal power during the era of the planned economy, which was subsequently strengthened by several waves of reforms in the domestic banking and insurance industries from the 1990s onward. Some scholars argue that the financial industry in China is characterized by asymmetric information and that Beijing as the information heartland is more attractive than other cities as a host for multinational corporation headquarters, an essential element of a world city, and thus best placed to become an IFC. Similarly, it is argued that Beijing surpasses Shanghai as a national financial center in terms of the strength of the former's financial industry and power in financial decision-making, as well as in other competitiveness factors such as urban infrastructure and human resources (Chen and Chen 2015).

The less high-profile city of Shenzhen, a major city in South China located north of Hong Kong, is a new contestant. Although most studies on Chinese IFCs do not consider this city to be more competitive than either Shanghai or Beijing, in The Global Financial Centers Index of 2014, Shenzhen is given a higher world ranking than either of the other two Chinese cities under discussion here. The city's rise as a financial power can be attributed to its proximity to Hong Kong (China's offshore IFC), its institutional support, and its vibrant economy.

23.3.2 Beijing, Shanghai, and Shenzhen in the Global Arena

There is no consensus on how financial centers should be measured such that scholars have ranked the world's financial centers according to various protocols. Some studies have utilized banking or capital market as measurements and subjected cities to statistical analyses based on these measures (Poon 2009). Others have evaluated financial centers based on interviews and perceptional factors (Li and Kwok 2009). Each method and the associated dataset have strengths and weaknesses and, therefore, the results have varied significantly. In quantitative analyses, when banking activities are used, the role of the equity market is often neglected, and vice versa. In qualitative studies, particularly those based on surveys, results may be biased, depending on the sampling strategy, the sample size, the geography of the survey participants, and the extent and nature of the participants' knowledge of financial centers.

In this chapter, Forbes Global 2000, a list of the world's leading public companies published annually by Forbes magazine since 2003, is relied on. The Global 2000 list measures firms according to four scales: assets, market value, profits, and sales. Most of the firms included in the list are MNCs. Information about all the financial firms on the Global 2000 list in the years 2005 and 2010 are collected. Three major types of firms are included: commercial banks, insurance companies, and all other diversified financial service companies. As compared to databases that present information on banking or equity markets, this database provides relatively comprehensive data on the entire financial industry. It is important to note that this database includes only the most competitive public financial institutions in the world; therefore, this chapter on financial centers does not take into account privately owned or small financial businesses. Despite this limitation, scholars of economics and finance have used the Global 2000 database in their studies (Taylor et al. 2009), as it offers comprehensive information on all financial sectors and is a good measure of a financial center's performance.

After collecting information on individual firms, the location of the firms' headquarters is determined from their websites and then compiled city-level data based on five performance measures: the total number of financial institutions with headquarters in the city and the four scales used in the Global 2000 list. Overall, Shanghai, Beijing, and Shenzhen were not among the world's top financial centers when considered in terms of the number of Global 2000 financial firms present in each city in either 2005 or 2010. However, all three cities improved their rankings on all five measures during this 5-year period. In particular, the gap between Beijing and the other top financial centers narrowed notably.

As of 2005, the majority of the 233 financial centers were located in Europe, East Asia, and the eastern United States. At the top of the list was Tokyo with 44 firms, followed by New York, London, Hong Kong, and Taipei, with 35, 19, 15, and 14 companies, respectively. Beijing had four firms, and Shenzhen had three, whereas Shanghai had only one firm listed. In terms of assets in the financial industry, Beijing's value was only 41% of Hong Kong's, and Shenzhen's was

87% of Beijing's, whereas Shanghai's value was 36% of Beijing's. In regard to market value, Beijing was worth less than a quarter of Hong Kong, Shenzhen was two-thirds of Beijing, and Shanghai was worth a mere one-seventh of Beijing. Regarding sales value, Beijing was close to Hong Kong, whereas Shenzhen's value was 60% that of Beijing with Shanghai lagging far behind. None of the financial industry in Beijing, Shanghai, or Shenzhen made a large profit in 2005.

In expanding from four to ten financial firms in 5 years, Beijing improved its ranking from 31st in 2005 to 10th in 2010. Shanghai increased the number of firms from three to four from 2005 to 2010 and therefore promoted its world ranking from 82nd to 31st. For the city of Shenzhen, its number of financial firms grew from three to four, moving its place from 35th to 31st. Thus, by 2010, all three cities have started to gain some status on the global map.

On other measures of performance in the financial industry, the gap between Beijing and the top IFCs narrowed considerably during this 5-year period. Even though the financial industry's assets and sale value in New York doubled those of Beijing, Beijing's market value and profit exceeded those of New York. Both Shanghai and Shenzhen improved on all these indicators over the 5 years. Although they remained behind Beijing in regard to the overall strength of the financial industry, these two cities reduced the gap with Beijing dramatically.

As expected, what is discovered here reflects only short-term changes from 2005 to 2010. The weakened performance of some leading IFCs in advanced economies may have been caused by the global financial crisis that spanned 2008 and 2009, when they suffered severely from downturns in stock markets and the subsequent economic recession. In contrast, the rise of Chinese cities in the global financial arena can be attributed to a relatively stable national economy and a consolidated banking system. With tremendous help from the central government on their balance sheets, the largest Chinese banks went public after 2005, and by 2011, the four largest state-owned commercial banks in China had made the top 20 list in the world (Chen and Chen 2015). This fact indicates that the state government is capable of consolidating its financial centers and improving their rankings in the world in turbulent times characterized by a global financial crisis, when cities in advanced economies suffer from recession.

The rise of China's financial centers is also accompanied by the growing Chinese economy and the growing power of the country's currency RMB. In 2009, the People's Bank of China, the country's central bank, tried to promote the global recognition of the RMB through currency swap lines with Asian and Latin American trading partners. In the same year, the governor of China's central bank challenged the US dollar's hegemony in global finance and called for the IMF to create a substitute for the dollar as the reserve currency in the world economy (Chen and Chen 2015). According to Chen and Chen (2015), the dollar's influence is waning in the emerging world, and the Chinese yuan is gaining global power. In East Asia, in particular, the US dollar has in the past played a dominant role. But RMB now plays a growing role in the Asia-Pacific region. Seven currencies in the region now follow the yuan more closely than the dollar. Outside East Asia, the influence of RMB is still limited. But with the internationalization of RMB, China's currency is expected to grow in stature as its economy and trading activity grow in size, and the rise of RMB suggests the continued growth of Chinese financial centers. In fact, some experts forecast that China's currency will surpass the dollar as a key currency around 2035 (Watts 2011).

Let us consider the strengths and weaknesses of Shanghai, Beijing, and Shenzhen as future IFCs.

This subsection offers an in-depth comparison of these three top cities by considering their strengths and weaknesses as candidates for acquiring IFC status. The hypothesis is that although the relative success of the three Chinese financial centers may appear to be driven by similar factors including agglomeration, a strong nation with incomplete marketization is the single dominant force in creating favorable conditions for financial centers. Such a hypothesis is a key to understanding and elaborating the development model of state capitalism in an emerging economy, wherein the state functions as the leading economic actor in a transitional market influenced by global forces.

To test this hypothesis, the cities were compared in regard to the following: the city's urban economy, the role of the nation in the city's local institutional environment, the city's command of and involvement in the global economy, and the city's path dependence. This focused comparison is based on data from multiple sources, namely, each city's yearly statistics from 2000 to 2010 together with other information from China Banking Regulatory Commission (CBRC), China Insurance Regulatory Commission (CIRC), China Securities Regulatory Commission (CSRC), the People's Bank of China Quarterly Bulletin, the Shanghai Stock Exchange Fact Book, and the World Federation of Exchanges.

First, let us look at Shanghai. In terms of its urban economy, Shanghai flourished as a center of commerce between east and west in the second half of the nineteenth century and became the predominant financial hub of the Asia-Pacific in the 1930s. However, during the planned economy era, the city's international influence declined sharply, and its path as a regional financial center was interrupted abruptly. In the 1990s, the city became prosperous once again and began attracting foreign investment. Unlike Beijing and Shenzhen, Shanghai has a large urban economy and is a center for manufacturing and commerce in mainland China. In 2010, Shanghai's GDP was US$256 billion surpassing Hong Kong (US$224 billion) and Singapore (US$222 billion). Shanghai's wealth is also attributed to an affluent hinterland composed of "star" cities such as Suzhou and Wuxi, which are well known for their high growth rate propelled by foreign direct investment (FDI) as well as privately owned manufacturing enterprises. In particular, FDI brings in international capital, new technology, and management experience, resulting in high productivity. In addition, foreign firms compete with local companies, which may also lead to greater efficiency and improved overall corporate governance standards, thereby catalyzing the area's economic growth and competition in the global market. Because of its history, locational advantages, and foreign investment, the established manufacturing base of the Yangzi-Delta area creates a strong domestic market from which Shanghai can rise as a dominant financial center in the region. For instance, the city concentrates 41 fund management firms that manage

45.3% of the funds nationwide in 2013, more than any other Chinese cities. Shanghai enjoys the most vibrant economy in the nation and is, therefore, a strong competitor in the global arena.

In terms of the role of the nation, Shanghai would not have become a financial center without policy support from the central government. In 1990, the state council declared the opening of Lujiazui District located in the eastern side of Shanghai as the first financial district of the nation. Financial firms in this district enjoy special tax policies, incentives, and support in regard to such matters as training personnel and expedited visa services. Based on these policies, domestic and foreign financial institutions have established branches in the area. In 2005, the State Council reaffirmed the positioning of the Lujiazui area as the only finance and trade zone among the 185 state-level development zones in mainland China, and the preferential policies have continued to draw financial firms. Given Shanghai's economic achievements and potential to grow further, the State Council passed a bill in 2009 that envisioned Shanghai becoming China's International Financial Center and Shipping Center by 2020. This bill demonstrates the central government's commitment of policy support for Shanghai and supports the city's image as a potential IFC. Four years later in 2013, an initiative called the Shanghai Free Trade Zone (SFTZ) was launched with the approval of the State Council. For this initiative, officials outlined six areas where industries including banking would be established over the next 3-year period. According to financial experts, the most significant advance that the SFTZ could bring is the "predictability of regulation," and there is hope that regulatory policies are being administered in a transparent and predictable fashion (Chen and Chen 2015).

Another policy-supported advantage that Shanghai enjoys is the development and growth of a stock exchange. In 1990, the Shanghai Stock Exchange (SSE) was established by the Chinese government. SSE provides a platform for companies to raise capital and enhance corporate governance and enables investors to mobilize savings and create investment opportunities for individuals. Gradually, Shanghai established diverse financial markets, including futures trading, a foreign currency exchange, and interbank lending. In 2002, the Chinese government allowed approved foreign institutional investors to invest in local Chinese stocks. In April 2014, Premier Li Keqiang expressed the Chinese government's support for mutual access between the stock markets of Shanghai and Hong Kong. Under this scheme, Hong Kong brokers have been able to place orders on the Shanghai Stock Exchange and Chinese brokers on the Hong Kong Stock Exchange on behalf of their clients (Chen and Chen 2015). The announced guidelines promise three new developments for international investors. First, international investors will have direct access to "eligible" individual stocks listed on the Shanghai Stock Exchange. Second, individual investors will have direct access to the SSE through their brokers in Hong Kong. Third, overseas investors will have greater access to China's domestic stocks than they did in 2014. These new policies are expected to provide a strong boost to the capital market in Shanghai.

In terms of the command of and involvement in the global economy, Shanghai has benefited from strong national policies that triggered a powerful localization effect, which attracted foreign financial firms. By 2013, 445 MNCs had established regional headquarters in Shanghai, far exceeding the number in Beijing, 142. These MNCs include world-renowned banks, such as Citibank, HSBC, and Standard Chartered, which may generate a snowball effect, whereby more foreign financial institutions are attracted to the city and strengthen the city's image as a potential IFC. These foreign banks have played an important role in introducing advanced management expertise, intensifying competition in the Chinese financial market, and promoting the improvement of efficiency and corporate governance of local banks. The involvement of foreign financial institutions improves the role of Shanghai as a major connecting gate between China and the rest of the financial world and as a regional command center with global reach. However, one of Shanghai's most significant disadvantages as a national financial center is the lack of regulatory power, dominant commercial banks, and major insurance companies in the nation. Although the second headquarter of the People's Bank of China is located in Shanghai, the city does not host the headquarters of any of the three regulatory bodies in banking, insurance, or securities, all of which are of paramount importance in regard to determining and implementing policies. Furthermore, of the top ten Chinese banks, only two are headquartered in Shanghai: the Bank of Communications and the Shanghai Pudong Development Bank. The former is ranked sixth nationwide, and the latter is tenth. Of the top ten insurance companies, Shanghai is home to only two: China Pacific Insurance and Taiping Life. In comparison, Beijing has six banks from the top ten list and five insurance companies that lead in the nation. Because Shanghai lacks powerful domestic financial institutions, it is undermined in terms of its drive to become a capital of capitals, a breeding ground to grow, train, and attract financial professionals, a center for financial renovation, and a magnet to generate localization economy. Further, because few domestic firms are headquartered in Shanghai, it also lags behind Beijing as a national command and control center. As of 2013, Shanghai hosted only 8 of the 87 Chinese firms that made the Fortune 500 list, compared to 48 in Beijing and 4 in Shenzhen. This is because most Chinese MNCs are state-owned enterprises (SOE), most of which are headquartered in the capital city of Beijing so that the party can easily manage them. These SOEs control a large portion of the national economy, particularly in strategic sectors, where no market competition is allowed. With the continued growth of China's economy, many SOEs have expanded globally in the past decade to advance the party's political aim of fostering national champions (Chen and Chen 2015). Without a large number of multinational corporation headquarters, Shanghai can hardly be considered a power center on a national scale and certainly not in global terms.

Second, let us look at Beijing. In terms of its urban economy, compared to Shanghai as a commerce and finance center, Beijing was a political and cultural center before it became the capital of China in 1949. Since then, the central government built the city's heavy industry as well as its public sectors. The economic reforms of the 1990s created an economic boom for Beijing with the influx of foreign capital and technology. At present, Beijing enjoys a large, vibrant, and growing urban economy, with GDP and per capita GDP comparable to those of

Shanghai. However, compared to Shanghai, Beijing has yet to develop an extensive economic hinterland with established manufacturing chains. Its longtime competitor, the nearby city of Tianjin, has recorded impressive GDP growth rates in recent years. Its other immediate neighbor, Hebei Province, is ranked 11th nationwide for per capita GDP in 2010. The city's northern neighbor, Neimenggu Province, is ranked 7th, whereas a neighboring province to the west, Shanxi, is ranked 21st. In comparison, Shanghai's two neighboring provinces Zhejiang and Jiangsu ranked 4th and 5th, respectively. This is an important reason that some MNCs chose to relocate their regional headquarters to Shanghai in the mid-1990s to tap into a more affluent and fully developed economic hinterland (Chen and Chen 2015).

In terms of the role of the nation, Beijing's rise as a national financial center is often attributed to its 1993 Master Plan, approved by the State Council. According to the plan, a so-called financial street in the center of the city was designed to host all regulatory agencies, including the central bank, the China Banking Regulatory Commission, the China Insurance Regulatory Commission, and the China Securities Regulatory Commission. Beijing also hosts the headquarters of some major national banks and non-banking enterprises. The development of the financial street has generated a strong localization economy. First of all, the spatial agglomeration of the central bank and government regulatory agencies serves as a financial policy center and information heartland (Chen and Chen 2015). Compared to the policies of advanced economies, financial policies are usually not transparent in China. Geographical proximity to an information center may be extremely important for financial institutions to swiftly access information and make interpretations correctly. In fact, the financial street attracted some world-renowned banks, such as Goldman Sacks, JP Morgan, and UBS, which set up regional offices there. In addition, in the early twenty-first century, some insurance companies moved their headquarters from Guangzhou to Beijing in order to foster communication with the CIRC (Chen and Chen 2015). The relocation choice of these businesses indicates Beijing's appeal as an information center. Also, by hosting major national banks and insurance companies, the financial street has become the national center of financial payment and settlement and financial talent. Around 2010, 90% of China's credit and loans and 65% of its insurance funds were concentrated in the financial street. In fact, Beijing holds the predominant power in terms of financial investment decisions. All these factors create a strong localization effect in terms of the financial talent pool, technology spillover, innovation, and lowered transaction costs.

A second policy that has contributed to the growth of Beijing as a financial center is the establishment of a central business district (CBD), located in Chaoyang in the eastern side of the city. In the 1993 Master Plan, the city government of Beijing conceived a strategic plan to build a central business district to promote finance, information, commerce, and culture industries in Beijing. In 2001, the Beijing CBD Administrative Committee was established to plan, build, and manage the district. The committee is also responsible for providing information on laws, taxes, and government policies as well as a one-stop service to simplify approval procedures. In 2011, the CBD hosted regional headquarters of 50 MNCs and secured investment from 160 Fortune 500 businesses. It is also drawing many international financial institutions from South Korea, Germany, Italy, and the United States. In addition, it appeals to overseas stock exchanges, such that NASDAQ, the New York Stock Exchange, and the Tokyo Stock Exchange, to establish offices in the district. In 2014, the city of Beijing hosts a total of 48 regional headquarters of Fortune 500 companies, far exceeding Shanghai with only four.

A third policy decision that may be responsible for fostering Beijing's financial industry is the city's announcements made in the years of 2008 and 2009 that it intends to become a "world financial center" and a "world city". To achieve these goals, Beijing has been strengthening its finance and commerce industries, improving its urban infrastructure, attracting international firms and organizations' headquarters, and strengthening its research and development capabilities. By clustering world-level technology and human resources, Beijing aims to be a competitive city like London and New York City. In a short period of time, all these institutional measures and policies have produced a strong agglomeration effect that supports the growth of the financial industry in Beijing.

Although China's central government does not have an explicit policy of ensuring that Beijing becomes an IFC, the nation is very involved in helping Beijing become more competitive in this regard. The financial industry has brought many benefits to the city, such as tax and human capital, such that this industry is one of the most important. The industry has also served to increase the city's global influence. In light of the rapid growth of the financial street and the ensuing financial rewards accruing to the city, the local government of Beijing proposed an official plan in 2008 to develop the city as a financial center with international influence (Zhang and Zhao 2009). Given Beijing's financial resources, this plan may attract more domestic and foreign financial institutions, thereby presenting a strong challenge to Shanghai. Even so, Beijing's bid to become an IFC is hampered by its lack of a stock market. All IFCs worldwide host a stock exchange market as a powerful and efficient tool for capital formation and as an indicator of the country's economic strength and development. Recent Western history shows a growing public interest in investing in the stock market and shows funds flowing directly to the financial markets instead of through traditional bank lending and deposit operations. Overall, financial markets are becoming more important for capital accumulation and economic growth. Correspondingly, the lack of a financial market is a major disadvantage for any city with hopes of becoming an IFC.

In terms of the command of and involvement in the global economy, as the capital city of China, Beijing hosts major state-owned enterprise (SOE) headquarters and holds prevailing political and economic control and command power at the national scale. For instance, all three national telecommunication companies are headquartered along the financial street. Expanded to the city level, in 2013, of the 87 companies in mainland China that made the Fortune 500 list, 48 were headquartered in Beijing. Most of these companies are SOEs that control essential resources and infrastructure, such as Sinopec, China Telecommunications, State Grid, and China National Offshore Oil. Despite three decades of privatization and restructuring since the economic reforms of the late 1970s, SOEs still exert major control over the nation's economy, accounting for more than 40% of China's nonagricultural GDP at around 2010. The dominant controlling power of the SOEs is attributed to a favorable business environment created by the national government. When compared to private sector companies, SOEs and their subsidiaries enjoy preferred access to bank capital, below-market interest rates on loans from state-owned banks, favorable tax treatment, and large capital injections from the national government when needed (Chen and Chen 2015).

Not only do SOEs have the paramount economic power at home, they are also becoming more influential in the global market. Advanced by China's "Going Out" policy and fueled by massive foreign exchange reserves, large-scale SOEs have invested overseas in the past decade, especially in infrastructure, natural resources, and the energy industry (Chen and Chen 2015). Therefore, SOEs are strengthened both at home and abroad through support from the central government, which, in turn, enforces Beijing's role as a domestic and potential international control and command center. However, Beijing is also at a disadvantage due to the potential weaknesses of the SOEs.

First, even though the four large state-owned banks receive significant assistance from the central government on their balance sheets and have also greatly improved their performance, nonperforming loans remain a problem and impair bank earnings (Chen and Chen 2015). Although these problems were not revealed to the general public, low accounting/auditing standards mean that such banks cannot be competitive if China abandons its closed financial system and opens the banking sector in the long run. Second, although China's SOEs are gaining a larger share of the global market, they are much less profitable than their international competitors (Zhang 2014). Unless the SOEs improve their management system and allocate resources more efficiently, they cannot develop into world-class enterprises with major control and command power in the global arena. However, it is uncertain whether the SOEs can achieve such goals without sustained government policy support. Third, these SOEs lack the ability to innovate. Their success so far has relied on their state-controlled monopoly status and associated national policy support. Almost none of them have core products or internationally renowned brands, a reflection of insufficient research and development capabilities. The SOEs need to make higher-quality products with higher margins and offer services to complement them. The lack of innovative ability may make them vulnerable in the international market, and even in the domestic market, if the monopoly is broken and the nation no longer provides preferential treatment. Therefore, the continued growth of SOEs is maintained by the incomplete marketization under the current growth model of state capitalism. As (Clemens 1999) cautioned, if China fully opens its financial market, revokes support for its four largest banks, and eliminates favorable policies for SOEs, the financial sector in Beijing may no longer be competitive.

Third, let us look at Shenzhen. In terms of its urban economy, when compared to its two northern rivals, Shenzhen has a smaller economy but higher productivity on a per capita basis. Located on the south coast of China, the city was a fishing town until the late 1970s. It became globally engaged when in 1980 the central government designated it the first special economic zone (SEZ) that could accept foreign investment. Unlike Shanghai, Shenzhen is a relatively young city and has not developed an economic hinterland. Similar to Shanghai, though, Shenzhen does not have strong political power in the nation, such as that enjoyed by Beijing. Instead, Shenzhen has mainly benefited from its geographical proximity to Hong Kong, and the city's links with Hong Kong provide a foundation for Shenzhen to specialize in manufacturing and finance.

In terms of the role of the nation, with national support Shenzhen has succeeded in developing some financial markets. In 1990, the Shenzhen Stock Exchange was established by the state council. From the year 2000 to 2004, Shenzhen Stock Exchange suspended listing new firms in preparation for a new board for high-tech start-ups. This severely undermined the stock exchange's ability to attract capital. Compared to the Shanghai Stock Exchange, which mainly lists large-cap companies, the Shenzhen Stock Exchange focuses on small- and mid-cap enterprises. The Shenzhen Stock Exchange opened the ChiNext board, a NASDAQ-type exchange for high-growth and high-tech start-ups in 2009. These have provided some platforms for technology innovation and firm growth. A more aggressive and ambitious step was proposed by the local government and subsequently approved by the central authority. In 2010, the state council approved the master plan for Qianhai Bay, a 15-square-kilometer zone on the city's west coast. The most significant feature of Qianhai is the proposed specialized laws and regulations on industrial policies, tax policies, and public administration that are close to international standards. Also, by charging a low corporate profit tax and not levying income taxes on finance professionals, lawyers, accountants, and creative people, it aims to attract modern service industries and talent. One of the city's central aims is to attract some of the offshore yuan that have pooled outside mainland China's borders. In Qianhai, the government will assist firms in their efforts to raise yuan offshore, and Hong Kong banks will be allowed to enter the zone more easily compared to the current situation. There will be greater cross-border lending, and Qianhai may become a pioneer in terms of the yuan's full convertibility. Based on these special policies, some major banking institutions have signed cooperation agreements with the new Qianhai Zone, which strengthens Shenzhen's position as a potential IFC (Zacharias and Tang 2010). It is highly likely that the creation of the Qianhai Zone will generate a strong localization effect.

In terms of the command of and involvement in the global economy, Shenzhen has only four major firms that made the Fortune 500 list in 2013, such that the city lags far behind Beijing and Shanghai, which have 48 and eight, respectively. Among the four Fortune 500 firms in Shenzhen is Huawei, a privately owned company that manufactures networking and telecommunication equipment. Although the founder of this company benefited from connections with the military, Huawei has a strong focus on research and development. Founded approximately 30 years ago, it is highly professional and impressively innovative, resembling a Western-style high-tech firm more than a typical Chinese SOE. After succeeding in the domestic market, Huawei expanded into Latin America, Africa, and Eastern

Europe (Deng 2012). In 2012, it overtook Ericsson and became the largest networking and telecommunication equipment maker in the world. Huawei can be considered one of the world's most influential and innovative companies. For the city of Shenzhen, Huawei's impact exceeds its monetary value. The company attracts bright young people, acts as a model for private enterprises, enriches the entrepreneurial environment, and attracts investment in information technology.

In regard to domestic banking institutions, Shenzhen falls behind Beijing and Shanghai. Of the top ten banks in China, Shenzhen hosts only China Merchants Bank (CMB), the first shareholding commercial bank wholly owned by legal corporate entities in China. Despite its relatively small size, CMB provides much better services in many areas than state-owned banks. For instance, based on its early introduction of a one-card-for-all debit card, CMB has attracted a large share of high-quality customers and established a strong reputation. It now leads the country in terms of credit card loans and other private banking businesses. This in turn may further increase CMB's competitiveness in retail banking.

In regard to insurance companies, Shenzhen is home to Ping An of China and Sino Life, two of China's top firms in this area. On this measure, Shenzhen is similar to Shanghai, which also hosts two top insurance companies, but falls behind Beijing, which has five. There is no doubt that Shenzhen's path to global engagement began with dependence on centrally directed resource allocations and a commitment to investment zones by national policy makers. However, Shenzhen has two major disadvantages. First, it is the lack of a large domestic market that strongly militates against Shenzhen's bid to become a national financial center. The city also lacks an affluent hinterland for developed manufacturing chains. Second, its proximity to Hong Kong may limit its growth. Although Shenzhen has benefited tremendously from its geographical proximity to Hong Kong, its potential IFC status is also overshadowed by this proximity. Given Hong Kong's international status, it is unlikely that Shenzhen will take over or even seriously challenge Hong Kong's role in the global financial industry.

One common point that all these three cities share is that they all have benefited from the central government's policy support in their progress toward becoming financial centers. Shanghai benefited from the nation's decision to establish a financial district with favorable policies and to establish financial markets. Beijing benefited from the nation's approval of the city's master plan to build a financial street and a central business district to attract major banking institutions, regulatory agencies, and SOE headquarters. The city's aspiration to become a world city also helps to grow its financial industry. Shenzhen benefited from the nation's decision to set up special economic zones as an experimental market economy. For all three cities, national policies have produced a strong localization economy for the financial industry.

However, each city has distinct strengths and weaknesses. Shanghai's advantages come from a strong local and hinterland economy, growing financial markets that are expecting continued reform and development, an established reputation as a financial center, and involvement in the global financial market. Its disadvantages include a lack of financial policy decision-making agencies, powerful domestic commercial banks, and domestic MNCs, which may prevent the city from becoming a control and command center and thus from becoming dominant as a financial capital. In contrast, Beijing's advantage lies in the fact that the city hosts the central bank and all regulatory commissions in banking, insurance, and securities industries, locates major commercial banks and insurance companies' headquarters, and concentrates the largest number of domestic MNC headquarters that are influential both at home and overseas. Therefore, Beijing is a national or even international power center. The city's disadvantage is related to the lack of a major financial market, the relatively weak performance and competitiveness of state-owned banks and non-banking enterprises, and a lower level of involvement in the global market as it hosts fewer foreign MNC regional headquarters than Shanghai. Regarding the southern rival Shenzhen, the city's main strength arises from its proximity to Hong Kong. Shenzhen enjoys the highest level of productivity when measured by per capita GDP among the three cities and has developed a competitive information technology industry that attracts talent and strengthens the city's position on a global scale. However, the city itself lacks both a large hinterland market and domestic or foreign MNC headquarters. Its geographical proximity to Hong Kong may also serve to prevent Shenzhen from achieving IFC status.

Overall, the outcomes of the competition among the three cities may well be shaped by the vicissitudes of national government policies and the power play between local and central governments. Indeed, it is no surprise that all three cities have strong connections with the central government. If the Chinese national government continues the current development model of state capitalism, Beijing's advantages as a growing financial center may continue. However, if China fully opens its financial market and removes favorable policy support for SOEs, the financial sector in Beijing may become less competitive, and Shanghai and Shenzhen may seize more power in the national financial sector. The race between Shanghai and Shenzhen may hinge on the institutional support and market freedom in the former's Free Trade Zone and latter's Qianhai Zone. Further, the dynamic contour map of China's future IFCs offers a chance to generate hypotheses on the development of IFCs in emerging economies. Whereas previous studies on global financial institutions have focused on the role of market forces and business environment in the growth of IFCs, the role of institutional forces under different economic systems and growth models is rarely discussed. In this chapter, it is found that although the factors, including agglomeration, evident in financial cities in an emerging market are similar to those evident in advanced economies, the Chinese central and local governments, in this case, appear to be the single dominant factor responsible for creating a localization economy and favorable conditions for the growth of financial centers. This observation may be the key to understanding the rise of financial centers in some emerging markets during a global economic undercurrent.

23.3.3 In Summary

In this section, the focus is on comparing the potential of three mainland Chinese cities, Shanghai, Beijing, and Shenzhen, as international financial centers. Data from the Global 2000 financial firms show that all three cities, Beijing, Shanghai, and Shenzhen, improved their performance from 2005 to 2010 and that Beijing leads the other two cities in both years. Then a detailed comparison indicated that Shanghai's major advantages include a diverse financial market and a strong appeal to overseas financial institutes, driven by the nation's policy support. On the other hand, Shanghai's major disadvantage lies in its lack of control power in the national economy. In contrast, Beijing's major advantage is its command and control power in the domestic and even global market, through a large concentration of state-owned enterprises. Such an advantage is deeply rooted in China's current development model of state capitalism. In comparison, Shenzhen has considerably less economic power than the other two cities do. But, it has benefited tremendously from national policies and its geographic proximity to Hong Kong.

Overall, all these three Chinese cities have strengthened their financial industries through institutional support, and the future power of the three leading cities may depend on the Chinese government's policies. If the national government continues the current model of state-directed capitalism, Beijing's advantages as a potential IFC may continue. Instead, if China fully opens its financial market and removes its policy support for SOEs, the financial sector in Shanghai and Shenzhen may seize more power in the national financial sector. Then the race between Shanghai and Shenzhen may hinge on the institutional support and market freedom in the former's Free Trade Zone and the latter's Qianhai Zone. This chapter provides some important insights into the interplay between institutional forces and globalization in a transitional economy in general and China in particular. Although the global economy and market openness are considered some of the most important factors underlying IFC status, in an emerging economic powerhouse like China, the nation is capable of empowering the country's financial centers in the world arena by consolidating its banking systems. The nation is also capable of strengthening a city's competitiveness as a national or global control and command center by strengthening SOEs through favorable policies. Additionally, the government demonstrated its commitment to creating strong agglomeration effects by providing space, physical structure, and resources to nurture financial industries in at least some of its cities. Therefore, in appearance, China's leading financial cities have presented a pattern of agglomeration that is similar to those of financial centers in market economies, while more fundamentally, a strong nation under incomplete marketization conditions plays a dominant role in promoting the development of China's cities into potential IFCs. Such a finding is a key in understanding the interplay between state capitalism and global forces in the emerging market, where the state can function as the leading economic actor in the global market. This end offers an important first step toward a theory capable of describing the growth of IFCs in a state capitalist system.

23.4 The Pace of Regionalizing Renminbi

As Asian countries are currently standing at a historic juncture, embracing both opportunities and challenges, Chinese President Xi Jinping's keynote speech at the Boao Forum for Asia on March 29, 2015, offered an enthralling vision for the region's new future and potential means to achieve it. That actually is a semaphore of the regional strategy for the emerging Chinese dollar.

"The vision and actions on jointly building the Silk Road Economic Belt and the twenty-first-Century Maritime Silk Road" (One Belt and One Road), an initiative raised by Chinese President Xi Jinping during visits to Central Asia and Southeast Asia in 2013, were issued by China's top economic planner, the National Development and Reform Commission and ministries of foreign affairs and commerce on March 28, 2015, with the State Council's authorization.

"One Belt and One Road" will be the economic corridor of the longest span in the world with a great potential for economic cooperation in the world. It will begin from China, linking Central Asia, Southeast Asia, South Asia, West Asia, and parts of Europe; it connects in the east to Asia-Pacific economic circle and west to European economic circle, covering a population of approximately 4.4 billion people and economic aggregate of approximately US$21 trillion, accounting for 63% and 29%, respectively, of the world population and economic aggregate. In 2014, President Xi Jinping pointed out at the 60th anniversary conference of the Five Principles of Peaceful Coexistence that China had proposed several important cooperation initiatives:

- The silk road economic belt
- The twenty-first-century maritime silk road
- The Bangladesh-China-India-Myanmar economic corridor
- The China-ASEAN community of common destiny

And China would seize the opportunity presented by these initiatives to launch a new round of all-inclusive opening-up, in order to build an open economic system and create new opportunities and spaces for the development of Asia and the world. (Xi Jinping 2014) states that "'one belt and one road' will constitute a new round of 'one body two wings' opening to the outside world, accelerating the pace of westward opening while at the same time improving the level of eastern opening, to promote the inland border areas to march forward from the edge of opening to the outside world to the frontier." The construction of "One Belt and One Road" would contribute to an overall utilization of two markets and two kinds of resources both home and abroad in the western area, forming the external economic corridor through the east and west while linking the south and the north, to further combine activities of development, opening-up, innovation, and creation (Gao 2014).

Through the construction of "One Belt and One Road," the development of China will be connected with the development of countries around China, and the Chinese dream of living better lives can be connected with the dreams of people in these countries, thus making these countries benefit from the development of China.

This section mainly focuses on how to promote the construction of "One Belt and One Road" with financial instruments and promote harmonious coexistence, common development, and simultaneous prosperity among countries of different races, different faiths, and different cultural traditions in the new regional normal. For further details, see (Ying 2016).

23.4.1 Preface

More than two millennia ago, the diligent and courageous people of Eurasia explored and opened up several routes of trade and cultural exchanges that linked the major civilizations of Asia, Europe, and Africa, collectively called the Silk Road by later generations. For thousands of years, the Silk Road Spirit – "peace and cooperation, openness and inclusiveness, mutual learning and mutual benefit" – has been passed from generation to generation, promoted the progress of human civilization, and contributed greatly to the prosperity and development of the countries along the Silk Road. Symbolizing communication and cooperation between the East and the West, the Silk Road Spirit is a historic and cultural heritage shared by all countries around the world.

In the twenty-first century, a new era marked by the theme of peace, development, cooperation, and mutual benefit, it is all more important for us to carry on the Silk Road Spirit in face of the weak recovery of the global economy and complex international and regional situations.

When Chinese President Xi Jinping visited Central Asia and Southeast Asia in September and October of 2013, he raised the initiative of jointly building the Silk Road Economic Belt and the 21st Century Maritime Silk Road (hereinafter referred to as the Belt and Road), which have attracted close attention from all over the world. At the China-ASEAN Expo in 2013, Chinese Premier Li Keqiang emphasized the need to build the Maritime Silk Road oriented toward ASEAN and to create strategic propellers for hinterland development. Accelerating the building of the Belt and Road can help promote the economic prosperity of the countries along the Belt and Road and regional economic cooperation, strengthen exchanges and mutual learning between different civilizations, and promote world peace and development. It is a great undertaking that will benefit people around the world.

The Belt and Road Initiative is a systemic project, which should be jointly built through consultation to meet the interests of all, and efforts should be made to integrate the development strategies of the countries along the Belt and Road. The Chinese government has drafted and published the Vision and Actions on Jointly Building Silk Road Economic Belt and 21st Century Maritime Silk Road to promote the implementation of the Initiative; instill vigor and vitality into the ancient Silk Road; connect Asian, European, and African countries more closely; and promote mutually beneficial cooperation to a new high and in new forms.

23.4.2 The Background

Complex and profound changes are taking place in the world. The underlying impact of the international financial crisis keeps emerging; the world economy is recovering slowly, and global development is uneven; the international trade and investment landscape and rules for multilateral trade and investment are undergoing major adjustments; and countries still face big challenges to their development.

The initiative to jointly build the Belt and Road, embracing the trend toward a multipolar world, economic globalization, cultural diversity, and greater IT application, is designed to uphold the global free trade regime and the open world economy in the spirit of open regional cooperation. It is aimed at promoting orderly and free flow of economic factors, highly efficient allocation of resources, and deep integration of markets; encouraging the countries along the Belt and Road to achieve economic policy coordination and carry out broader and more in-depth regional cooperation of higher standards; and jointly creating an open, inclusive, and balanced regional economic cooperation architecture that benefits all. Jointly building the Belt and Road is in the interests of the world community. Reflecting the common ideals and pursuit of human societies, it is a positive endeavor to seek new models of international cooperation and global governance and will inject new positive energy into world peace and development.

The Belt and Road Initiative aims to promote the connectivity of Asian, European, and African continents and their adjacent seas; establish and strengthen partnerships among the countries along the Belt and Road; set up all-dimensional, multi-tiered, and composite connectivity networks; and realize diversified, independent, balanced, and sustainable development in these countries. The connectivity projects of the Initiative will help align and coordinate the development strategies of the countries along the Belt and Road, tap market potential in this region, promote investment and consumption, create demands and job opportunities, enhance people-to-people and cultural exchanges and mutual learning among the peoples of the relevant countries, and enable them to understand, trust, and respect each other and live in harmony, peace, and prosperity.

China's economy is closely connected with the world economy. China will stay committed to the basic policy of opening-up, build a new pattern of all-round opening-up, and integrate itself deeper into the world economic system. The Initiative will enable China to further expand and deepen its opening-up and to strengthen its mutually beneficial cooperation with countries in Asia, Europe, Africa, and the rest of the world. China is committed to shouldering more responsibilities and obligations within its capabilities and making greater contributions to the peace and development of mankind.

23.4.3 Principles

The Belt and Road Initiative is in line with the purposes and principles of the UN Charter. It upholds the Five Principles of Peaceful Coexistence: mutual respect for each other's sovereignty and territorial integrity, mutual nonaggression, mutual noninterference in each other's internal affairs, equality and mutual benefit, and peaceful coexistence.

The Initiative is open for cooperation. It covers, but is not limited to, the area of the ancient Silk Road. It is open to all countries and international and regional organizations for engagement, so that the results of the concerted efforts will benefit wider areas.

The Initiative is harmonious and inclusive. It advocates tolerance among civilizations, respects the paths and modes of development chosen by different countries, and supports dialogues among different civilizations on the principles of seeking common ground while shelving differences and drawing on each other's strengths, so that all countries can coexist in peace for common prosperity.

The Initiative follows market operation. It will abide by market rules and international norms, give play to the decisive role of the market in resource allocation and the primary role of enterprises, and let the governments perform their due functions.

The Initiative seeks mutual benefit. It accommodates the interests and concerns of all parties involved and seeks a conjunction of interests and the "biggest common denominator" for cooperation so as to give full play to the wisdom and creativity, strengths, and potentials of all parties.

23.4.4 Framework

The Belt and Road Initiative is a way for win-win cooperation that promotes common development and prosperity and a road toward peace and friendship by enhancing mutual understanding and trust and strengthening all-round exchanges. The Chinese government advocates peace and cooperation, openness and inclusiveness, mutual learning, and mutual benefit. It promotes practical cooperation in all fields and works to build a community of shared interests, destiny, and responsibility featuring mutual political trust, economic integration, and cultural inclusiveness.

The Belt and Road run through the continents of Asia, Europe, and Africa, connecting the vibrant East Asia economic circle at one end and developed European economic circle at the other and encompassing countries with huge potential for economic development. The Silk Road Economic Belt focuses on bringing together China, Central Asia, Russia, and Europe (the Baltic); linking China with the Persian Gulf and the Mediterranean Sea through Central Asia and West Asia; and connecting China with Southeast Asia, South Asia, and the Indian

Ocean. The 21st Century Maritime Silk Road is designed to go from China's coast to Europe through the South China Sea and the Indian Ocean in one route and from China's coast through the South China Sea to the South Pacific in the other.

On land, the Initiative will focus on jointly building a new Eurasian Land Bridge and developing China-Mongolia-Russia, China-Central Asia-West Asia, and China-Indochina Peninsula economic corridors by taking advantage of international transport routes, relying on core cities along the Belt and Road, and using key economic industrial parks as cooperation platforms. At sea, the Initiative will focus on jointly building smooth, secure, and efficient transport routes connecting major seaports along the Belt and Road. The China-Pakistan Economic Corridor and the Bangladesh-China-India-Myanmar Economic Corridor are closely related to the Belt and Road Initiative and therefore require closer cooperation and greater progress.

The Initiative is an ambitious economic vision of the opening-up of and cooperation among the countries along the Belt and Road. Countries should work in concert and move toward the objectives of mutual benefit and common security. To be specific, they need to improve the region's infrastructure and put in place a secure and efficient network of land, sea, and air passages, lifting their connectivity to a higher level; further enhance trade and investment facilitation, establish a network of free trade areas that meet high standards, maintain closer economic ties, and deepen political trust; enhance cultural exchanges; encourage different civilizations to learn from each other and flourish together; and promote mutual understanding, peace, and friendship among people of all countries.

23.4.5 Cooperation Priorities

Countries along the Belt and Road have their own resource advantages, and their economies are mutually complementary. Therefore, there is a great potential and space for cooperation. They should promote policy coordination, facilities connectivity, unimpeded trade, financial integration, and people-to-people bonds as their five major goals and strengthen cooperation in the following key areas:

23.4.5.1 Policy Coordination

Enhancing policy coordination is an important guarantee for implementing the Initiative. We should promote intergovernmental cooperation, build a multilevel intergovernmental macro policy exchange and communication mechanism, expand shared interests, enhance mutual political trust, and reach new cooperation consensus. Countries along the Belt and Road may fully coordinate their economic development strategies and policies, work out plans and measures for regional cooperation, negotiate to solve cooperation-related issues, and jointly provide policy support for the implementation of practical cooperation and large-scale projects.

23.4.5.2 Facilities Connectivity

Facilities connectivity is a priority area for implementing the Initiative. On the basis of respecting each other's sovereignty and security concerns, countries along the Belt and Road should improve the connectivity of their infrastructure construction plans and technical standard systems, jointly push forward the construction of international trunk passageways, and form an infrastructure network connecting all subregions in Asia and between Asia, Europe, and Africa step by step. At the same time, efforts should be made to promote green and low-carbon infrastructure construction and operation management, taking into full account the impact of climate change on the construction.

With regard to transport infrastructure construction, we should focus on the key passageways, junctions, and projects and give priority to linking up unconnected road sections, removing transport bottlenecks, advancing road safety facilities and traffic management facilities and equipment, and improving road network connectivity. We should build a unified coordination mechanism for whole-course transportation; increase connectivity of customs clearance, reloading, and multimodal transport between countries; and gradually formulate compatible and standard transport rules, so as to realize international transport facilitation. We should push forward port infrastructure construction, build smooth land-water transportation channels, advance port cooperation, increase sea routes and the number of voyages, and enhance information technology cooperation in maritime logistics. We should expand and build platforms and mechanisms for comprehensive civil aviation cooperation and quicken our pace in improving aviation infrastructure.

We should promote cooperation in the connectivity of energy infrastructure, work in concert to ensure the security of oil and gas pipelines and other transport routes, build cross-border power supply networks and power transmission routes, and cooperate in regional power grid upgrading and transformation.

We should jointly advance the construction of cross-border optical cables and other communications trunk line networks, improve international communications connectivity, and create an information Silk Road. We should build bilateral cross-border optical cable networks at a quicker pace, plan transcontinental submarine optical cable projects, and improve spatial (satellite) information passageways to expand information exchanges and cooperation.

23.4.5.3 Unimpeded Trade

Investment and trade cooperation is a major task in building the Belt and Road. We should strive to improve investment and trade facilitation and remove investment and trade barriers for the creation of a sound business environment within the region and in all related countries. We will discuss with countries and regions along the Belt and Road on opening free trade areas so as to unleash the potential for expanded cooperation.

Countries along the Belt and Road should enhance customs cooperation such as information exchange, mutual recognition of regulations, and mutual assistance in law enforcement; improve bilateral and multilateral cooperation in the fields of inspection and quarantine, certification and accreditation, standard measurement, and statistical information; and work to ensure that the WTO Trade Facilitation Agreement takes effect and is implemented. We should improve the customs clearance facilities of border ports, establish a "single-window" in border ports, reduce customs clearance costs, and improve customs clearance capability. We should increase cooperation in supply chain safety and convenience, improve the coordination of cross-border supervision procedures, promote online checking of inspection and quarantine certificates, and facilitate mutual recognition of Authorized Economic Operators. We should lower non-tariff barriers, jointly improve the transparency of technical trade measures, and enhance trade liberalization and facilitation.

We should expand trading areas, improve trade structure, explore new growth areas of trade, and promote trade balance. We should make innovations in our forms of trade and develop cross-border e-commerce and other modern business models. A service trade support system should be set up to consolidate and expand conventional trade, and efforts to develop modern service trade should be strengthened. We should integrate investment and trade and promote trade through investment.

We should speed up investment facilitation, eliminate investment barriers, and push forward negotiations on bilateral investment protection agreements and double taxation avoidance agreements to protect the lawful rights and interests of investors.

We should expand mutual investment areas; deepen cooperation in agriculture, forestry, animal husbandry and fisheries, agricultural machinery manufacturing, and farm produce processing; and promote cooperation in marine product farming, deep-sea fishing, aquatic product processing, seawater desalination, marine biopharmacy, ocean engineering technology, environmental protection industries, marine tourism, and other fields. We should increase cooperation in the exploration and development of coal, oil, gas, metal minerals, and other conventional energy sources; advance cooperation in hydropower, nuclear power, wind power, solar power, and other clean, renewable energy sources; and promote cooperation in the processing and conversion of energy and resources at or near places where they are exploited, so as to create an integrated industrial chain of energy and resource cooperation. We should enhance cooperation in deep-processing technology, equipment, and engineering services in the fields of energy and resources.

We should push forward cooperation in emerging industries. In accordance with the principles of mutual complementarity and mutual benefit, we should promote in-depth cooperation with other countries along the Belt and Road in new-generation information technology, biotechnology, new energy technology, new materials, and other emerging industries and establish entrepreneurial and investment cooperation mechanisms.

We should improve the division of labor and distribution of industrial chains by encouraging the entire industrial chain and related industries to develop in concert; establish R&D, production, and marketing systems; and improve industrial supporting capacity and the overall competitiveness of regional industries. We should increase the openness of our service industry to each other to accelerate the development of regional service industries. We should explore a new mode of investment cooperation, working together to build all forms of industrial parks, such as overseas economic and trade cooperation zones and cross-border economic cooperation zones, and promote industrial cluster development. We should promote ecological progress in conducting investment and trade; increase cooperation in conserving eco-environment, protecting biodiversity, and tackling climate change; and join hands to make the Silk Road an environment-friendly one.

We welcome companies from all countries to invest in China, encourage Chinese enterprises to participate in infrastructure construction in other countries along the Belt and Road, and make industrial investments there. We support localized operation and management of Chinese companies to boost the local economy, increase local employment, improve local livelihood, and take social responsibilities in protecting local biodiversity and eco-environment.

23.4.5.4 Financial Integration

Financial integration is an important underpinning for implementing the Belt and Road Initiative. We should deepen financial cooperation and make more efforts in building a currency stability system, investment and financing system, and credit information system in Asia. We should expand the scope and scale of bilateral currency swap and settlement with other countries along the Belt and Road, open and develop the bond market in Asia, make joint efforts to establish the Asian Infrastructure Investment Bank and BRICS New Development Bank, conduct negotiation among related parties on establishing Shanghai Cooperation Organization (SCO) financing institution, and set up and put into operation the Silk Road Fund as early as possible. We should strengthen practical cooperation of China-ASEAN Interbank Association and SCO Interbank Association and carry out multilateral financial cooperation in the form of syndicated loans and bank credit. We will support the efforts of governments of the countries along the Belt and Road and their companies and financial institutions with good credit rating to issue Renminbi bonds in China. Qualified Chinese financial institutions and companies are encouraged to issue bonds in both Renminbi and foreign currencies outside China and use the funds thus collected in countries along the Belt and Road.

We should strengthen financial regulation cooperation, encourage the signing of memorandums of understanding (MOUs) on cooperation in bilateral financial regulation, and establish an efficient regulation coordination mechanism in the region. We should improve the system of risk response and crisis management, build a regional financial risk early warning system, and create an exchange and cooperation mechanism of addressing cross-border risks and crises. We should increase cross-border exchange and cooperation between credit investigation regulators, credit investigation institutions, and credit rating institutions. We should give full play to the role of the Silk Road Fund and that of sovereign wealth funds of countries along the Belt and Road and encourage commercial equity investment funds and private funds to participate in the construction of key projects of the Initiative.

23.4.5.5 People-to-People Bond

People-to-people bond provides the public support for implementing the Initiative. We should carry forward the spirit of friendly cooperation of the Silk Road by promoting extensive cultural and academic exchanges, personnel exchanges and cooperation, media cooperation, youth and women exchanges, and volunteer services, so as to win public support for deepening bilateral and multilateral cooperation.

We should send more students to each other's countries and promote cooperation in jointly running schools. China provides 10,000 government scholarships to the countries along the Belt and Road every year. We should hold culture years, arts festivals, film festivals, TV weeks, and book fairs in each other's countries; cooperate on the production and translation of fine films, radio, and TV programs; and jointly apply for and protect World Cultural Heritage sites. We should also increase personnel exchange and cooperation between countries along the Belt and Road.

We should enhance cooperation in and expand the scale of tourism, hold tourism promotion weeks and publicity months in each other's countries, jointly create competitive international tourist routes and products with Silk Road features, and make it more convenient to apply for tourist visa in countries along the Belt and Road. We should push forward cooperation on the 21st Century Maritime Silk Road cruise tourism program. We should carry out sports exchanges and support countries along the Belt and Road in their bid for hosting major international sports events.

We should strengthen cooperation with neighboring countries on epidemic information sharing, the exchange of prevention and treatment technologies, and the training of medical professionals and improve our capability to jointly address public health emergencies. We will provide medical assistance and emergency medical aid to relevant countries and carry out practical cooperation in maternal and child health, disability rehabilitation, and major infectious diseases including AIDS, tuberculosis, and malaria. We will also expand cooperation on traditional medicine.

We should increase our cooperation in science and technology; establish joint labs (or research centers), international technology transfer centers, and maritime cooperation centers; promote sci-tech personnel exchanges; cooperate in tackling key sci-tech problems; and work together to improve sci-tech innovation capability.

We should integrate existing resources to expand and advance practical cooperation between countries along the Belt and Road on youth employment, entrepreneurship training, vocational skill development, social security management, public administration and management, and in other areas of common interest.

We should give full play to the bridging role of communication between political parties and parliaments and promote friendly exchanges between legislative bodies, major political parties, and political organizations of countries along the Belt and Road. We should carry out exchanges and cooperation among cities; encourage major cities in these countries to become sister cities; focus on promoting practical cooperation, particularly cultural and people-to-people exchanges; and create more lively examples of cooperation. We welcome the think tanks in the countries along the Belt and Road to jointly conduct research and hold forums.

We should increase exchanges and cooperation between nongovernmental organizations of countries along the Belt and Road; organize public interest activities concerning education, health care, poverty reduction, biodiversity, and ecological protection for the benefit of the general public; and improve the production and living conditions of poverty-stricken areas along the Belt and Road. We should enhance international exchanges and cooperation on culture and media and leverage the positive role of the Internet and new media tools to foster harmonious and friendly cultural environment and public opinion

23.4.6 Cooperation Mechanisms

The world economic integration is accelerating and regional cooperation is on the upswing. China will take full advantage of the existing bilateral and multilateral cooperation mechanisms to push forward the building of the Belt and Road and to promote the development of regional cooperation.

We should strengthen bilateral cooperation and promote comprehensive development of bilateral relations through multilevel and multichannel communication and consultation. We should encourage the signing of cooperation MOUs or plans and develop a number of bilateral cooperation pilot projects. We should establish and improve bilateral joint working mechanisms and draw up implementation plans and road maps for advancing the Belt and Road Initiative. In addition, we should give full play to the existing bilateral mechanisms, such as joint committee, mixed committee, coordinating committee, steering committee, and management committee to coordinate and promote the implementation of cooperation projects.

We should enhance the role of multilateral cooperation mechanisms; make full use of existing mechanisms, such as the Shanghai Cooperation Organization (SCO), ASEAN Plus China (10 + 1), Asia-Pacific Economic Cooperation (APEC), Asia-Europe Meeting (ASEM), Asia Cooperation Dialogue (ACD), Conference on Interaction and Confidence-Building Measures in Asia (CICA), China-Arab States Cooperation Forum (CASCF), China-Gulf Cooperation Council Strategic Dialogue, Greater Mekong Subregion (GMS) Economic Cooperation, and Central

Asia Regional Economic Cooperation (CAREC) to strengthen communication with relevant countries; and attract more countries and regions to participate in the Belt and Road Initiative.

We should continue to encourage the constructive role of the international forums and exhibitions at regional and subregional levels hosted by countries along the Belt and Road, as well as such platforms as Boao Forum for Asia, China-ASEAN Expo, China-Eurasia Expo, Euro-Asia Economic Forum, China International Fair for Investment and Trade, China-South Asia Expo, China-Arab States Expo, Western China International Fair, China-Russia Expo, and Qianhai Cooperation Forum. We should support the local authorities and general public of countries along the Belt and Road to explore the historical and cultural heritage of the Belt and Road; jointly hold investment, trade, and cultural exchange activities; and ensure the success of the Silk Road (Dunhuang) International Culture Expo, Silk Road International Film Festival, and Silk Road International Book Fair. We propose to set up an international summit forum on the Belt and Road Initiative.

23.4.7 China's Regions in Pursuing Opening-Up

In advancing the Belt and Road Initiative, China will fully leverage the comparative advantages of its various regions; adopt a proactive strategy of further opening-up; strengthen interaction and cooperation among the eastern, western, and central regions; and comprehensively improve the openness of the Chinese economy.

Northwestern and northeastern regions: We should make good use of Xinjiang's geographical advantages and its role as a window of westward opening-up to deepen communication and cooperation with Central, South, and West Asian countries and make it a key transportation, trade, logistics, culture, science, education center, and a core area on the Silk Road Economic Belt. We should give full scope to the economic and cultural strengths of Shaanxi and Gansu provinces and the ethnic and cultural advantages of the Ningxia Hui Autonomous Region and Qinghai Province; build Xi'an into a new focus of reform and opening-up in China's interior; speed up the development and opening-up of cities, such as Lanzhou and Xining; and advance the building of the Ningxia Inland Opening-up Pilot Economic Zone with the goal of creating strategic channels, trade and logistics hubs, and key bases for industrial and cultural exchanges opening to Central, South, and West Asian countries. We should give full play to Inner Mongolia's proximity to Mongolia and Russia; improve the railway links connecting Heilongjiang Province with Russia and the regional railway network; strengthen cooperation between China's Heilongjiang, Jilin, and Liaoning provinces and Russia's Far East region on sea-land multimodal transport; and advance the construction of an Eurasian high-speed transport corridor linking Beijing and Moscow with the goal of building key windows opening to the north.

Southwestern region: We should give full play to the unique advantage of Guangxi Zhuang Autonomous Region as a neighbor of ASEAN countries, speed up the opening-up and development of the Beibu Gulf Economic Zone and the Pearl River-Xijiang Economic Zone, build an international corridor opening to the ASEAN region, create new strategic anchors for the opening-up and development of the southwest and mid-south regions of China, and form an important gateway connecting the Silk Road Economic Belt and the 21st Century Maritime Silk Road. We should make good use of the geographical advantage of Yunnan Province, advance the construction of an international transport corridor connecting China with neighboring countries, develop a new highlight of economic cooperation in the Greater Mekong Subregion, and make the region a pivot of China's opening-up to South and Southeast Asia. We should promote the border trade and tourism and culture cooperation between Tibet Autonomous Region and neighboring countries such as Nepal.

Coastal regions, Hong Kong, Macao, and Taiwan: We should leverage the strengths of the Yangtze River Delta, Pearl River Delta, west coast of the Taiwan Straits, Bohai Rim, and other areas with economic zones boasting a high level of openness, robust economic strengths, and strong catalytic role; speed up the development of the China (Shanghai) Pilot Free Trade Zone; and support Fujian Province in becoming a core area of the 21st Century Maritime Silk Road. We should give full scope to the role of Qianhai (Shenzhen), Nansha (Guangzhou), Hengqin (Zhuhai), and Pingtan (Fujian) in opening-up and cooperation; deepen their cooperation with Hong Kong, Macao, and Taiwan; and help to build the Guangdong-Hong Kong-Macao Big Bay Area. We should promote the development of the Zhejiang Marine Economy Development Demonstration Zone, Fujian Marine Economic Pilot Zone, and Zhoushan Archipelago New Area and further open Hainan Province as an international tourism island. We should strengthen the port construction of coastal cities, such as Shanghai, Tianjin, Ningbo-Zhoushan, Guangzhou, Shenzhen, Zhanjiang, Shantou, Qingdao, Yantai, Dalian, Fuzhou, Xiamen, Quanzhou, Haikou, and Sanya, and strengthen the functions of international hub airports, such as Shanghai and Guangzhou. We should use opening-up to motivate these areas to carry out deeper reform, create new systems and mechanisms of open economy, step up scientific and technological innovation, develop new advantages for participating in and leading international cooperation and competition, and become the pacesetter and main force in the Belt and Road Initiative, particularly the building of the 21st Century Maritime Silk Road. We should leverage the unique role of overseas Chinese and the Hong Kong and Macao Special Administrative Regions and encourage them to participate in and contribute to the Belt and Road Initiative. We should also make proper arrangements for the Taiwan region to be part of this effort.

Inland regions: We should make use of the advantages of inland regions, including a vast landmass, rich human resources, and a strong industrial foundation, focus on such key regions as the city clusters along the middle reaches of the Yangtze River, around Chengdu and Chongqing, in central Henan Province, around Hohhot, Baotou, Erdos, and Yulin, and around Harbin and Changchun to propel regional interaction and cooperation and industrial concentration. We should build Chongqing into an important pivot for developing and opening up the western region and make Chengdu, Zhengzhou, Wuhan, Changsha, Nanchang, and Hefei leading areas of opening-up in the inland regions. We should accelerate cooperation between regions on the upper and middle reaches of the Yangtze River and their counterparts along Russia's Volga River. We should set up coordination mechanisms in terms of railway transport and port customs clearance for the China-Europe corridor, cultivate the brand of "China-Europe freight trains," and construct a cross-border transport corridor connecting the eastern, central, and western regions. We should support inland cities, such as Zhengzhou and Xi'an, in building airports and international land ports, strengthen customs clearance cooperation between inland ports and ports in the coastal and border regions, and launch pilot e-commerce services for cross-border trade. We should optimize the layout of special customs oversight areas, develop new models of processing trade, and deepen industrial cooperation with countries along the Belt and Road.

23.4.8 China in Action

For more than a year, the Chinese government has been actively promoting the building of the Belt and Road, enhancing communication and consultation, and advancing practical cooperation with countries along the Belt and Road and introduced a series of policies and measures for early outcomes.

High-level guidance and facilitation: President Xi Jinping and Premier Li Keqiang have visited over 20 countries, attended the Dialogue on Strengthening Connectivity Partnership and the sixth ministerial conference of the China-Arab States Cooperation Forum, and met with leaders of relevant countries to discuss bilateral relations and regional development issues. They have used these opportunities to explain the rich contents and positive implications of the Belt and Road Initiative, and their efforts have helped bring about a broad consensus on the Belt and Road Initiative.

Signing cooperation framework: China has signed MOUs of cooperation on the joint development of the Belt and Road with some countries and on regional cooperation and border cooperation and mid- and long-term development plans for economic and trade cooperation with some neighboring countries. It has proposed outlines of regional cooperation plans with some adjacent countries.

Promoting project cooperation: China has enhanced communication and consultation with countries along the Belt and Road and promoted a number of key cooperation projects in the fields of infrastructure connectivity, industrial investment, resource development, economic and trade cooperation, financial cooperation, cultural exchanges, ecological protection, and maritime cooperation where the conditions are right.

Improving policies and measures: The Chinese government will integrate its domestic resources to provide stronger policy support for the Initiative. It will facilitate the establishment of the Asian Infrastructure Investment Bank. China has proposed the Silk Road Fund, and the investment function of the China-Eurasia

Economic Cooperation Fund will be reinforced. China will encourage bank card clearing institutions to conduct cross-border clearing operations and payment institutions to conduct cross-border payment business. We will actively promote investment and trade facilitation and accelerate the reform of integrated regional customs clearance.

Boosting the role of cooperation platforms: A number of international summits, forums, seminars, and expos on the theme of the Belt and Road Initiative have been held, which have played an important role in increasing mutual understanding, reaching consensus, and deepening cooperation.

23.4.9 Embracing a Brighter Future Together

Though proposed by China, the Belt and Road Initiative is a common aspiration of all countries along the routes. China is ready to conduct equal-footed consultation with all countries along the Belt and Road to seize the opportunity provided by the Initiative and promote opening-up, communication, and integration among countries in a larger scope, with higher standards and at deeper levels, while giving consideration to the interests and aspirations of all parties. The development of the Belt and Road is open and inclusive, and we welcome the active participation of all countries and international and regional organizations in this Initiative.

The development of the Belt and Road should mainly be conducted through policy communication and objective coordination. It is a pluralistic and open process of cooperation which can be highly flexible and does not seek conformity. China will join other countries along the Belt and Road to substantiate and improve the content and mode of the Belt and Road cooperation, work out relevant timetables and roadmaps, and align national development programs and regional cooperation plans.

China will work with countries along the Belt and Road to carry out joint research, forums and fairs, personnel training, exchanges, and visits under the framework of existing bilateral, multilateral, regional, and subregional cooperation mechanisms, so that they will gain a better understanding and recognition of the contents, objectives, and tasks of the Belt and Road Initiative.

China will work with countries along the Belt and Road to steadily advance demonstration projects, jointly identify programs that accommodate bilateral and multilateral interests, and accelerate the launching of programs that are agreed upon by parties and ready for implementation, so as to ensure early harvest.

The Belt and Road cooperation features mutual respect and trust, mutual benefit and win-win cooperation, and mutual learning between civilizations. As long as all countries along the Belt and Road make concerted efforts to pursue our common goal, there will be bright prospects for the Silk Road Economic Belt and the 21st Century Maritime Silk Road, and the people of countries along the Belt and Road can all benefit from this Initiative.

23.5 Some Final Words

Because of the magnificent benefits and great advantages of owning an international currency, China has been regionalizing and internationalizing its currency, the RMB, in recent years. To this end, the Chinese government has been actively introducing measures to promote the liberalization of its capital account, facilitating cross-border domestic and foreign investments, and further opening up its capital market.

To understand how China might be thinking and what China might be doing in the future, this chapter focuses on the birth, growth, and the future plans of RMB. It is expected that the presentation of this chapter will be beneficial for policy decision-makers from around the world.

Chapter 24
Avoiding Currency Wars with a Single World Currency?

Contents

As the title suggests, this chapter attempts to address the question of whether or not introducing and adopting a single world currency can help to avoid and end all currency wars. To this end, it is shown that a single world currency can be issued only if the current world system of states is eliminated and a unified world government is established, that as long as natural resources are not evenly distributed throughout the world and as long as there are civilizations with inconsistent value systems, there will not be any unified world government, and that under the condition of common existence of sovereign states, it is possible for a regional single currency to be introduced and adopted if the states involved share similar values and world views. That is, it is practically impossible for the mankind to avoid currency wars by employing a single world currency.

The rest of this chapter is organized as follows: Sect. 24.1 establishes a systemic evolutionary model for the development of world currencies. Section 24.2 looks at the possibility of introducing and adopting a unified world currency. Section 24.3 considers how regional single currencies are workable in theory. And Sect. 24.4 concludes this chapter and the book.

24.1 A Systemic Evolutionary Model of World Currencies

By employing the logic of systemic thinking, (Lin and Forrest 2011) positively addressed the following question: Is the appearance of the global identity crisis in the 1990s an indicator for the United States to cease its global dominance as the sole superpower? Consequently, one can see that the US dollar is unsustainable as the leading international currency; and therefore it will not be sustained for the long

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term. In the process of diminishing dominance, there might be four possible scenarios:

- The dollar will join a basket of several reserve currencies.
- The dollar will be subordinated to a more widely acceptable symbol of wealth, such as the special drawing rights (SDRs) or something else newly introduced.
- The dollar will be rejuvenated by some symbol of standard for wealth, such as gold.
- The dollar will descend into chaos with both redemptive and terminal possibilities.

The first scenario is the present state of affairs, although the dollar still occupies the dominant position in international trades and financial transactions. However, this situation is not expected to last long because it does not solve any of the debt and deficit problems, experienced by various countries from around the world. Instead, it merely pushes one country's problem to another country or countries so that the current forms of currency conflicts continue and even get worsened.

For the second scenario, it has been promoted by some global elites in the G20 finance ministries and IMF executive suites. However, the current effort is limited to replacing national paper currencies with a global paper currency. So in the process of implementation, assuming the world even reaches that stage, local rejections can be reasonably expected and regional instabilities can naturally appear.

As for the third scenario, the world will be returning to the gold standard. Although a well-studied, orderly implemented return to the gold standard will offer a very good chance of stability for the world finance, this option has received little academic respect as a possible solution in the current debates. At the same time, the history has well shown that imbalance in the accumulation of wealth will still occur, leading to economic conflicts between nations and regions (Forrest 2014). That presents simply a different form of the present currency wars.

So, that leaves the dollar to descend into chaos as a strong possibility. If we identify such a chaos as the state of motion of the fluid in the dishpan experiment when various eddy leaves appear, then there is a second chance for any of the first three scenarios to occur. When such a dynamic process continues, the dishpan experiment indicates that the development of the currencies would follow the following cycle: … → a leading international currency appears → a basket of reserve currencies is in use → another leading currency appears → another basket of reserve currencies is in use → … Here, chaos and a basket of reserve currencies would exist one after another or simultaneously, and so do a "gold" standard and a leading international currency.

However, comparing to any paper currency, a flexible gold standard should be more in favor and could be used to reduce such uncertainties as inflation, interest rates, and exchange rates. When greater economic certainty and price stability are more or less assured, businesses and investors will be able to take on new, riskier investments. There is enough uncertainty involved in entrepreneurship without adding those of inflation, deflation, interest rates, and exchange rates to the list of barriers standing in the way of innovation. Since the United States left gold in the 1970s, the US economy has been seeing asset bubbles, crashes, panics, booms, and busts one after another. So, it is really time to diminish the role of currency and empower the role of commerce.

24.2 Is a Unified World Currency Possible?

Proposition 24.1 Only if the current world system of states is eliminated and a unified world government is established, a single world currency can be issued.
The premise of issuing and adopting a single world currency is that all individually existing sovereign states disappear or become subordinated to a unified world government that issues the currency and provide the backup for the currency. It is because in the viewpoint of Karl Marx (1843, 1846, 1848), the existence of states is the product of irreconcilable classes. If compromises among classes are possible, then states will not be formed and maintained. Friedrich Engels (1844) thought that using a single currency without eliminating the system of states would cause counties to fight for their shares of benefits and will end in disasters.

Each state represents tools of exploiting the oppressed class, while the exploited class will rise up against the system; the fundamental problem underneath revolutions is the power of the state. Before 1848, Marx and Engels only described their general thought of the proletariat dictatorship. After the experience of revolution during 1848–1851, Marx put forward a conclusion that the proletariat must break the bourgeois state machine, although at that time he did not know what to use for the purpose. In 1871, the practical experience of the Paris Commune provided Marx and Engels a possible political form to replace the broken bourgeois state machine. During the late nineteenth and the early twentieth century, the capitalism developed into the imperialism stage. The inherent inconsistencies of the capitalism were worsened and became more intensify. As Lenin (1960) said, imperialism is the eve of the proletariat social revolution. In 1914 the outbreak of the World War I brought a serious damage to the belligerent states' economy, making people suffer from serious hardships of the war: many European countries experienced continuous strikes of workers and riots of soldiers. So, the movement against the imperialist war began; the condition for a proletarian revolution matured.

By employing the thinking logic of system research and the systemic yoyo model, Lin and Forrest (2011) provide an explanation on how civilizations initially form and how nations within the same civilization could potentially be constructed. In either case, it is the landscape of the environment and the distribution of natural resources that lead to the formations of civilizations and nations. So, the following result can be derived as a consequence of the previous proposition:

Corollary 24.1 As long as natural resources are not evenly distributed throughout the world and as long as there are civilizations with inconsistent value systems, there will not be any unified world government.

It has been quite clear that natural resources are not evenly distributed throughout the world. For example, fresh water is one of the many natural resources; and its distribution throughout the world is extremely uneven. As for civilizations with inconsistent or even contradictory value systems, they clearly exist and are determined by different landscapes of the environment. For example, people who live in environments of extremely difficult natural conditions tend to hold the beliefs of collectivism, while people who live in comfortable environments with relatively even distributions of natural resources tend to pursue after individualism. For more details of the relevant discussion, see (Lin and Forrest 2011).

A direct consequence of Corollary 24.1 is that it is impossible for the world to adopt a truthful single world currency.

24.3 Regional Single Currencies

Historically, there is indeed a precedent of using a single currency within a small region. For example, from 1957 to 2001, it was a long 45 years for the euro to be in circulation. Although the success of the euro gives people the hope of introducing a single world currency, two facts need to be noticed:

- The politics, economies, and cultures of the European countries were blending so that these countries could be considered as one country in some regards. Even so, it had been tough to promote the euro in Europe. Considering how the rest of the world is in a variety of historical and realistic inconsistencies, filled with intertwined interests, it can be seen that implementing a single world currency would be a mission impossible.
- Not all European countries used the euro, such as Sweden and the United Kingdom. If a country has the right of coinage, the country will enjoy the advantage of seigniorage. It is this benefit that no country is willing to give up. And there is no absolute fairness in the formulation of the exchange monetary policy, while any absolute fairness is a kind of unfairness.

From the European example, it can be seen that the system of sovereign states, or more generally, inconsistency in belief systems, is one of the biggest barriers to the implementation of a single world currency.

Proposition 24.2 Under the condition of common existence of sovereign states, it is possible for a regional single currency to be introduced and adopted if the states involved share similar values and world views.

In a regionally unified administration, the unified currency is a behoove thing. For instance, about 2100 years ago after the State of Qin unified China by violently eliminating all other states, the consequent Qin Dynasty immediately introduced and implemented a unified currency in the newly conquered lands. And even after the short-lived Qin Dynasty faded quickly into the dust of time, such idea of a unified currency continued throughout the land.

From ancient to modern times, many nations have voluntarily used a same currency, such as the Latin Monetary Union in the nineteenth century (Willis 1901), the later Scandinavian Monetary Union (Henriksen and Kærgård 1995), and the current Eurozone. Additionally, a country may voluntarily use other country's currency as its legal currency. For example, since the 1990s, the Latin American countries had gone on a trend of dollarization.

24.4 Some Final Remarks

This chapter and this entire volume present an exciting research topic that is theoretically intriguing and practically significant. Because monetary conflicts are not unavoidable, as discussed in this volume, the next best thing one can do is to reduce the disastrous aftermath to minimal.

Other than all the theoretical aspects covered in this volume, what will make this work practically complete is to look at an actual national economy in terms of the following:

- How it can be written in the control systems' format
- How its order or dimension can be reduced to a manageable level
- How an invisible variable regarding the state of the economy can be estimated by using observers
- How foreign capital could throw the economy off-balance
- Where the vulnerability of the economy is located
- How the vulnerability can be strengthened
- What could be the consequence if the economy is attacked
- What could be done to reduce the disastrous consequences to minimal
- Etc.

In short, in both theory and practice, this volume only barely opens the door of a wide-ranging research area that is direct and important real-life consequences.

Bibliography

Abad P (2009) EMU and European government bond market integration. ECB Working Paper, No. 1079

Agénor PR (2001) Monetary policy under flexible exchange rates: an introduction to inflation targeting (No. 124). Banco Central de Chile, Santiago

Agur I, Demertzis M (2015) Will macroprudential policy counteract monetary policy's effects on financial stability? IMF working paper No. 15/283

Akbar YH, McBride JB (2004) Multinational enterprise strategy, foreign direct investment and economic development: the case of the Hungarian banking industry. J World Bus 39(1):89–105

Alba P, Bhattacharya A, Claessens S, Ghosh S, Hernandez L (1999) The role of macroeconomic and financial sector links in East Asia's financial crisis. In: Agenor PR, Miller M, Vines D, Weber A (eds) The Asian financial crisis: causes, contagion and consequences. Cambridge University Press, New York, pp 9–66

Allayanis G, Ofek E (2001) Exchange rate exposure, hedging and the use of foreign currency derivative. J Int Money Financ 20(2):273–296

Allen R, Goldsmith E (1972) Towards the stable society: strategy for change. Ecologist Arch Ecologist. Located at http://www.theecologist.info/page32.html. Accessed 22 May 2012

Altimari N (2001) Does money lead inflation in the EURO area? European Central Bank Working Paper, No. 63

Angeloni I, Bénassy-Quéré A, Carton B, Darvas Z, Destais C, Gauvin L, Pisani-Ferry J, Sapir A, Vallee S (2011) Reforming the international monetary system: options and implications. Joint Bruegel-CEPII report, April 2011

Antoulas AC, Sorensen DC, Gugercin S (2001) A survey of model reduction methods for large scale systems. In: Contemporary mathematics, vol 280. AMS Publications, Providence, pp 193–219

Arellano M, Bond S (1991) Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev Econ Stud 58:277–297

Arnason R, Sandal LK, Steinshamn SI, Vestergaard N (2004) Optimal feedback controls: comparative evaluation of the cod fisheries in Denmark, Iceland, and Norway. Am J Agric Econ 86 (2):531–542

Bai ZJ (2002) Krylov subspace techniques for reduced-order modeling of large-scale dynamical systems. Appl Numer Math 43(1–2):9–44

Bailliu J, Lafrance R, Perrault JF (2001) Exchange rate regimes and economic growth in emerging markets. Proceedings of the Bank of Canada's tenth annual research conference, entitled "Revisiting the case for flexible exchange rates", pp 317–345

J. Yi-Lin Forrest et al., *Currency Wars*, Contemporary Systems Thinking,
https://doi.org/10.1007/978-3-319-67765-1

Barry E, Rose AK, Wyplosz C (1996) Contagious currency crises: first tests. Scand J Econ 98 (4):463–484

Beechey M, Gruen D, Vickrey J (2000) The efficient markets hypothesis: a survey. Reserve Bank of Australia in its series RBA Research Discussion Papers numbered rdp2000–01

Bejarano FJ, Zheng G (2014) Observability of linear systems with commensurate delays and unknown inputs. Automatica 50(8):2077–2083

Bejarano FJ, Floquet T, Perruquetti W, Zheng G (2013) Observability and detectability of singular linear systems with unknown inputs. Automatica 49(3):793–800

Bekaert G, Harvey CR, Lundblad C (2001) Emerging equity markets and economic development. J Dev Econ 66(2):465–504

Bellman R (1966) Dynamic programming. Science 153:34–37

Bénassy-Quéré A, Capelle D (2014) On the inclusion of the Chinese renminbi in the SDR basket. Int Econ 139:133–151

Benner P, Mehrmann V, Sorensen DC (2005) Dimension reduction of large-scale systems. Springer, Berlin

Berg A (1999) The Asian crisis: causes, policy responses, and outcomes. IMF working paper 99/138

Bergsten CF (2012) The euro versus the dollar: will there be a struggle for dominance? J Policy Model 24(4):307–314

Bergsten CF (2015) Architect of the global economic order. Int Econ 29(4):5

Berkovitz LD (2013) Optimal control theory, vol 12. Springer, New York

Berlinski D (1976) On systems analysis. MIT Press, Cambridge, MA

Bernanke BS (2000) Japanese monetary policy: a case of self-induced paralysis?. Presentation at the ASSA meetings, Boston, January 9

Bernanke BS (2007) Global imbalances: recent developments and prospects. Speech at Berlin Bundesbank Lecture. http://www.federalreserve.gov/newsevents/speech/bernanke20070911a.htm. Accessed 16 Aug 2015

Bernanke BS, Gertler M (1999) Monetary policy and asset price volatility. Economic review, Federal Reserve Bank of Kansas City, fourth quarter, pp 17–51

Bhagwati J, Dinopoulos E, Wong KY (1992) Quid pro quo foreign investment. Int Factor Mobility New Issues 82(2):186–190

Bhattacharya A, Linn JF (1988) Trade and industrial policies in the developing countries of East Asia. World Bank, Washington, DC

Bilginsoy C (2015) A history of financial crises: dreams and follies of expectations. Routledge/ Taylor & Francis, London

Bini Smaghi L (2011a) The reform of the international monetary system. Speech at the 'Conference in memory of Tommaso Padoa-Schioppa', Rome, 16 December 2011

Bini Smaghi L (2011b) The Triffin dilemma revised. Speech at the Triffin International Foundation, Brussels, 3 October 2011

Bisignano JR, Hunter WC, Kaufman GG (eds) (2012) Global financial crises: lessons from recent events. Springer, New York

Blanchard JMF, Mansfield ED, Ripsman NM (2014) Power and the purse: economic statecraft, interdependence and National Security. Routledge, Oxfordshire/New York

Blauberg IV, Sadovsky VN, Yudin EG (1977) Systems theory, philosophy and methological problems. Progress Publishers, Moscow

Boddewyn JJ (2015) Political aspects of MNF theory. In: The eclectic paradigm. Palgrave Macmillan, pp 85–110

Borensztein E, De Gregorio J, Lee JW (1998) How does foreign direct investment affect economic growth? J Int Econ 45(1):115–135

Boukhobza T, Hamelin F (2013) Discrete mode observability of structured switching descriptor linear systems: a graph-theoretic approach. Automatica 49(10):3042–3048

Bouzas R (1996) Chapter 5: the Mexican peso crisis and Argentina's convertibility plan: monetary virtue or monetary impotence? In: Roett R (ed) The Mexican peso crisis: international perspectives. Lynne Rienner, London

Brandelik R, Braunschweig W, Gather K, Kadansky V, Lubelsmeyer K, Mattig P, Martyn HU, Peis G, Rimkus J, Sander HG, Schmitz D, Schultz von Dratzig A, Trines D, Wallraff W (1979) Evidence for planar events in e+e- annihilation at high energies. Phys Lett B 86:243–249

Brenner R (2006) The economics of global turbulence. Verso, New York

Brock WA, Scheinkman J (1976) Global asymptotic stability of optimal control systems with applications to the theory of economic growth. J Econ Theory 12(1):164–190

Brouthers LE, Brouthers KD, Werner S (2015) Is Dunning's eclectic framework descriptice or normative? In: The eclectic paradigm. Palgrave Macmillan, pp 143–156

Brunnermeier M (2008) Deciphering the liquidity and credit crunch 2007–2008. National Bureau of Economic Research, Cambridge

Buehn A, Schneider F (2012) Shadow economies around the world: novel insights, accepted knowledge, and new estimates. Int Tax Public Financ 19(1):139–171

Buiter WH, Corsetti G, Pesenti PA (1998) Financial markets and European monetary cooperation. Cambridge University Press, New York

Buiter WH, Corsetti G, Pesenti PA (2001) Financial markets and European monetary cooperation: the lessons of the 1992–93 exchange rate mechanism crisis. Cambridge University Press, New York

Burger AE (1969) A historical analysis of the credit crunch of 1966. In: Review of Federal Reserve Bank of St Louis, vol 51. Federal Reserve Bank of St Louis, St Louis, pp 13–30

Burnside C, Eichenbaum M, Rebelo S (2001) Hedging and financial fragility in fixed exchange rate regimes. Eur Econ Rev 45:1151–1193

Burnside C, Eichenbaum M, Rebelo S (2004) Government guarantees and self-fulfilling speculative attack. J Econ Theory 119:31–63

Buzan B, Wæver O, De Wilde J (1998) Security: a new framework for analysis. Lynne Rienner Publishers, Boulder

Byström HNE (2004) The market's view on the probability of banking sector failure: cross-country comparisons. J Int Finan Markets Inst Money 14(5):419–438

Calice G, Chen J, Williams J (2013a) Liquidity spillovers in sovereign bonds and CDS markets: an analysis of the Eurozone sovereign debt crisis. J Econ Behav Organ 85:122–143

Calice G, Chen J, Williams J (2013b) Are there benefits to being naked? The returns and diversification impact of capital structure arbitrage. Eur J Financ 19(9):815–840

Calvo GA (1978) On the time consistency of optimal policy in a monetary economy. Econometrica 46:1411–1428

Calvo GA, Reinhart CM (2000) Fear of floating. Natl Bur Econ Res. NBER Working Paper No. 7993

Campa JM, Goldberg LS (2005) Exchange rate pass-through into import prices. Rev Econ Stat 87 (4):679–690

Cankao Information Network (2015) German media comments on RMB joining SDR: the world economy experiences a huge shift of power. http://finance.qq.com/a/20151201/015259.htm. Accessed 29 Feb 2016

Caprio G, Klingebiel D (1996) Bank insolvencies: cross-country experience. World Bank, Research working paper, no. WPS 1620

Carroll RL, Lindorff DP (1973) An adaptive observer for single-input single-output linear systems. IEEE Trans Autom Control 18:428–435

Casti J (1987) Linear dynamical systems. Academic Press, New York

Caves RE (1974) Multinational firms, competition, and productivity in host-country markets. Economica 41:176–193

Cerny PG (1993) Finance and world politics: markets, regimes, and states in the post-hegemonic era. Edward Elgar, Brookfield

Chandler L (1958) Benjamin strong, central banker. Brookings Institution, Washington, DC

Chang R, Velasco A (1998) Financial crises in emerging markets. National Bureau of Economic Research, Working paper No. w6606
Chang LC, Shoemaker CA, Liu PL (1992) Optimal time-varying pumping rates for groundwater remediation: application of a constrained optimal control algorithm. Water Resour Res 28 (12):3157–3173
Chang C, Liu Z, Spiegel MM (2015) Capital controls and optimal Chinese monetary policy. J Monet Econ 74:1–15
Chen GR (2007) The original state of the world: the theory of ether whirltrons. Tianma Books, Hong Kong
Chen Y (2014) Asymmetric shocks and dynamic correlations between onshore and offshore RMB foreign exchange markets: an empirical analysis with AG-DCC-MVGARCH model. J Financ Econ 29(4):77–85
Chen K, Chen G (2015) The rise of international financial centers in mainland China. Cities 47:10–22
Chen J, Patton RJ (1999) Robust model-based Fult diagnosis for dynamical systems. Kluwer Academic Publishers, New York
Chen DY, Wang LJ (2000) The robust control via state observer for the uncertain time-varying systems with delay. J Harbin Univ Sci Technol 5(6):19–21
Chen YL, Yang D (2016) Every true history is financial history. Jiangxi Education Publishing House, Nancang
Chen K, Ying YR (2012) China's capital account liberation in the post-financial crisis era. Press of Shanghai University, Shanghai
Chen K, Ying YR (2014) Impacts and monitoring system of financial crisis based on differential dynamics. Press of University of Electronic Science and Technology of China, Chengdu
Chen QH, Ying YR, Forrest YLJ (2017) A novel defense solution towards currency war. Adv Syst Sci Appl, 17(1):25–39
Cheng SW (1999) Complex science and management. Bull Chin Acad Sci (3):175–183
Cheng LK, Kwan YK (2000) What are the determinants of the location of foreign direct investment? The Chinese experience. J Int Econ 51:379–400
Cheung YW, Rime D (2014) The offshore renminbi exchange rate: microstructure and links to the onshore market. J Int Money Financ 49(part A):170–189
CHFS (Survey and Research Center for China Household Finance) (2013) Bank and household finance behavior. Southwestern University of Finance and Economics. http://news.163.com/13/0703/04/92R4EI8Q0001124J.html. Accessed 16 Dec 2015
Chinn M, Frankel J (2005) Will the euro eventually surpass the dollar as leading international reserve currency? NBER Working Paper, No. 11510
Chinn M, Frankel J (2007) Will the euro eventually surpass the dollar as leading international as leading international currency? In: G7 current account imbalances and adjustment. University of Chicago Press, Chicago
Chinn C, Frankel J (2008) The euro may over the next 15 years surpass the USD as leading international currency. NBER Working Paper, No. 13909
Chiodo AJ, Owyang MT (2002) A case study of a currency crisis: the Russian default of 1998. In: The Federal Reserve Bank of St Louis Review, St. Louis, vol 84, pp 7–18
Chitu L, Eichengreen B, Mehl A (2012) When did the dollar overtake sterling as the leading international currency? Evidence from the bond markets. NBER Working Paper Series, Working Paper 18097. http://www.nber.org/papers/w18097.pdf
Choksi AM, Papageorgiou D (1986) Economic liberalization in developing countries. Blackwell, Oxford
Chong A, Calderon C (2000) Causality and feedback between institutional measures and economic growth. Econ Polit 12(1):69–81
Chow GC (1975) Analysis and control of dynamic economic systems. Wiley, New York
Chow GC (1976) Control methods for macroeconomic policy analysis. J Am Econ Assoc 66:340–345

Chung W (2001) Mode, size, and location of foreign direct investments and industry markups. J Econ Behav Organ 45(2):185–211
Cinlar E (2013) Introduction to stochastic processes (Reprint edition). Dover Publications, New York
Claessens S, Djankov S, Xo LC (2000) Corporate performance in the East Asian financial crisis. World Bank Res Obs World Bank Group 15(1):23–46
Clemens WC Jr (1999) China: alternative futures. Communis Post-Commun 32(1):1–21
Cobb D (1981) Feedback and pole placement in descriptor variable systems. Int J Control 33 (6):1135–1146
Coddington EA, Levinson N (1955) Theory of ordinary differential equations. McGraw-Hill Education, New York
Cohen D (1992) The debt crisis: a postmortem. NBER Macroecon Annu (7):65–105
Cohen BJ (2007) Enlargement and international role of the euro. Rev Int Polit Econ 14:746–773
Colander D, Goldberg M, Haas A et al (2009) The financial crisis and the systemic failure of the economics profession. Crit Rev 21(2–3):249–267
Collas-Monsod S (1989) Management of the debt crisis: a debtor's viewpoint. In: Bogdanowicz-Bindert CA (ed) Solving the global debt crisis: strategies and controversies by key stake-holders. Harper and Row, New York, pp 59–70
Constâncio V (2011) The future of the international monetary system. Speech at the Golden Series lecture at the Official Monetary and Financial Institutions Forum, London, 23 November 2011
Corsetti G, Pesenti P, Roubini N (1999) What caused the Asian currency and financial crisis? Jpn World Econ 11(3):305–373
Coverstone-Carroll VL, Wilkey NM (1995) Optimal control of a satellite-robot system using direct collocation with non-linear programming. Acta Astronaut 36(3):149–162
Cross J, Nguyen BH (2017) The relationship between global oil price shocks and China's output: a time-varying analysis. Energy Econ 62:79–91
Cui P, Zhang C (2008) Observer design and output feedback stabilization for linear singular time-delay systems with unknown inputs. Control Theory Appl 6(2):177–183
Cushman DO (1983) The effects of real exchange rate risk on international trade. J Int Econ 15 (1):45–63
Cushman DO (1985) Real exchange rate risk, expectations and the level of direct investment. Rev Econ Stat 67(2):297–308
Cypher JM (1996) Mexico: financial fragility or structural crisis? J Econ Issues 30(2):451–461
D'Azzo JJ, Houpia CH (1981) Linear control system: analysis and design. McGraw-Hill, New York
Da Costa GC (1991) External debt of developing countries: crisis of growth. Econ Polit Wkly 26 (8):433–438
Dabrowski M (2012) Currency crises in emerging markets. Springer, New York
Darouach M (2009) Functional observers for linear descriptor systems. Proceedings of Mediterranean conference on control and automation, pp 1535–1539
Dehghani M, Goel L, Li WY (2014) PMU based observability reliability evaluation in electric power systems. Electr Power Syst Res 116:347–354
Demirgüç-Kunt A, Detragiache E (1998) Financial liberalization and financial fragility. IMF Working Paper, WP/98/83
Deng P (2012) Accelerated internationalization by MNCs from emerging economies: determinants and implications. Organ Dyn 41(4):318–326
Denisia V (2010) Foreign direct investment theories: an overview of the main FDI theories. Eur J Interdiscipl Stud 2(2):104–110
Desai P (2003) Financial crisis, contagion, and containment: from Asia to Argentina. Princeton University Press, Princeton
Detken C, Hartmann P (2000) The euro and international capital markets. Int Financ 3(1):53–94
Detken C, Hartmann P (2002) Features of the euro in international financial markets. Econ Policy 17:555–569

Di QQ (1999) Economics of trade costs. Press of Economic Science, Beijing
Diaz-Alejandro C (1985) Good-bye financial repression, hello financial crash. J Dev Econ 19 (1):1–24
Diehl M, Amrit R, Rawlings JB (2011) A Lyapunov function for economic optimizing model predictive control. IEEE Trans Autom Control 56(3m):703–707
Dimsdale N, Hotson A (eds) (2014) British financial crises since 1825. Oxford University Press, Oxford
Ding L, Huang YR, Pu XL (2014) Volatility linkage across global equity markets. Glob Financ J 25(2):71–89
Dobson W, Masson P (2009) Will the Renminbi become a world currency? China Econ Rev (3):124–135
Dominguez KME (2006) The European Central Bank, the euro and global financial markets. J Econ Perspect 20:67–88
Dooley MP (1995) A survey of academic literature on controls over international capital transactions. National Bureau of Economic Research. Working paper No. w5352
Dornbusch R (1976) Expectations and exchange rate dynamics. J Polit Econ 84(6):1161–1176
Dorrucci E, McKay J (2011) The international monetary system after the financial crisis. ECB Occasional Paper, No. 123, February 2011, Frankfurt am Main
Dosi G, Fagiolo G, Napoletano M et al (2015) Fiscal and monetary policies in complex evolving economies. J Econ Dyn Control 52:166–189
Drees B, Pazarbasioglu C (1998) The Nordic banking crises: pitfalls in financial liberalization? IMF Occasional Paper 161
Dungey M, Jan PAM, Lestano J (2015) The internationalisation of financial crises: banking and currency crises 1883–2008. North Am J Econ Financ 32:29–47
Dunning JH (1988) The eclectic paradigm of international production: a restatement and some possible extensions. J Int Bus Stud 19(1):1–31
Dury H (2011) http://is.muni.cz/el/1456/podzim2011/MPF_AFIN/um/27608616/27608949/Black_Wednesday.pdf. Retrieved 24 Feb 2016
EBRD (2009) Transition report 2009. http://www.ebrd.coni/downloads/research/transitioii/TR09.pdf. Accessed 2 July 2016
Echeverrial C, Darbar MSM, Johnston MR (1997) Sequencing capital account liberalization: lessons from the experiences in Chile, Indonesia, Korea, and Thailand. International Monetary Fund. Working paper No. 97–157
Edmund JC, Zou FG (2015) Does foreign direct investment matter anymore? Appl Econ Financ 2 (4):95–102
Edwards S (1984) The order of liberalization of the external sector in developing countries. In: Essays in international finance. International Finance Section, Department of Economics, Princeton University, Princeton
Edwards S (1989a) Real exchange rates, devaluation, and adjustment: exchange rate policy in developing countries. MIT press, Cambridge
Edwards S (1989b) Chapter 4: Structural adjustment politics in highly indebted countries. In: Sachs JD (ed) Developing country debt and economic performance, vol 1. University of Chicago Press, Chicago
Edwards S (1990) The sequencing of economic reform: analytical issues and lessons from Latin American experiences. World Econ 13(1):1–14
Edwards S (2000) Capital flows and economic performance. Unpublished Paper, UCLA, Los Angeles
Edwards S (2001) Capital mobility and economic performance: are emerging economies different? National Bureau of Economic Research, Working Paper No. 8076
Edwards S (2002) Capital mobility, capital controls, and globalization in the twenty-first century. Ann Am Acad Pol Soc Sci 579(1):261–270

Edwards S (2008) Financial openness, currency crises, and output losses. In: Edwards S, Garcia MG (eds) Financial markets volatility and performance in emerging markets. University of Chicago Press, Chicago, pp 97–120
Eichengreen B (1988) Real exchange rate behavior under alternative international monetary regimes: interwar evidence. Eur Econ Rev 32(2–3):363–371
Eichengreen B (2000) The EMS crisis in retrospect. NBER Working Paper 8035, Cambridge
Eichengreen B (2001) Capital account liberalization: what do cross-country studies tell us? World Bank Econ Rev 15(3):341–365
Eichengreen B (2005) Sterling's past, dollar's future: historical perspectives on reserve currency competition. NBER Working Paper, No. 11336
Eichengreen B (2011) Exorbitant privilege: the rise and fall of the dollar and the future of the international monetary system. Oxford University Press, Oxford
Eichengreen B (2012) Implications of the Euro's crisis for international monetary reform. J Policy Model 34(4):541–548
Eichengreen B, Flandreau M (2009) The rise and fall of the dollar (or when did the dollar replace sterling as the leading reserve currency?). Eur Rev Econ Hist 13(3):377–411
Eichengreen B, Flandreau M (2010) The Federal Reserve, the Bank of England and the rise of the dollar as an international currency, 1914–39. BIS Working Papers, No. 328
Eichengreen B, Hausmann R (2005) Other people's money: debt denomination and financial instability in emerging market economies. University of Chicago Press, Chicago
Eichengreen B, Portes R (1990) The interwar debt crisis and its aftermath. World Bank Res Obs 5:69–94
Eichengreen B, Rose A (2014) Capital controls in the 21st century. J Int Money Financ 48(Part A):1–16
Eichengreen B, Gullapalli R, Panizza U (2011) Capital account liberalization, financial development and industry growth: a synthetic view. J Int Money Financ 30(6):1090–1106
Einstein A (1997) The collected papers of Albert Einstein. Princeton University Press, Princeton
Ellis M, Zhang J, Liu J et al (2014) Robust moving horizon estimation based output feedback economic model predictive control. Syst Control Lett 68:101–109
Engel C, Rogers JH (2004) European product market integration after the euro. Econ Policy 19:347–384
Engels F (1844) The condition of the working class in England. https://www.marxists.org/archive/marx/works/1845/condition-working-class/index.htm. Accessed 15 Jan 2017
English J, Feng GF (1972) Tao De Ching. Vintage Books, New York
Eun CS, Kim SH, Lee K (2015) Currency competition between the dollar and euro: evidence from exchange rate behaviors. Financ Res Lett 12:100–108
European Central Bank (2013) Intra-euro area trade linkages and external adjustment. ECB Mon Bull:59–74
European Central Bank (2014) Financial integration in Europe. ECB Ann Rep:59–74
European Central Bank (various issues) Review of the international role of the euro. Frankfurt am Main
Evans JL, Archer SH (1968) Diversification and the reduction of dispersion: an empirical analysis. J Financ 23:761–767
Fatum R, Yamamoto Y (2016) Intra-safe haven currency behavior during the global financial crisis. J Int Money Financ 66:49–64
Fay S (1982) The great silver bubble. Hodder & Stoughton Ltd, London
FCIC (2010) Shadow banking and the financial crisis. Preliminary Staff Report
Feige EL (1989) The underground economies: tax evasion and information distortion. Cambridge University Press, Cambridge
Feng W, Han L, Shi L, Zhao D, Yang K (2016) Optimal control for a cooperative rendezvous between two spacecraft from determined orbits. J Astronaut Sci:1–24
Fields D, Vernengo M (2013) Hegemonic currencies during the crisis: the dollar versus the euro in a cartalist perspective. Rev Int Polit Econ 20:740–759

Flandreau M, Jobst C (2009) The empirics of international currencies: network externalities, history and persistence. Econ J 119(537):643–664

Fleming JM (1972) Towards a new regime for international payments. J Int Econ 2(4):345–337

Forbes K (2012) International monetary reform. Panel discussion at the AEA Annual Meetings, Chicago, 7 January 2012

Forrest YLJ (2013) A systemic perspective on cognition and mathematics. CRC Press, an imprint of Taylor and Francis, Balkema

Forrest J (2014) A systems perspective on financial systems. CRC Press, an imprint of Taylor and Francis, Balkema

Forrest J, Tao LX (2014) Investment and employment opportunities in China. CRC Press, an imprint of Taylor and Francis, New York

Forrest J, Hopkins Z, Liu SF (2013a) Currency wars and a possible self-defense (I): how currency wars take place. Adv Syst Sci Appl 13:198–217

Forrest J, Hopkins Z, Liu SF (2013b) Currency wars and a possible self-defense (II): a plan of self-protection. Adv Syst Sci Appl 13(4):298–315

Förster M, Jorra M, Tillmann P (2014) The dynamics of international capital flows: results from a dynamic hierarchical factor model. J Int Money Financ 48(part A):101–124

Forsyth AR (2012) Calculus of variations. Cambridge University Press, New York

Fosfuri A, Rønde T (2004) High-tech clusters, technology spillovers, and trade secret laws. Int J Ind Organ 22(1):45–65

Frankel J (2011a) Historical precedents for the internationalization of the RMB. Paper written for a workshop organized by the Council of Foreign Relations and the China Development Research Foundation

Frankel J (2011b) Historical precedents for internationalization of the RMB. Council on Foreign Relations Working Paper, November

Frankel J (2015) The euro crisis: where to from here? J Policy Model 37(3):428–444

Franks PM (2009) Fault diagnosis in dynamic systems using analytical and knowledge-based redundancy a survey and some new results. Automatica 26:459–474

Fratianni M, Artis MJ (1996) The lira and the pound in the 1992 currency crisis: fundamentals or speculation? In: The collapse of exchange rate regimes. Springer, New York, pp 143–159

Fratianni M, Hauskrecht A (1998) From the gold standard to a bipolar monetary system. Open Econ Rev 9:609–635

Fratzscher M (1998) Why are currency crises contagious? A comparison of the Latin American crisis of 1994–1995 and the Asian crisis of 1997–1998. Weltwirtschaftliches Arch 134 (4):664–691

Fratzscher M, Mehl A (2011) China's 'dominance' hypothesis and the emergence of a tripolar global currency system. CEPR Discussion Paper, No. 8671

Freund RW (2003) Model reduction methods based on Krylov subspaces. Acta Numer 12:267–319

Fu YM, Duan GR, Song SM (2004) Design of unknown input observer for linear time-delay systems. Int J Control Autom Syst 2(4):530–535

Fukao M (2003) Japanese financial deregulation and market disciple. In: Demaestri E, Masci P (eds) Financial crises in Japan and Latin America. Inter-American Development Bank, Washington, DC, pp 129–162

Fultz D, Long RR, Owens GV, Bohan W, Kaylor R, Weil J (1959) Studies of thermal convection in a rotating cylinder with some implications for large-scale atmospheric motion. Meteorol Monogr Am Meteorol Soc 21(4)

Furlong F, Ingenito R (1996) Commodity prices and inflation. Fed Reserve Bank San Francisco Economic Rev (2):27–47

Gagnon JE (2013) Currency wars. Milken Inst Rev 15(1):47–55

Gagnon JE, Bergsten CF (2012) Currency manipulation, the US economy, and the global economic order. Policy Briefs:1–25

Gallagher K (2007) Toward a theory of innovation and industrial population: evidence from Mexican manufacturing. In: Parto S, Herbert-Copley B (eds) Industrial innovation and environmental regulation: developing workable solutions. UNU Press, Tokyo, pp 138–155

Gao B (2001) Japan's economic dilemma. Cambridge University Press, Cambridge

Gao HC (2014) Deepen economic and trade cooperation, create new brilliance. People's Daily, 02 July 2014, (11)

Gao ZH, Xu L (2009) Aggregated reduction model based on partial block observability matrix. International conference on computational intelligence and software engineering, p 12

Gao ZG, Zhang BJ, Yu H (2012) Anti-money laundering regulations of RMB offshore market based on the financial degree of freedom model. Financ Econ (9):19–25

Geisst CR (2006) Encyclopedia of American business history, vol 2. Infobase Publishing, New York

Gen-hua QSYH (2011) Empirical analysis of diamond model of national economic competitive advantage and upgrading tactics based on national economic security. Asia Pac Econ Rev (3):109–115

Ghosh A, Ostry J, Tsangarides C (2011) Exchange rate regimes and the stability of the international monetary system, IMF Occasional Paper, No. 270

Ghysels E, Santa-Clara P, Valkanov R (2006) Predicting volatility: getting the most out of return data sampled at different frequencies. J Econ 131(1):59–95

Giddy IH (1994) Global financial markets. D.C. Heath and Company, Lexington

Gleick J (1987) Chaos: making a new science. Viking, New York

Glick R, Hutchison M (2001) Banking and currency crises: how common are the twins? In: Financial crises in emerging markets. Cambridge University Press, Cambridge

Glick R, Hutchison M (2005) Capital controls and exchange rate instability in developing economies. J Int Money Financ 24:387–412

Glick R, Guo X, Hutchison M (2006) Currency crises, capital-account liberalization, and selection bias. Rev Econ Stat 88(4):698–714

Gluschenko K (2015) Impact of the global crisis on spatial disparities in Russia. Pap Reg Sci 94 (1):3–23

Gobbin N, Merlevede B (2000) The Russian crisis: a debt perspective. Post-Communist Econ 12 (2):141–163

Goldstein M (1998) The Asian financial crisis: causes, cures, and systemic implications, vol 55. Peterson Institute, Washington, DC

Goldstein M, Turner P (1996) Banking crises in emerging economies: origins and policy options, BIS Economic Paper 46, Bank for International Settlements, Monetary and Economic Department, Basle

Goodfriend M (2005) The monetary policy debate since October 1979: lessons for theory and practice. Fed Reserve Bank St Louis Rev 87(2):243–262

Gorton G, Metrick A (2009) The run on Repo and the panic of 2007–2008, Yale Working Paper

Granger CWJ (1963) Economic processes involving feedback. Inf Control 6(1):28–48

Griffiths, D. J. (2004), Introduction to quantum mechanics (2nd edition), Prentice Hall, Englewood Cliffs

Griffith-Jones S, Sunkel O (1986) Debt and development crises in Latin America. Oxford University Press, New York

Griliches Z (1961) A note on the serial correlation bias in estimates of distributed lags. Econometrica 29:65–73

Grimme EJ (1997) Krylov projection methods for model reduction, Ph.D. Thesis, ECE Dept, University of Illinois, Urbana-Champaign

Gruben WC, McLeod D (2002) Capital account liberalization and inflation. Econ Lett 77 (2):221–225

Gruić B, Wooldridge PD (2012) Enhancements to the BIS debt securities statistics. BIS Q Rev 2012:63–76

Grusky DB, Western B, Wimer C (2011) The great recession. Russell Sage Foundation, New York

Gu L, McNelis PD (2013) Yen/dollar volatility and Chinese fear of floating: pressures from the NDF market. Pac Basin Financ J 22:37–49
Gugercin S (2002) Projection methods for model reduction of large-scale dynamical systems, Ph. D. Dissertation, ECE Dept. Rice University, December 2002
Gui HF, Liu XS (2001) Modern theories of international capital flows and their policy significance. J Jiangxi Univ Financ Econ (5):22–25
Guitian M (1997) Reality and the logic of capital flow liberalization. In: Capital Controls in Emerging Economies, vol 174, pp 17–32
Guo JQ, Zhou MR (2003) Economic effects of capital flows under flexible exchange rate system – a dynamic analysis based on a modified Dombuch model. Econ Res (5):475–480
Habib MM, Joy M (2010) Foreign-currency bonds: currency choice and the role of uncovered and covered interest parity. Appl Financ Econ 20(8):601–626
Hached M (2015) A note on the Davision-man method for Sylvester matrix equations. Comput Appl Math. https://doi.org/10.1007/s40314-015-0244-1
Hacker JS, Huber GA, Nichols A, Rehm P, Schlesigner M, Valletta R, Craig S (2014) The economic security index: a new measure for research and policy analysis. Rev Income Wealth 60(S1):S5–S32
Hadsell L, MacDermott R (2012) Faculty perceptions of grades: results from a national survey of economics faculty. Int Rev Econ Educ 11(1):16–35
Haggard S (2000) The political economy of the Asian financial crisis. Institute for International Economics, Washington, DC
Haidar JI (2012) Currency crisis transmission through international trade. Econ Model 29 (2):151–157
Hall AD, Fagen RE (1956) Definitions of systems. Gen Syst 1:18–28
Hall SG, Kenjegaliev A, Swamy PA, Tavlas GS (2013) Measuring currency pressures: the cases of the Japanese yen, the Chinese yuan, and the UK pound. J Jpn Int Econ (29):1–20
Halloran R (1998) China's decisive role in the Asian financial crisis. Glob Beat Issue Brief 24:27
Hanish G (2013) Impending disaster to Euro. China Youth Press, Beijing
Hanna D (2000) Restructuring Asia's financial system. In: Woo WT, Sachs J, Schwab K (eds) The Asian financial crisis: lessons for a resilient Asia. MIT Press, Cambridge
Hao F (2006) Full-order observer design for descriptor systems with delayed state and unknown inputs. Proceedings of the 2006 Chinese Control Conference. pp 766–770
Hartmann P (1998) Currency competition and foreign exchange markets – the dollar, the yen and the euro. Cambridge University Press, Cambridge
Hatanaka M (1974) An efficient two-step estimator for the dynamic adjustment model with autoregressive errors. J Econ 2:199–220
Hausmann R, Fernandez-Arias E (2000) Foreign direct investment: good cholesterol? IADB Working Papers
He CF (2003) Location of foreign manufacturers in China: agglomeration economies and country of origin effects. Reg Sci 82:351–372
He HG (2007) RMB internationalization: mode selection and path arrangements. Financ Econ 2:10–15
He DX, Zheng LS (2009) The shadow banking system and its impacts on financial stability. Econ Manag J 31(11):20–25
He Q, Korhonen I, Guo JJ, Liu FG (2016) The geographic distribution of international currencies and RMB internationalization. Int Rev Econ Financ 42:442–458
Heidarinejad M, Liu J, Christofides PD (2012) State-estimation based economic model predictive control of nonlinear systems. Syst Control Lett 61(9):926–935
Hein E, Detzer D, Dodig N (eds) (2016) Financialisation and the financial and economic crises: country studies. Edward Elgar Publishing, Cheltenham
Helbing D (2012) Systemic risks in society and economics. In: Social self-organization. Springer, Berlin, pp 261–284
Hendrix H (2001) Getting the love you want: a guide for couples. Owl Books, New York

Hennart JF (1982) A theory of multinational Enterprise. University of Michigan Press, Ann Arbor
Henriksen I, Kærgård N (1995) The Scandinavian currency union 1875–1914. In: Reis J (ed) International monetary Systems in Historical Perspective. Palgrave Macmillan, London, pp 91–112
Henry PB (2000) Do stock market liberalization cause investment booms? J Financ Econ 58:301–334
Hess SL (1959) Introduction to theoretical meteorology. Holt, Rinehart and Winston, New York
Hide R (1953) Some experiments on thermal convection in a rotating liquid. Quart J Roy Meteorol Soc 79:161
Higgins B (1993) Was the ERM crisis inevitable?, Federal Reserve Bank of Kansas City Economic Review 4
Hightower MJ (2013) Penn square: the shopping center bank that shook the world. In: Chronicles of Oklahoma, vol 90. pp 68–99 and 204–236
Hirschman AO (1958) The strategy of economic development. Yale University Press, New Haven
Hoholik J (2016) U.S. homeownership rate falls to five-decade low. Wall Street J. Published on August 1, 2016
Hoque H, Andriosopoulos D, Andriosopoulos K, Douady R (2015) Bank regulation, risk and return: evidence from the credit and sovereign debt crises. J Bank Financ 50:455–474
Horn RA, Johnson CR (2012) Matrix Theory (2nd edition), Cambridge University Press, Cambridge, UK.
Hoshi T, Kashyap A (2000) The Japanese banking crisis: where did it come from and how will it end? In: NBER macroeconomics annual 1999, vol 14. MIT, pp 129–212
Hoshi T, Kashyap AK (2004) Japan's financial crisis and economic stagnation. J Econ Perspect 18 (1):3–26
Hsu S (2013) Financial crises, 1929 to the present. Edward Elgar Publishing, Northampton
Hsu J, Moroz M (2010) Shadow banks and the financial crisis of 2007–200. Social Science Electronic Publishing
Hu GY, Hu AG (2005) Application of the state variable control theory to regional economic policy adjustment and control. J Tsinghua Univ (Science and Technology edition) 45(9):1273–1276
Hu M, Li YF, Yang JJ, Chao CC (2016) Actual intervention and verbal intervention in the Chinese RMB exchange rate. Int Rev Econ Financ 43:499–508
Huang Y, Kou G, Peng Y (2017) Nonlinear manifold learning for early warnings in financial markets. Eur J Oper Res 258(2):692–702
Hui YV (1991) Economic design of a complete inspection plan with feedback control. Int J Prod Res 29(10):2151–2158
Huntington SP (1996) The clash of civilizations and the remaking of world order. Simon & Schuster, New York
Hunya G (2002) Restructuring through FDI in Romanian manufacturing. Econ Syst 26 (4):387–394
Hutchison MM (1986) Japan's 'money focused' monetary policy. Econ Rev (Federal Reserve Bank of San Francisco), Summer (3):33–46
IMF (2011) People's Republic of China: staff report for the 2011 article IV consultation, http://www.imf.org/external/index.htm. Accessed on 10 Jan 2017
IMF (2015) IMF executive board completes the 2015 review of SDR valuation, IMF December 1, 2015, Retrieved on 10 Jan 2016
Infante EF, Stein JL (1973) Optimal growth with robust feedback control. Rev Econ Stud 40 (1):47–60
Inoue T, Okimoto T (2008) Where there structural breaks in the effects of Japanese monetary policy? Reevaluating policy effects of the lost decades. J Japanaese Inter Econ 22(3):320–342
International Monetary Fund (2008) Containing systemic risks and restoring financial soundness, Global Financial Stability Report
Ishii S, Habermeier KF, Canales-Kriljenko JI (2002) Capital account liberalization and financial sector stability, International Monetary Fund, no. 211

Jamshidi M, Tarokh M, Shafai B (1992) Computer-aided analysis and design of linear control systems. Prentice-Hall, Englewood Cliffs

Jevons WS (1875) Money and the mechanism of exchange. D. Appleton and Company, New York

Jiang BK, Zhang QL (2005) Currency internalization: academic review of its terms and impact. New Finance 8:6–9

Jiang FX, Ma YB, Shi BB (2017) Stock liquidity and dividend payouts. Finance 42:295–314

Xi Jinping (2014) Carry forward the five principles of peaceful coexistence to build a better world through win-win cooperation, address at the meeting marking the 60th Anniversary of the Initiation of the Five Principles of Peaceful Coexistence. People's Daily, June 29, 2014(2)

Johnson HG (1972) Further essays in monetary economics. Allen and Unwin, London

Johnson HG (1977) The monetary approach to the balance of payments: a nontechnical guide. J Int Econ 7(3):251–268

Johnston RB (1998) Sequencing capital account liberalizations and financial sector reform, International Monetary Fund, Monetary and Exchange Affairs Department, working paper No. 98

Jun SG, Marathe A, Shawky HA (2003) Liquidity and stock returns in emerging equity markets. Emerg Mark Rev 4(1):1–24

Kaczorek T (1985) Pole placement for linear discrete-time systems by periodic output feedbacks. Syst Control Lett 6(4):267–269

Kahler M (1985) Politics and international debt. Int Organ 39(3):357–382

Kaminsky GL (2004) International capital flows: a blessing or a curse? George Washington University, Washington DC

Kaminsky GL, Reinhart CM (1998) Financial crises in Asia and Latin America: then and now. Am Econ Rev 88(2):444–448

Kaminsky GL, Lizondo S, Reinhart CM (1998) Leading indicators of currency crises. IMF Staff Pap. Palgrave Macmillan 45(1):1–48

Kane EJ (1989) The S&L Insurance Mess: how did it happen? The Urban Institute, Washington, DC

Kaplan E, Rodrik D (2001) Did the Malaysia capital controls work? NBER Working Paper, 8142

Kapstein E (1994) Growing the global economy. Harvard University Press, Cambridge

Kareken J, Wallace N (1981) On the indeterminacy of equilibrium exchange rates. Q J Econ 96 (2):207–222

Karnopp DC, Margolis DL, Rosenberg RC (2012) System dynamics: modeling, simulation, and control of mechatronic systems, 5th edn. Wiley, New York

Kasekende L, Martin M (1995) Macroeconomic policy research issues: The sequencing, consistency and credibility of structural adjustment in Africa. In: AERC Senior Policy Seminar. African Economic Research Consortium, Nairobi, March

Kawai M (1998) The east Asian currency crisis: causes and lessons. Contemp Econ Policy 16 (2):157–172

Kawai M, Pontines V (2016) Is there really a renminbi bloc in Asia?: a modified Frankel – Wei approach. J Int Money Financ 62:72–97

Kawano Y, Ohtsuka T (2013) Observability at an initial state for polynomial systems. Automatica 49(5):1126–1136

Kedia S, Mozumdar A (2003) Foreign currency denominated debt: an empirical examination. J Bus 76(4):521–546

Kendrick DA (1981) Stochastic control for economic models. McGraw-Hill, New York

Kenen PB (2002) The euro versus the dollar: will there be a struggle for dominance? J Policy Model 24:347–354

Kenen PB (2011) Beyond the dollar, paper presented at the AEA Allied Social Science Association Meetings, Denver, Colorado

Kenourgios D, Padhi P (2012) Emerging markets and financial crises: regional, global or isolated shocks? J Multinatl Financ Manag 22(1):24–38

Kenourgios D, Samitas A, Paltalidis N (2011) Financial crises and stock market contagion in a multivariate time-varying asymmetric framework. J Int Finan Markets Inst Money 21 (1):92–106

Keynes JM (1930) A treatise on money. Harcourt, Brace and Company, New York

Kiekintveld C, Wellman MP, Singh SP, Estelle J, Vorobeychik Y, Soni V, Rudary MR (2004) Distributed feedback control for decision making on supply chains. In: ICAPS-04 Proceedings, pp 384–392

Kim SY (2001) International transmission of U.S. monetary policy shocks: evidence from VAR's. J Monet Econ 48(2):339–372

Kindleberger CP (1984) Financial institutions and economic development: a comparison of great Britain and France in the eighteenth and nineteenth centuries. Explor Econ Hist 21(2):103–124

Kindleberger CP (2015) A financial history of Western Europe. Routledge

Kirk DE (2012) Optimal control theory: an introduction. Courier Corporation

Klein MW (2003) Capital account openness and the varieties of growth experience, NBER Working Paper, p 9500

Kline M (1972) Mathematical thought from ancient to modern times. Oxford University Press, Oxford

Klir G (1985) Architecture of systems problem solving. Plenum Press, New York

Klir G (2001) Facets of systems science. Springer, New York

Kojima K, Osawa T (1984) Micro and macro-economic models of foreign direct investment. Hitosubashi J Econ 25(1):1–20

Kose MA, Prasad E, Rogoff KS, Wei SJ (2006) Financial globalization: a reappraisal, National Bureau of Economic Research, working paper no. w12484

Koulischer F, Struyven D (2014) Central bank liquidity provision and collateral quality. J Bank Financ 49:113–130

Krugman P (1979) A model of balance-of-payments crises. J Money Credit Bank 11:311–325

Krugman P (1980) Vehicle currencies and the structure of international exchange. J Money Credit Bank 12(3):513–526

Krugman P (1984) The international role of the dollar: theory and prospects. In: Bilson J, Marston R (eds) Exchange rate theory and practice. University of Chicago Press, Chicago

Krugman P (1988) Exchange rates and international adjustment. Jpn World Econ 1(1):63–87

Krugman P (1996) Are currency crises self fulfilling? In: NBER macroeconomics annual, Cambridge, MA

Krugman P (1999) Balance sheets, the transfer problem, and financial crises. Int Tax Public Financ 6(4):459–472

Krugman PR, Rogoff KS, Fischer S, McDonough WJ (1999) Currency crises. In: Fieldstein M (ed) International capital flows. University of Chicago Press, Chicago, pp 421–466

Krugman PR, Obstfeld M, Melitz MJ (2012) International economics: theory and policy, 9th edn. New York, Pearson Education Limited

Kurita CT (2014) Dynamic characteristics of the daily yen–dollar exchange rate. Res Int Bus Financ 30:72–82

Kydland FE, Prescott EC (1980) Dynamic optimal taxation, rational expectations and optimal control. J Econ Dyn Control (2):79–91

Kyrtsou C, Labys W (2006) Evidence for chaotic dependence between US inflation and commodity prices. J Macroecon 28(1):256–266

Laird J (2000) Money politics, globalization, and crisis: the case of Thailand. Graham Brash, Singapore

Lane PR (2006) The real effects of European monetary union. J Econ Perspect 20:47–66

Lane PR, Milesi-Ferretti GM (2007) Capital flows to central and Eastern Europe. Emerging Mark Rev 8(2):106–123

Lane PR, Milesi-Ferretti GM (2011) The cross-country incidence of the global crisis. IMF Econ Rev 59(1):77–110

Laozi (2012) Tao Te Ching. China Renmin University Press, Beijing

Larrain F, Velasco A (1990) Can swaps solve the debt crisis? Lessons from the Chilean experience, Princeton studies in international finance 69. Princeton University, Princeton

Lauridsen LS (1998) The financial crisis in Thailand: causes, conduct and consequences? World Dev 26(8):1575–1591

Lee CC, Lin CW, Zeng JH (2016) Financial liberalization, insurance market, and the likelihood of financial crises. J Int Money Financ 62:25–51

Lenin VI (1960) Lenin on imperialism: the eve of the proletarian social revolution. Foreign Languages Press, Beijing

Lewis C (1938) America's stake in international investments. Brookings Institution, Washington, DC

Li Q (2007) VEC model of currency substitution in China: 1994 – 2005. Modem Econ Sci 29 (1):10–14

Li JM (2015) Rouble: from plunging to quick rebound. World Aff:49–51

Li X (2016) Exchange rate regime choice, signaling, FDI inflow and growth in developing countries, Doctoral dissertation, King's College London (University of London)

Li X, Ding YB (2010) Research on RMB regionalization. Tsinghua University Press, Beijing

Li X, Kamikawa T (2010) RMB and yen cooperate with Asian currency. Tsinghua University Press, Beijing

Li KW, Kwok ML (2009) Output volatility of five crisis-affected East Asia economies. Jpn World Econ 21(2):172–182

Li Y, Matsui A (2005) A theory of international currency and seigniorage competition. Br J Pain 7 (3):124–129

Li W, Zhang C (2008) The impact on fluctuations in real exchange rate and domestic output fluctuations by opening FDI. Manage World 20(6):11–20

Li JJ, Zhao Q (2012) A comparison of international shadow banking regulations after the sub-prime crisis. J Jinggangshan Univ (Social sciences) 33(3):69–73

Li L, Jia YM, Du JP, Yuan SY (2008) Observer-based H_∞ control of uncertain singular systems with time-varying delay, Proceedings of the 2008 World Congress on Intelligent Control Automation, pp 2940–2945

Li C, Liu H, Jiang Y (2015a) Exchange rate risk, political environment and Chinese outward FDI in emerging economies: a panel data analysis. Economics 3(5–6):145–155

Li HL, Jiang YL, Wang ZL, Hu C (2015b) Global stability problem for feedback control systems of impulsive fractional differential equations on networks. Neurocomputing 161:155–161

Lilienfeld D (1978) The rise of systems theory. Wiley, New York

Lin Y (1987) A model of general systems. Math Model Int J 9:95–104

Lin Y (1988a) An application of systems analysis in sociology. Cybern Syst Int J 19:267–278

Lin Y (1988b) Can the world be studied in the viewpoint of systems?? Math Comput Model 11:738–742

Lin Y (1989) Multi-level systems. Int J Syst Sci 20:1875–1889

Lin Y (1994) Feedback transformation and its application. J Syst Eng 1:32–38

Lin Y (1995) Developing a theoretical foundation for the laws of conservation. Kybernetes Inter J Syst Cybern Manag Sci 24:52–60

Lin Y (1998) Mystery of nonlinearity and Lorenz's Chaos. A special double issue. Kybernetes Inter J Syst Cybern Manag Sci 27(6–7):605–854

Lin Y (1999) General systems theory: a mathematical approach. Plenum and Kluwer Academic Publishers, New York

Lin Y (2007) Systemic yoyo model and its application in Newton's laws of mechanics, universal gravitation, Kepler's laws and the three body problem. Kybernetes Int J Syst Cybern 36 (3):484–516

Lin Y (2008) Systemic Yoyo Model: some impacts of the second dimension. Auerbach Publications, an imprint of Taylor and Francis, New York

Lin Y (2009) Systemic Yoyos: impacts of the second dimension. Auerbach Publications, an imprint of Taylor and Francis, New York

Lin Y, Fan TH (1997) The fundamental structure of general systems and its relation to knowability of the physical world. Kybernetes Inter J Syst Cybern 26:275–285
Lin Y, Forrest B (2011) Systemic Structure behind Human Organizations: from civilizations to individuals. Springer, New York
Lin Y, Ma YH (1987) On the stabilities of input-output systems. Cybern Syst Int J 18(4):285–298
Lin Y, Ma Y, Port R (1990) Several epistemological problems related to the concept of systems. Math Comput Model 14:52–57
Lindgren CJ, Balino TJ, Enoch C, Gulde AM, Quintyn M, Teo L (1999) Financial sector crisis and restructuring lessons from Asia, Occasional Paper 188, International Monetary Fund, Washington, DC
Litterick D (2002) Billionaire who broke the Bank of England, The Telegraph, 13 September 2002
Liu DB (2007) The research on the free exchange of renminbi – based on the double-account mechanism, Shanghai Finance, August: 67–71+66
Liu SF, Lin Y (2006) Grey information: theory and practical applications. Springer, London
Liu Q, Shi S (2010) Currency areas and monetary coordination. Int Econ Rev 51(3):813–836
Liu LZ, Xu QY (2006) Exploration of RMB internationalization. People's Publishing House, Beijing
Liu XM, Ren H, Wu Y, Kong DP (2013) An analysis of the demonstration projects for renewable energy application buildings in China. Energy Policy 63:382–397
Liu X, Saidi R, Bazaz M (2014) Institutional incentives and earnings quality: the influence of government ownership in China. J Contemp Account Econ 10(3):248–261
Liviatan N (1963) Consistent estimation of distributed lags. Int Econ Rev 4:44–52
Lorenz EN (1993) The essence of Chaos. Washington University Press, Seattle
Lu QJ, Zhu LN (2011) An analysis on the effect of monetary policy instruments on money base and money multiplier: the data from 2003 to 2011 in China. J Shanghai Univ Financ Econ 13 (1):50–56
Luenberger DG (1964) Observing the state of a linear system. IEEE Trans Mil Electron 8(2):74–80
Luo P (1996) Currency convertibility and financial sector reform. China Financial Publishing House, Beijing
Luo TY (2010) Macro financial regulation: the dynamics of money perspective. J Guizhou Univ Financ Econ (1):28–33
Ma GN, McCauley RN (2013) Is China or India more financially open? J Int Money Financ 39:6–27
MacFarquhar R, Schoenhals M (2008) Mao's Last Revolution. Harvard University Press, Cambridge
Mai N (2008) Lessons from the 1990s Scandinavian banking crises JP Morgan Chase Research Note, May 9
Markusen JR, Venables AJ (1999) Foreign direct investment as a catalyst for industrial development. Eur Econ Rev 43(2):335–356
Marx K (1843) Critique of Hegel's Philosophy of Right, https://www.marxists.org/archive/marx/works/1843/critique-hpr/index.htm. Accessed on 1 Feb 2017
Marx K (1846) The German ideology. In: Riv-kin J, Ryan M (eds) Literary theory: an anthology. Blackwell Publishing, Malden. 2004
Marx K (1848) The communist manifesto, http://www.marxists.org/archive/works/marx/1848/communist-manifesto/ch01.htm. Accessed on 1 Feb 2017
Marx K, Engels F (2009) Complete works of Marx and Engels. People's Publishing House, Beijing
Matsuyama K, Kiyotaki N, Matsui A (1993) Toward a theory of international currency. Rev Econ Stud 60:283–307
Mathematical Sciences (1985) A unifying and dynamic resource. Not Am Math Soc 33:463–479
McBrady MR, Schill MJ (2007) Foreign currency denominated borrowing in the absence of operating incentives. J Financ Econ 86(1):145–177
McCann M (2001) Cross-border acquisitions: the UK experience. Appl Econ 33(4):457–461

McCulley P (2009) The shadow banking system and Hyman Minsky's economic journey. Res Found Publ 2009(5):257–268

McKinnon RI (1973) Money and capital in economic development. Brookings Institution, Washington, DC

McKinnon RI (1982) The order of economic liberalization: lessons from Chile and Argentina. In: Carnegie-Rochester conference series on public policy, vol 17. North-Holland, pp 159–186

McKinnon RI (1993) The order of economic liberalization: financial control in the transition to a market economy. Johns Hopkins University Press, Baltimore

McKinnon RI (1995) Intergovernmental competition in Europe with and without a common currency. J Policy Model 17(5):463–478

McKinnon RI, Pill H (1998) International overborrowing: a decomposition of credit and currency risks. World Dev 26(7):1267–1282

McPherson MF (1995) The sequencing of economic reforms: lessons from Zambia, Harvard Institute for International Development Papers, No. 516

Meade JE (1951) Theory of international economic policy Vol. 1: the balance of payments. Oxford University Press, Landon

Mehrez G, Kaufmann D (2000) Transparency, liberalization, and financial crisis, World Bank Policy Research, Working Paper no. 2286

Meissner CF (1984) Debt: reform without governments. Foreign Policy 56:81–93

Meng H (2013) The formation mechanism and the impact of the exchange rate spread between the RMB offshore and onshore markets – based on the analysis of IS-LM-BP model. Huabei Financ (1):8–10

Meng JJ (2016) Asian emerging-market currencies in the international debt market (1994–2014). J Asian Econ 42:20–32

Mesarovic MD, Takahara Y (1975) General systems theory: mathematical foundations. Academic Press, New York

Meyer DR (2009) Financial centers, international. In: International encyclopedia of human geography. Elsevier, Oxford, pp 146–152

Meyers M (1936) Paris as a financial center. P.S. King, London

Micco A, Stein E, Ordonez G (2003) The currency union effect on trade: early evidence from EMU. Econ Policy 18:316–356

Michaely M (1981) Foreign aid, economic structure, and dependence. J Dev Econ 9(3):313–330

Millner A, Dietz S (2015) Adaptation to climate change and economic growth in developing countries. Environ Dev Econ 20(3):380–406

Mintz I (1951) Deterioration in the quality of foreign bonds issued in the United States, 1920–1930. National Bureau of Economic Reserch, New York

Mishkin FS (1999a) Lessons from the Asian crisis. J Int Money Financ 18(4):709–723

Mishkin FS (1999b) Global financial instability: framework, events, issues. J Econ Perspect 13 (4):3–20

Mishkin FS (2006) The next great globalization. Princeton University Press, Princeton

Mitchell CL (2006) Beyond barriers: examining root causes behind commonly cited cleaner production barriers in Vietnam. J Clean Prod 14(18):1576–1585

Mitchener K, Weidenmeier M (2005) Empire, public goods and the Roosevelt corollary. J Econ Hist 65:658–692

Moe TM (1985) Control and feedback in economic regulation: the case of the NLRB. Am Polit Sci Rev 79(04):1094–1116

Moggridge D (1971) British controls on long term capital movements, 1924-31. In: McCloskey DN (ed) Essays on a mature economy: Britain since 1840. Princeton, Princeton University Press, pp 113–138

Mohaddes K, Pesaran MH (2016) Country-specific oil supply shocks and the global economy: a counterfactual analysis. Energy Econ 59:382–399

Mohanty M (1992) Strategies for solution of debt crisis: an overview. Econ Polit Wkly 27 (9):465–476

Monteforte L, Moretti G (2013) Real-time forecasts of inflation: the role of financial variables. J Forecast 32(1):51–61

Montes MF (1998) The currency crisis in Southeast Asia, Vol 218(2114). Institute of Southeast Asian Studies, Singapore

Moraes CO, Montes GC, Antunes JAP (2016) How does capital regulation react to monetary policy? New evidence on the risk-taking channel. Econ Model 56:177–186

Moro B, Beker VA (2016) Modern financial crises: Argentina, United States and Europe. Springer, Heidelberg

Moulton H, Pasvolsky L (1926) World war debt settlements. Macmillan, New York

Mundell RA (1957) International trade and factor mobility. Am Econ Rev 47:321–335

Mundell RA (1963) Capital mobility and stabilization policy under fixed and flexible exchange rates. Can J Econ Politi Sci/Revue canadienne de economiques et science politique 29 (4):475–485

Mundell RA (1972) In: Salin P, Claassen E (eds) The optimum balance of payments deficit, in stabilization policies in interdependent economies. North-Holland Press, Amsterdam

Mundell RA (2000) Currency areas, volatility and intervention. J Policy Model 22:281–299

Mussa MM, Dell'Ariccia MG, Eichengreen MBJ, Detragiache ME (1998) Capital account liberalization: theoretical and practical aspects, International Monetary Fund, Working paper no. 172

Myoken H (1979) A comparative study on the use of state-space representations for multivariable economic systems and the structural properties. Kybernetes (8):193–201

Nakaso H (2001) The financial crisis in Japan during the 1990s: how the Bank of Japan responded and the lessons learnt, BIS Papers No. 6

Nersisyan Y, Wray LR (2010) The global financial crisis and the shift to shadow banking. Levy Economies Institute

Newman JH (1989) Developing country debt and market reality. In: Bogdanowicz-Bindert CA (ed) Solving the global debt crisis: strategies and controversies by key stakeholders. Harper and Row, New York, pp 165–176

Nguyen QC, Krylov S (2015) Nonlinear tracking control of vibration amplitude for a parametrically excited microcantilever beam. J Sound Vib 338:91–104

Niu WW (2014) The inspiration of the Hong Kong offshore RMB market for the euro dollar market. Southwest Financ (3):23–26

Norman AL (1974) On the relationship between linear feedback control and first period certainty equivalence. Int Econ Rev 15(1):209–215

Norrlof C (2009) Key currency competition: the euro versus the dollar. Coop Confl 44:420–442

Norrlof C (2014) Dollar hegemony: a power analysis. Rev Int Polit Econ 21:1042–1070

Noy I (2004) Financial liberalization, prudential supervision, and the onset of banking crises. Emerg Mark Rev 5(3):341–359

Nyberg P (2001) Opening financial services to competition: the economic and political economy arguments, Http://www.mof.go.jp/english/asem03g.htm. Accessed on 8 July 2016

O'Sullivan-Greene E, Mareels I, Kuhlmann L, Burkitt A (2014) Observability limits for networked oscillators. Automatica 50(4):1087–1099

Obstfeld M (1986) Rational and self-fulfilling balance-of-payments crises. Am Econ Rev 76 (1):72–81

Ogata K (1995) Discrete-time control systems. Prentice Hall, Englewood Cliffs

Okina K, Shirakawa M, Shiratsuka S (2001) The asset price bubble and monetary policy: Japan's experience in the late 1980s and the lessons. In: Monetary and economic studies, Special Edition, pp 395–450

Okubo Y (2003) Financial sector reform in Japan: progress and challenges. In: Demaestri E, Masci P (eds) Financial crises in Japan and Latin America. Inter-American Development Bank, Washington, DC, pp 37–60

Online NewsHour (2010) Russia's Crisis – September 17, 1998. Pbs.org. Retrieved on 3 Nov 2010

Orăştean R (2013) Chinese currency internationalization: present and expectations. Procedia Econ Financ 6:683–687
Orphanides A (2001) Monetary policy rules based on real-time data. Am Econ Rev 91(4):964–985
Orphanides A (2004) Monetary policy rules, macroeconomic stability, and inflation: a view from the trenches. J Money Credit Bank 36(2):151–175
OuYang SC, Miao JH, Wu Y, Lin Y, Peng TY, Xiao TG (2000) Second stir and incompleteness of quantitative analysis. Kybernetes Inter J Syst Cybern 29:53–70
OuYang SC, Chen GY, Lin Y (2009) Digitization of Information and Prediction. Meteorological Press, Beijing
Pacces AM (2010) Uncertainty and the financial crisis. J Financ Transform (29):79–93
Peng L, Wang TS, Guo DL (2011) Effect of the shadow economy and its impact on economic security. J Henan Normal Univ 38(4):55–59
Perkins DH, Woo WT (2000) Malaysia: adjusting to deep integration. In: Woo WT, Sachs J, Schwab K (eds) The Asian financial crisis: lessons for a resilient Asia. MIT Press, Cambridge
Perko L (2013) Differential equations and dynamical systems, vol 7. Springer, New York
Phongpaichit P, Baker CJ (2000) Thailand's crisis. Institute of Southeast Asian Studies, Singapore
Pindyck RS (1977) Optimal economic stabilization policies under decentralized control and conflicting objectives. IEEE Trans Autom Control 2:517–530
Pisani-Ferry J, Posen AS (2009) The euro at ten: the next global currency? Peterson Institute for International Economics, Washington, DC
Polat B, Payaslıoğlu C (2015) Exchange rate uncertainty and FDI inflows: the case of Turkey. Asia-Pac J Account Econ:1–18
Pomfret R (2014) European crises and the Asian economies. J Asian Econ 31:71–81
Ponsot JF (2016) The "four I's" of the international monetary system and the international role of the euro. Res Int Bus Financ 37:299–308
Pontryagin LS (1987) Mathematical theory of optimal processes. CRC Press, New York
Poon M (2009) From new deal institutions to capital markets: commercial consumer risk scores and the making of subprime mortgage finance. Acc Organ Soc 34(5):654–674
Portes R, Rey H (1998) The emergence of the euro as an international currency. Econ Policy 26:307–343
Pozsar Z, Adrian T, Ashcraft A (2010) Shadow banking. In: Federal Reserve Bank of new York Staff Reports. Federal Reserve Bank of New York, New York
Qi HQ, Li MQ (2013) Excess liquidity, CPI inflation measure and change mechanism in China. Res Financ Econ Iss (2):12–17
Qiao B (2013) Research on the development of the offshore RMB market – based on the perspective of RMB internationalization, PhD dissertation, Guangxi University, Nanning, Guanxi, China
Qiu YL (1997) Europe's economic future and destiny. Int Econ Rev (2):49–56
Quesnay F (1759) Tebleau economique. In: Monroe AE (ed) Early economic thought, vol 1923, Cambridge, pp 336–348
Quirk P (1994) Capital account convertibility: a new model for developing countries, IMF Working Paper
Radelet S, Sachs J (1998a) The East Asian financial crisis: diagnosis, remedies, prospects. Harvard Inst Int Dev (1):1–90
Radelet S, Sachs J (1998b) The onset of the East Asian currency crisis, NBER Working paper, 6680
Radelet S, Woo TW (2000) Indonesia: a troubled beginning. In: Woo WT, Sachs J, Schwab K (eds) The Asian financial crisis: lessons for a resilient Asia. MIT Press, Cambridge
Rafiq S (2013) Sources of time-varying trade balance and real exchange rate dynamics in East Asia. J Jpn Int Econ 29:117–141
Rajan RS (2007) Financial crisis, capital outflows, and policy responses: examples from East Asia. J Econ Educ 38(1):92–108

Rajan RG, Zingales L (1998) Which capitalism? Lessons from the east Asian crisis. J Appl Corp Financ 11(3):40–48

Ram YM, Mottershead JE, Tehrani MG (2011) Partial pole placement with time delay in structures using the receptance and the system matrices. Linear Algebra Appl 434(7):1689–1696

Ramirez de la OR (1996) The Mexican peso crisis and recession of 1994 – 1995: preventable then, avoidable in the future? In: Roett R (ed) The Mexican peso crisis: international perspectives. Lynne Rienner, London

Rashidi F, Abiri E, Niknam T, Salehi MR (2015) Optimal placement of PMUs with limited number of channels for complete topological observability of power systems under various contingencies. Int J Electr Power Energy Syst 67:125–137

Ratnayake R (1999) Industry concentration and competition: New Zealand experience. Int J Ind Organ 17(7):1041–1057

Rausch J (2013) Black Wednesday 1992. Crisis scenario around the British pound and one-way-bet scenario. GRIN Verlag GmbH

Rawlings JB, Angeli D, Bates CN (2012) Fundamentals of economic model predictive control. Proceedings of 2012 I.E. 51st annual conference on decision and control, pp 3851–3861

Razin A, Rosefielde S (2011) Currency and financial crises of the 1990s and 2000s. CESifo Econ Stud 57(3):499–530

Reifschneider D, Wascher W, Wilcox D (2015) Aggregate supply in the United States: recent developments and implications for the conduct of monetary policy. IMF Econ Rev 63 (1):71–109

Ren ZQ (1996) The resolution of the difficulties in the research of earth science. In: Wu FH, He XJ (eds) Earth science and development. Earthquake Press, Beijing, pp 298–304

Reports on Government Works (2006) http://www.npc.gov.cn/npc/dbdhhy/11_4/2011-03/15/content_1647404.htm. Accessed on 31 Dec 2015

Rey H (2001) International trade and currency exchange. Rev Econ Stud 68(2):443–464

Rey H (2015) Dilemma not trilemma: the global financial cycle and monetary policy independence, National Bureau of Economic Research, working paper no. w21162

Ren ZQ, Nio T (1994) Discussions on several problems of atmospheric vertical motion equations. Plat Meteorol 13(1):102–105

Rhodes WR (1989) A negotiator's view. In: Bogdanowicz-Bindert CA (ed) Solving the global debt crisis: strategies and controversies by key stakeholders. Harper and Row, New York, pp 19–28

Ricardo D (1817) On the principles of political economy and taxation. Reprint by Dover Publications in 2004

Richalet J (1978) Model predictive heuristic control: applications to industrial processes. Automatica 14(5):413–428

Rickards J (2012) Currency wars: the making of the next global crisis, reprint edn. Portfolio, an imprint within Penguin Group

Riding A (1987) Brazil to suspend interest payment to foreign banks, New York Time, February 21

Ries CP, Sweeney R (1997) Capital controls and corporate investment behavior. In: Capital controls in emerging economies, vol 174, p 89

Rivadeneira PS, Moog CH (2015) Observability criteria for impulsive control systems with applications to biomedical engineering processes. Automatica 55:125–131

Rodrik D, Subramanian A (2009) Why did financial globalization disappoint? IMF Staff Pap 56 (1):112–138

Roll R, Solnik B (1979) On some parity conditions encountered frequently in international economics. J Macroecon 1(3):267–283

Rose AK (2000) One money, one market: the effect of common currencies on trade. Econ Policy 15:9–45

Rose AK, van Wincoop E (2001) National money as a barrier to international trade: the real case for currency union. Am Econ Rev 91:386–390

Rosen RJ (2009) Too much rights can make a wrong: setting the stage for the financial crisis, Working Paper, Federal Reserve Bank of Chicago

Rossi M (1999) Financial fragility and economic performance in developing economies: do capital controls, prudential regulation and supervision matter? IMF Working Paper

Rotberg E (1989) The politics of the debt crisis. In: Bogdanowicz-Bindert CA (ed) Solving the global debt crisis: strategies and controversies by key stakeholders. Harper and Row, New York, pp 3–16

Rüffer R, Stracca L (2006) What is global excess liquidity, and does is matter?, European Central Bank, Working Paper, No. 696

Sachs J (1989) Introduction. In: Sachs JD (ed) Developing Country Debt and Economic Performance, vol. 1, chapter 1. University of Chicago Press, Chicago

Sadaka H, Shafai B, Sipahi R (2009) Robust PI observer design for linear time-delay systems. IEEE International Conference on Control Application. pp 1535–1539

Salant S, Henderson D (1978) Market anticipations of government policies and the price of gold. J Polit Econ 86:627–648

Samuelson PA (1982) Bertil Ohlin 1899 – 1979. J Int Econ 12(1):31–49

Samuelson PA (2000) Japan's future financial structure. Jpn World Econ 12(2):185–187

Sarno L, Taylor MP (1999) Hot money, accounting labels and the permanence of capital flows to developing countries: an empirical investigation. J Dev Econ 59(2):337–364

Sassen S (2015) Cities: capital, global, and world. In: International encyclopedia of the Social & Behavioral Sciences, 2nd edn, pp 585–592

Sayers R (1976) The Bank of England 1891–1944. Cambridge University Press, Cambridge

Schimmel K, Liu SF, Nicholls J, Nechval NA, Forrest YLJ (2017) Economic security under disturbances of foreign capital, Adv Syst Sci Appl 17(2):14–28

Schneider B (2001) Issues in capital account convertibility in developing countries. Dev Policy Rev 19(1):31–82

Schneider F, Enste DH (2013) The shadow economy: an international survey. Cambridge University Press, Cambridge

Schneider F, Klinglmair R (2004) Shadow economies around the world: what do we know? Working Paper, Department of Economics, Johannes Kepler University of Linz, No. 0403

Schneider F, Raczkowski K, Mróz B (2015) Shadow economy and tax evasion in the EU. J Money Laund Control 18(1):34–51

Schularick M, Taylor A (2012) Credit booms gone bust: monetary policy, leverage cycles, and financial crises, 1870–2008. Am Econ Rev. forthcoming

Seierstad A, Sydsaeter K (1986) Optimal control theory with economic applications. Elsevier, North Holland

Shanhian B, Hassul M (1992) Control system design using MATRIX. Prentice-Hall, Englewood Cliffs

Shaw ES (1973) Financial deepening in economic development. Oxford University Press, New York

Shefrin HM, Thaler RH (1981) An economic theory of self-control. J Polit Econ 89(2):392–406

Shen J, Zheng XW (2015) Positivity and stability of coupled differential–difference equations with time-varying delays. Automatica J IFAC Int Fed Autom Control 57:123–127

Shilnikov LP, Shilnikov AL, Turaev DV, Chua LO (1998) Methods of qualitative theory in nonlinear dynamics. World Scientific, Singapore

Siebrand JC, Buiter WH, Flemming JS (1988) Macroeconomic modelling for economic policy. In: Contributions to economic analysis, vol 178, pp 99–135

Skidelsky R (2015) Keynes, John Maynard (1883–1946). In: Wright J (ed) International encyclopedia of the social & behavioral sciences, 2nd edn. Elsevier, pp 14–19

Skrobec QR (2015) The 100 most important American financial crises: an Encyclodiedia of the lowest points in American economic history. Greenwood, Santa Barbara

Slater R (1996) Soros: the life, times & trading secrets of the world's greatest investor. McGraw-Hill, New York

Smith A (1776) An inquiry into the nature and causes of the wealth of nations. W. Strahan and T. Cadell, London

Smith CE (1996) International perspectives on the Mexican peso crisis: an introduction. In: Roett R (ed) The Mexican peso crisis: international perspectives. Lynne Rienner, London

Smith A (2012–10-31) Eurozone unemployment hits record high. Money.cnn.com. Retrieved 2013–08-17

Smith VL, Suchanek GL, Williams AW (1988) Bubbles, crashes, and endogenous expectations in experimental spot asset markets. Econometrica 56(5):1119–1151

Sobel R (1999) When giants stumble: classic business blunders and how to avoid them. Prentice Hall, Paramus

Solnik BH (1974) Why not diversify internationally rather than domestically? Financ Anal J 30:48–54

Soros G (2010) The crisis and the Euro. The New York Review of Books

Spero JE (1980) Failure of the Franklin National Bank: challenge to the international banking system. Columbia University Press, New York

Springer GL, Molina JL (1995) The Mexican financial crisis: genesis, impact, and implications. J Interam Stud World Aff 37(2):57–81

Stiglitz JE (1998) Boats, planes and capital flows, Financial Times, 03/25/1998

Stiglitz JE (2002) Globalization and its discontents, vol 500. Norton, New York

Storper M, Scott AJ (1995) The wealth of regions: market forces and policy imperatives in local and global context. Futures 27(5):505–526

Su J (2014) On development of off shore RMB market. China Opening J 3:62–64

Su P, He YX, Tang A (2014) Study of impact on domestic monetary policy of the Hong Kong RMB offshore market. Southwest Financ (3):16–19

Subramanian A (2011) Renminbi rules: the conditional imminence of the reserve currency transition, Peterson Institute for International Economics Working Paper 11–14

Subramanian N, Rahman S, Abdulrahman MD (2015) Sourcing complexity in the Chinese manufacturing sector: an assessment of intangible factors and contractual relationship strategies. Int J Prod Econ 166:269–284

Sun HY, Ma Y (2005) Policy strategies to deal with revaluation pressures on the renminbi. China Econ Rev 16(2):103–117

Sun J, Wei XH, Tang AP (2005) Strategic path choice of internationalization of RMB based on the developmental process of three main currencies. Asia Pac Econ Rev 2:69–71

Suplisson AW, Cobb R, Baker W, Jacques D (2015) An optimal control approach to aircraft automatic ground collision avoidance, Proceedings of AIAA guidance, navigation, and control conference. p 1316

Sussmann HJ, Willems JC (1997) 300 years of optimal control: from the brachystochrone to the maximum principle. Control Syst IEEE 17(3):32–44

Syriopoulos T, Makram B, Boubaker A (2015) Stock market volatility spillovers and portfolio hedging: BRICS and the financial crisis. Int Rev Financ Anal 39:7–18

Tanzi V (1999) Uses and abuses of estimates of the underground economy. Econ J 109 (456):338–347

Taylor B, Fankhauser RA, Fowler T (2009) Financial impact of a capitation matrix system on total knee and total hip arthroplasty. J Arthroplast 24(5):783–788

The World Bank (2013) The 2013 annual report, at http://www.worldbank.org/en/publication/reference, Accessed on 23 June 2014

Tian WH (2013) Study on the properties of General Delta operators. Press of Qingdao University, Qingdao

Triffin R (1960) Gold and the dollar crisis: the future of convertibility. Yale University Press, New Haven

Tschoegl AE (2009) Who owns the major US subsidiaries of foreign banks?: a note. J Int Finan Markets Inst Money 14(3):255–266

Tsuyuguchi Y, Wooldridge PD (2008) The evolution of trading activity in Asian foreign exchange markets. Emerg Mark Rev 9(4):231–246
U.S. Department of the Treasury (2016) China holds US$1,190 billion worth of US treasury securities, https://www.treasury.gov/Pages/default.aspx, Accessed 23 Jan 2017
UNCTAD (2012) World investment report 2012: towards a new generation of investment policies. United Nations Conference on Trade and Development
United Nations (1948) Public Debt, 1914–1946, Department of Economic Affairs, (Lake Success, New York, 1948: United Nations)
Van Dam A (1977) The future of global business forecasting. Bus Horiz 20(4):46–50
Vasconcellos GM, Kish RJ (1998) Cross-border mergers and acquisitions: the European–US experience. J Multinatl Financ Manag 8(4):431–450
Vernon R (1966) International investment and international trade in the product cycle. Q J Econ 80(2):190–207
Vine SL, Chen BQ, Polak J (2014) Does the income elasticity of road traffic depend on the source of income? Transp Res A Policy Pract 67:15–29
von Bertalanffy L (1924) Einfuhrung in Spengler's werk. Literaturblatt Kolnische Zeitung, May
Wade R (2001) From 'miracle' to 'cronyism': explaining the great Asian slump. In: Chang HJ, Palma G, Whittaker DH (eds) Financial liberalization and the Asian crisis. Palgrave, New York, pp 63–81
Wade R, Veneroso F (1998) The Asian crisis: the high-debt model vs. the Wall Street-treasury-IMF complex, New Left Review, March/April, 323
Wagner WH, Lau SC (1971) The effect of diversification on risk. Financ Anal J 27:48–54
Wall K, Westcott J (1974) Macroeconomic modeling for control. IEEE Trans Autom Control 19(6):862–873
Wang Y (1985) A simplified computational scheme for pole assignment problem. Control Theory Appl 2(1):115–120
Wang PB (1998) The process and thinking of Hong Kong dollar defense in august. J Shanghai Financ (4):60–62
Wang SC (2008) On RMB's internationalization. Contemp Internal Relat 8:29–33
Wang J (2009) The impact of the global financial crisis on the countries of Eastern Europe: causes and countermeasures. World Econ Outlook (6):4–9
Wang YL (2012a) 2012 Global outlook: Chinese and the United State to compete for currency influence, http://www.docin.com/p-985514784.html
Wang YL (2012b) On the strategy of global currency influence of both Chinese and united state. Acad J Zhongzhou (4):44–48
Wang FQ (2014) The circulation mechanism between the offshore and onshore RMB market – based on the Kalman filter applied in state space model. J Financ Dev Res (04):33–36
Wang D (2015) The Future of RMB. Shanghai Scientific and Technological Literature Press, Shanghai
Wang Y, Gao X (2015) RMB accepted into SDR: Meeting the historical moment, Shanghai Securities News, December 1, 2015
Wang RX, Hu GH (2005) International finance. Press of Wuhan University of Science and Technology, Wuhan, Hubei
Wang H, Liu HY (2009) Research on the RMB offshore market and the domestic market information transmission – empirical analysis based on the NFD exchange rate and the base period exchange rate. Financ Theory Pract (3):341–454
Wang Y, Wang XF (1995) The base of automatic control. Higher Education Press, Beijing
Wang ZS, Wang DB (2006) Optimal control with ideal control strategy and expected trajectory. Control Decis 21(1):100–103
Wang LS, Xia YQ (2015) Observability analysis of Mars entry integrated navigation. Adv Space Res 56(5):952–963
Wang GJ, Xie C (2013) Cross-correlations between Renminbi and four major currencies in the Renminbi currency basket. Physica A Stat Mech Appl 392(6):1418–1428

Wang SC, Liu YQ, Hu QL (2005) Study of the observer-based robust control problem. J Harbin Engineering Univ 26(3):409–413
Wang XB, Yu CY, Zhang JH (2009) Can controlling capital flow suppress currency crises? – an empirical analysis based on panel logit model. Res Financ Econ Issues 3:64–69
Watts J (2011) China's environment in 2020. In: China 2020, pp 113–135
Weintraub RE (1984) International debt: crisis and challenge. Cato J 4(1):21–61
Weller CE (2001) Financial crises after financial liberalisation: exceptional circumstances or structural weakness? J Dev Stud 38(1):98–127
Westcott JH (1977) An experiment on controlling a national economy. In: Bensoussan A, Lions JJ (eds) New trends in systems analysis. Springer, Berlin, pp 591–611
Wilhalm R, Baynes C (1967) The I Ching or book of changes, 3rd edition edn. Princeton University Press, Princeton
Wilhelmus HA, Schilders HA, van der Vorst JR (2008) Model order reduction: theory, research aspects and applications. Springer, Berlin
Williamson J (1985) On the optimal currency peg for developing countries: reply. J Dev Econ 18 (2–3):561–562
Williamson OE (1995) Transaction cost economics. Free Press, New York
Williamson J (1997) Orthodoxy is right: liberalize the capital account last. In: Capital controls in emerging economies, vol 174, pp 13–16
Williamson J (1998) Whither financial liberalization. In: Keynote address delivered at the second annual Indian derivatives conference, vol 12, Mumbai
Willis HP (1901) A history of the Latin monetary union. University of Chicago Press, Chicago
Wilson JD (1986) The chase: the chase Manhattan Bank, N. A., 1945–85. Harvard Business School Press, Cambridge, MA
Winkler M (1933) Foreign bonds, an autopsy: a study of defaults and repudiations of government obligations. Roland Swain, Philadelphia
Wisman JD (2012) Wage stagnation, rising inequality and the financial crisis of 2008. Cambridge J Econ 37(4):921–945
Wójcik D (2009) Governance, corporate. In: International encyclopedia of human geography, pp 600–605
World Bank (2012) World development indicators database, www.data-bank.worldbank.org
World Bank (various years) Global development finance. World Bank, Washington, DC
Wu XM (1990) The pansystems view of the world. Press of Chinese People's University, Beijing
Wu Y, Lin Y (2002) Beyond nonstructural quantitative analysis: blown-ups, spinning currents and the modern science. World Scientific, River Edge
Wu JL, Liu F (2004) Control and decision model of macro-economy movement. Control Decis 19 (5):550–553
Xiao DR, Lu ZY (2002) Analysis of macroeconomic system using robust control theory. Control Decis 17(5):629–630
Xie SQ (2008) The research on estimate and macro-economy effect of the underground economy's scale in China, PhD dissertation, Jilin University, pp 99–100
Xiu J (2012) The empirical study of relevance of different market rate, during the internationalization of RMB based on the data of CNY, CNH and NDF markets. South China Financ (8):17–22
Xu MQ (2005) The internationalization and regionalization of RMB: drawing the experiences and lessons from the internationalization of Japanese yen. World Econ Stud 12:39–44
Xu YG (2008) Financial liberalization: path and its effects. China Economic Press, Beijing
Xu NN (2014) China-ASEAN cooperation will have a major breakthrough in 2015, The official archive, located at http://fta.mofcom.gov.cn/article/shidianyj/201412/19716_1.html, Accessed on Dec 21 2014
Xu HT (2016) Domestic railroad infrastructure and exports: evidence from the silk route. China Econ Rev 41:129–147

Xu L, Su J (2016) From government to market and from producer to consumer: transition of policy mix towards clean mobility in China. Energy Policy 96:328–340

Yang YH, Liu XH (2009) Observer-based robust predictive control of singular systems with time-delay and parameter uncertainties. J Syst Eng Electron 3(20):590–597

Yang L, Zhang X (2016) Assessing regional eco-efficiency from the perspective of resource, environmental and economic performance in China: a bootstrapping approach in global data envelopment analysis. J Clean Prod. In Press, Corrected Proof, Available online 28 July 2016

Yang F, Zhang QL, Zhai D (2004) Optimal control of dynamic economic systems with state constraint. J Northeastern Univ 25(5):475–477

Yao HX, Sheng ZH (2002) Improved method for feedback control in economic chaotic model. J Syst Eng 17(6):507–511

Ye YQ (1984) Theory of limit cycles. Shanghai Scientific and Technical Publishers, Shanghai

Yee H (2012) Analyzing the state-accounting profession dynamic: some insights from the professionalization experience in China. Acc Organ Soc 37(6):426–444

Ying YR (2015) Golden brick tower: strategies for capital account liberation of the BRICS. Shanghai University Press, Shanghai

Ying YR (2016) Gold brick can be engraved: the strategy of capital account liberation of the BRICs. Press of Shanghai University, Shanghai

Ying YR, Forrest YLJ (2015) Capital account liberation: methods and applications. CRC Press, an imprint of Taylor and Francis, New York

Ying YR, Ye Y (2016) Research on behavior of capital flight: an analysis of evolutionary game theory. Int J Hybird Inf Technol 9(11):337–352

Yu LN, Xie HZ (2011) Spillover effect of monetary policy: causes, influence and strategies. J Graduate School of Chinese Academy of Social Sciences (1):51–57

Yuan CM, Chen R (2015) Policy transmissions, external imbalances, and their impacts: cross-country evidence from BRICS. China Econ Rev 33:1–24

Zacharias J, Tang YZ (2010) Restructuring and repositioning Shenzhen, China's new mega city. Prog Plan 73(4):209–249

Zafiriou E (1990) Robust model predictive control of processes with hard constraints. Comput Chem Eng 14(4):359–371

Zaman K, Abdullah AB, Khan A, Mohd-Nasir MRB, Hamzah TA, Hussain S (2016) Dynamic linkages among energy consumption, environment, health and wealth in BRICS countries: green growth key to sustainable development. Renew Sust Energ Rev 56:1263–1271

Zhang SM (2003) An analysis on demonstrative effect of financial crisis and devaluation effect of competitiveness – the revelation of China's transitional economy with the opening condition. World Econ Stud 3:36–40

Zhang YS (2009) Research on economic globalization and world crisis relationship. Macroeconomics 10:3–8

Zhang YL (2014) From state to market: private participation in China's urban infrastructure sectors, 1992–2008. World Dev 64:473–486

Zhang ZJ, Zhang QR (1981) State space realization of linear econometric system. Inf Control (4):1–14

Zhang LQ, Zhang QH (2015) Observability conservation by output feedback and observability Gramian bounds. Automatica 60:38–42

Zhang L, Zhao SXB (2009) City branding and the Olympic effect: a case study of Beijing. Cities 26(5):245–254

Zhang J, Gay H, Kummer D (2006) Can RMB appreciation reduce the US trade deficit? Chin World Econ 14(1):44–56

Zhang J, Liu S, Liu J (2014) Economic model predictive control with triggered evaluations: state and output feedback. J Process Control 24(8):1197–1206

Zhang ZW, Makin AJ, Bai QX (2016) Yen internationalization and Japan's international reserves. Econ Model 52(Part B):452–466

Zheng DZ (1990) Linear systems theory. Press of Qinghua University, Beijing

Zhou R (1997) Currency exchange in a random search model. Rev Econ Stud 64:289–310
Zhou T (2015) On the controllability and observability of networked dynamic systems. Automatica 52:63–75
Zhou MR, Guo JQ (2004) Abandonment costs, government preference, and control on capital flow – a prudent opportunism exchange rate regime choice model. Econ Res (5):423–430
Zhou SP, Wang J, Wang HB (1998) The role of macroeconomic regulation and control policy coordination in the “soft landing” of the economy. Econ Res J (2):31–37
Zhou C, Chen MY, Zhu DS (2002a) The controllability of general systems. J Huazhong University of Science and Technology (Nature Science) 30(8):34–36
Zhou D, Li S, David KT (2002b) The impact of FDI on the productivity of domestic firms: the case of China. Int Bus Rev 11(4):465–484
Zhu JM (2002) Industrial globalisation and its impact on Singapore’s industrial landscape. Habitat Int 26(2):177–190
Zhu SZ, Han J (2015) The causes and hazards of the Russian currency crisis and enlightenment to China. Financ Econ (4):11–21
Zubov NE, Mikrin EA, Misrikhanov MS, Ryabchenko VN (2013) Modification of the exact pole placement method and its application for the control of spacecraft motion. Int J Comput Syst Sci 52(2):279–292

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