

Food Security, Poverty and Nutrition Policy Analysis

Statistical Methods and Applications

Suresh C. Babu • Prabuddha Sanyal



To

Per Pinstrup-Andersen

Humanist, Food & Nutrition Economist and Teacher

Food & Nutrition Economist par Excellence

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Preface

This book has its conceptual origin from the lecture materials of the training courses taught by one of the authors in the early nineties. It was during this period that in several developing nations, particularly in Africa, even when the signs of widespread hunger and abject poverty were visible, policy makers did not act for want of 'empirical evidence'. Some policy makers even dismissed the severity of the problem saying that the hunger reports prepared by government officials were not rigorous enough to take them seriously. Some decision makers entirely rejected the reports prepared by the officials, stating that the analysis of data was 'not statistically sound' to draw reliable inference and undertake the desirable public actions. The final result was inaction on the part of the policy makers. Little has changed since then as evidenced by the continuing food crises in several countries. Generating empirical evidence on causal factors and severity of food insecurity and poverty problems becomes more urgent also in the context of the recent sharp increases in global food prices.

The capacity to collect, process and analyze data on food security, nutrition and poverty problems continues to remain low in many developing countries. While students are trained adequately in their individual fields of specialization, such as nutrition, economics, sociology, political science, international development, anthropology and geography, they are often ill prepared for the task of policy analysts in the governments, academic and research institutions, civil society organizations and the private sector. Developing applied policy analysis skills requires a combination of several related abilities in statistical data analysis, computer literacy and using the results for developing policy alternatives. In addition, an understanding of issues, constraints and challenges facing policy makers on particular hunger, malnutrition and poverty problems is critical.

This book is largely motivated by and based on three decades of food and nutrition policy research at the International Food Policy Research Institute. In the mid-nineties, the data based statistical methods were combined with selected case studies from IFPRI research on food and nutrition security issues to form a training manual. It was well received among the training institutions and university departments teaching courses on food security and nutrition policy analysis both in the North and in the South. Selected contents of this manual were taught by one of the authors over the years at various institutions in many parts of the world including University of Maryland, University of Sweden, University of Hohenheim, Tufts University, University of Malawi, University of Zimbabwe, Indian Agricultural Research Institute, Andhra Pradesh Agricultural

University, Eduardo Mondlane University, Ghana University of Development Studies and Lamolina University.

This book, a substantially revised version of the manual, attempts to impart the combined skills of statistical data analysis, computer literacy and using the results for developing policy alternatives through a series of statistical methods applied to real world food insecurity, malnutrition and poverty problems. It bases its approach of combining case studies with data based analysis for teaching policy applications of statistical methods from several training courses and class lectures taught in the last fifteen years. Thus, this version has the benefit of the feedback and comments from the users of the earlier version of the manual and the participants of the above training courses. It contains new sections on some advanced statistical methods, including poverty analysis and linear programming for solving diet problems. It has been prepared to cover a semester long course of fifteen weeks.

The book is primarily addressed to students with a bachelor degree who have familiarity with food security, nutrition and poverty issues and who have taken a beginners' course in statistics. It is ideally suited for first year postgraduate courses in food sciences, nutrition, agriculture, development studies, economics and international development. The book is self-contained with its downloadable dataset, statistical appendices, computer programs and interpretation of the results for policy applications. It could be used as course material in face-to-face and distance learning programs.

We hope that the book will be useful in developing a new generation of policy analysts who are well equipped to address the real world problems of poverty, hunger and malnutrition, whose reports will not be rejected for want of empirical evidence and will result in swift public and private action.

Introduction

The nature and scope of food security, poverty and nutrition policy analysis

Problems related to increasing food availability, feeding the population, improving their nutritional status and reducing poverty levels continue to confront decision makers in many developing and developed countries. Program managers and policy makers who constantly deal with design, implementation, monitoring and evaluation of food security, nutrition and poverty related interventions have to make best decisions from a wide range of program and policy options. Information for making such policy and program decisions must be based on sound data-based analysis. Such analysis should be founded on statistical theory that provides an inferential basis for evaluating, refining and, sometimes, rejecting the existing policy and program interventions.

This book deals with the application of statistical methods for analysis of food security, poverty and nutrition policy and program options. A range of analytical tools is considered that could be used for analyzing various technological, institutional and policy options and for developing policy and program interventions by making inferences from household level socioeconomic data.

The objective of policy analysis is to identify, analyze and recommend policy options and strategies that would achieve the specific goals of policy makers (Dunn, 1994). Issues related to increasing food security, reducing malnutrition and alleviating poverty are high on the global development policy agenda as evidenced by recent unprecedented increases in food prices, resultant unrest in several developing countries and a series of international summits convened to mitigate the effects of food price increase (UN Summit, 2008). This book addresses a wide range of policy and program options typically designed and implemented by government agencies, non-governmental organizations and communities to address the development challenges such as hunger, poverty and malnutrition faced by households and communities.

Such policy and program options, for example, aim at increasing the availability of food, increasing the household entitlement, improving the efficiency of food distribution programs, enhancing the market availability for selling and buying food commodities, reducing malnutrition through the school feeding and nutrition programs, increasing technological options through introduction of high yielding varieties of seeds that farming communities in rural areas could grow to increase income, investing in technological advancements, implementing land reforms and distribution of land to poor households, increasing the

education of mothers, improving child-care and promoting changes in consumption patterns and so on. Using such real world policy options and interventions as case studies, the chapters of this book attempt to show how using the analysis of socioeconomic datasets can help in the development of policy and program interventions. The chapters also introduce various approaches to the collection of data, processing of collected data and generation of various socioeconomic variables from the existing datasets. They also demonstrate applications of analysis of the relationship between causal policy variables and welfare indicators that reflect household and individual food security, nutrition and poverty.

Why should a book that teaches statistical methods for analyzing socioeconomic data for generating policy and program options be important?

The goal of the decision maker is to select the best option for intervention from a set of choices that are politically feasible and economically viable. Yet making such decisions requires a full understanding of the intended and unintended consequences of the proposed interventions. While the need for rigorous analysis – through assessment of the existing situation – is largely recognized by the policy decision makers before taking necessary action, the needed capacity for undertaking such analysis is grossly lacking in many countries. Hence much of the policy and program decisions related to food security, poverty and nutrition continue to be made under the veil of ignorance.

Improved capacity for food security, poverty and nutrition policy analysis is essential for achieving the Millennium Development Goals (MDG) (UN, 2005). At the global level, the major Millennium Development Goal of ‘reducing hunger, poverty and malnutrition by half by the year 2015’ remains unachievable in many parts of the world. It has been recognized that one of the major constraints in attaining the MDGs related to hunger and malnutrition is the lack of capacity for scaling up of food and nutrition interventions (World Bank, 2006). Scaling up requires capacity for monitoring, evaluation and adoption of successful food and nutrition programs. Such capacity is severely lacking at the global, national and local levels.

A good conceptual understanding of the issues related to food and nutrition, economic concepts, statistical techniques and policy applications with case studies will help in understanding how quantitative analysis could be used for designing program and policy interventions. Students who take up jobs that involve designing, implementing, monitoring and evaluation of development programs are often ill prepared to undertake these tasks. Based on one statistical course students take in the undergraduate program and with their little exposure to food and nutrition issues, for example, they are expected to perform the role of policy and program analysts. Even if they are well trained in the individual disciplines such as food and nutrition, statistics, monitoring and evaluation, or policy analysis, they are often not adequately trained to combine these disciplines to address real world food and nutrition challenges.

A book that brings together concepts and issues in food security, nutrition and poverty policy analysis in a self-learning mode can serve thousands of policy

analysts, program managers and prospective students dealing with designing, implementing, monitoring and evaluation of food security, nutrition and poverty reduction programs.

Objectives of the book

The purpose of this book is to provide readers with skills for specifying and using statistical tools that may be appropriate for analyzing socioeconomic data and enable them to develop various policy and program alternatives based on the inferences of data analysis.

The chapters of the book introduce a wide range of analytical methods through the following approaches:

- review a broad set of studies that apply various statistical techniques and bring out inferences for policy applications
- demonstrate the application of the statistical tools using real world datasets for policy analysis
- use the results of the analysis for deriving policy implications that provide useful learning for policy analysts in designing policy and program options.

Organization of the book

The fifteen chapters of the book are organized into three broad sections. The first section deals with food security policy analysis, the second section addresses nutrition policy analysis and the third section covers the special and advanced topics on food and nutrition policy analysis including measurement and determinants of poverty. This section also provides an introduction to modeling with linear programming methods.

To show the interconnectedness of the issues addressed by the chapters of this book to broad development goals, [Figure I.1](#) identifies the placement of the chapters as they relate to specific policy challenges. The broad conceptual approach used throughout this book, explained later in greater detail, is also depicted in [Figure I.1](#).

The conceptual framework outlined in [Figure I.1](#) is a tool for analyzing the impacts of policies and programs on food and nutrition security outcomes at the household level. It links various policies at the macro, meso (markets) and micro (household) levels (Metz, 2000). Economic changes induced by various macro policies influence markets which, in turn, affect food security at the household level. Food entitlements in terms of availability and access to food at the household level are affected by various policy interventions. Both macroeconomic (exchange rate, fiscal and monetary policies) and sector-specific policies (agriculture, health, education and other social services) affect markets, infrastructure and institutions. The markets can be subclassified into food markets and other markets for essential consumer goods, production inputs and credit.

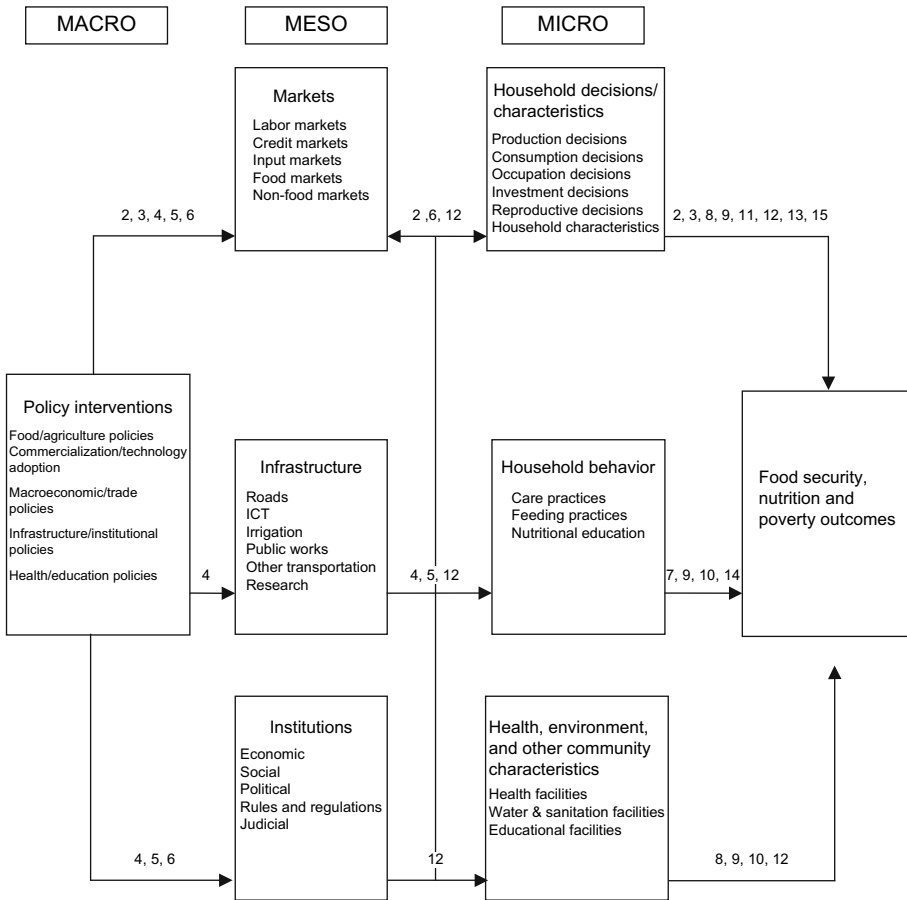


Figure I.1 Conceptual framework for designing food and nutrition security interventions*. *Numbers denote linkage across chapters in this book. (Source: adapted from Metz, 2000)

The main issues addressed in the chapters of this book relate to policy changes that affect food security through these markets. Infrastructure comprises the economic, social, as well as physical infrastructure; institutions are also affected by policy changes and affect household food security.

Changes induced by policies on different markets and on infrastructural factors affect household incomes, assets, human capital and household behavioral changes. The above factors in turn determine household food security as well as household resources devoted to food production. Income is one of the major determinants of household food security.

Both the supply and the demand factors determine the level of household food entitlement. *Household food security* is achieved if subsistence production and household food purchases are sufficient to meet the household food

requirements. *Nutrition security*, on the other hand, is determined by a complex set of interactions between food and non-food determinants. For example, non-food determinants, such as the quality of health care facilities and services, education, sanitation, clean water, caring practices and effective mechanisms for delivering these services are important in improving the nutritional situation (IFPRI, 1995).

The above conceptual framework could be used to illustrate the linkages of the chapters of this book. Chapter 1 presents an introduction to the concepts, indicators and causal factors of household food security and nutritional outcomes.

In Chapter 2, we address the following issues:

1. to what extent adoption of new technologies improves household or individual food consumption
2. how does technology adoption in agriculture including post-harvest technologies translate into improved food security?

From the arrows in the diagram, we see that agricultural policies, such as technology adoption or commercialization, have close linkages to food and nutrition security, through securing food production and supply. The linkages are given by arrows bearing number 2.

Similarly, for example, Chapter 6 addresses the issue of how market access plays an important role in the agricultural food markets and thus affects household food security. Since marketing and pricing policies are affected by both supply and demand side of the food economy, it is important for national governments simultaneously to provide incentive prices to producers in order to increase their incomes and to protect consumers against rapid price fluctuations to ensure steady food supplies. One of the ways that government marketing and pricing policies can reduce price instability is by allowing the private sector to participate in the market along with state parastatals through alteration of the infrastructural and institutional policies that affect food markets. The linkages are given by arrows bearing number 6.

As another example, in Chapter 10, we address the pathways through which maternal education improves child health. These pathways help us in understanding the impact of community characteristics (such as presence of hospitals and water and sanitation conditions) on child nutritional status. Social infrastructure, such as the presence of medical centers and improved water and sanitation conditions, can be beneficial for certain subgroups of the population, such as the low-income and less educated households. The time saved by not traveling to a medical center can be reallocated to leisure, health production and other agricultural activities, which can improve household productivity and child nutritional status. As indicated by arrows with number 10, health and education policies, through their effect on markets and social infrastructure, can lead not only to improved provision of services but also alter household behavior through better child-care and hygienic practices, which can eventually improve child nutritional status.

Rationale for statistical methods illustrated in the book

Before launching into an analytical technique, it is important to have a clear understanding of the form and quality of the data. The form of the data refers to whether the data are categorical or continuous. The quality of the data refers to the distribution, i.e. to what extent it is normally distributed or not. Additionally, it is important to understand the magnitude of missing values in observations and to determine whether to ignore them or impute values to the missing observations. Another data quality measure is outliers and it is important to determine whether they should be removed.

Quantitative approaches in this book consist of descriptive, inferential and non-inferential statistics. Descriptive statistics organize and summarize information in a clear and effective way (for example, means and standard deviations). Inferential statistics analyze population differences, examine relationships between two or more variables and examine the effect of one variable or variables on other variables. The key distinction for inferential and non-inferential techniques is in whether hypotheses need to be specified beforehand. In the latter methods, normal distribution is not a pre-requisite. For example, in cluster analysis, one can use continuous or categorical variables to create cluster memberships and there is no need for a predefined outcome variable.

The choice and application of analytical tools is largely motivated by policy and program issues at hand and the type of data that is collected which, in turn, is related to the policy and program objectives. In inferential methods, users can draw inferences about the population from a sample because it provides a measure of precision or variation with regard to the sample data. Inferential methods generally focus on parameter estimation and its changes over time. The primary inferential procedures are confidence intervals and statistical tests. While confidence intervals can be used both for point and interval estimates, statistical tests are ways to determine the probability that a result occurs by chance alone.

Different objectives related to the question at hand and the types of data necessitate that the user choose an analysis from a number of possible approaches. The selection of a statistical procedure must consider the following key characteristics: independence of samples; type of data; equality of variances; and distribution assumptions. The conceptual diagram (Figure I.2) illustrates how an analysis can be undertaken using different approaches for bivariate and multivariate statistical procedures.

The conceptual diagram can be understood with the following questions and answers that lead to the appropriate statistical technique:

1. how many variables does the problem involve? For example, are there two variables or more than two variables?

A question related to the first one is how does one want to treat the variables with respect to the scale of measurement? For example, are they both categorical (which

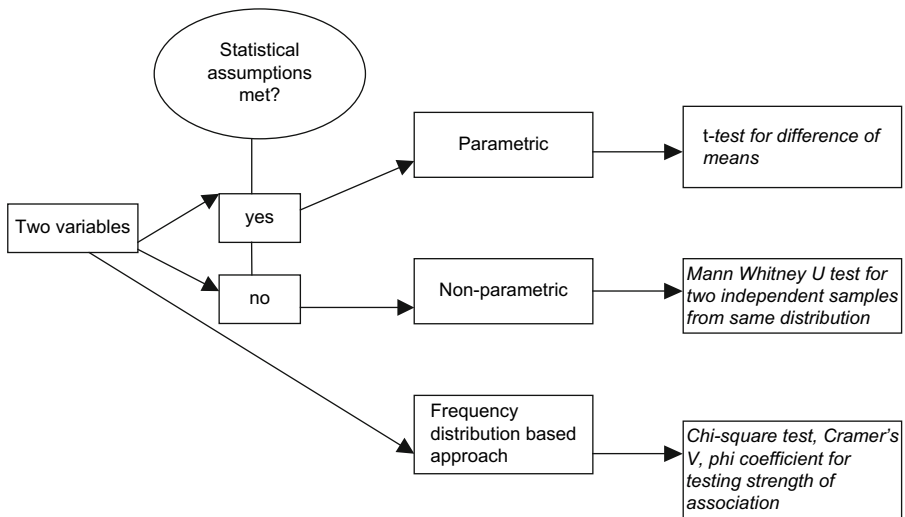


Figure I.2 Statistical procedures to test for determinants of food security, nutritional status and poverty.

includes nominal and ordinal variables)? Nominal variables are unordered categorical variables, such as sex of the child, while ordinal variables are ordered ones. For example, height of a child can be converted into short, average and tall.

2. what do we want to know about the distribution of the variables? For example, in the case of a continuous variable, is the distribution normal? One can test this condition by superimposing the normal density over the histogram of the variable or by drawing a Q-Q plot.

Examples of statistical tests used in this book

In the case of both the variables being nominal, with no distinction made between a dependent and an independent variable, one can measure association using a statistic based on the number of cases in each category. Various statistics based on the number of cases in each category are chi-square, Cramer's V and phi or the contingency coefficient as illustrated in Chapters 3 and 4.

In contrast, in the case of two variables being continuous and no distinction being made between a dependent and an independent variable, one can test whether the means on the two variables are equal (for example, in Chapter 2, we address whether food security differs between the hybrid maize growers versus non-growers). The difference of the means can be inferred using the *t*-test.

In the case of two variables, with one being nominal and the other continuous (the continuous variable being dependent), one can test the null hypothesis of statistical significance of differences between groups. By assuming homoscedasticity across levels of the independent variable, one can undertake an analysis of variance (ANOVA)/*F*-test. In Chapter 5, we address the issue of whether the

share of calories from various food groups differs across households classified by different expenditure brackets. Since the per capita expenditure of different food groups is continuous and the expenditure brackets are nominal, this approach is appropriate.

It is important to mention here by way of digression that while t - and F -tests are based on assumptions such as equal variances and normality, data are rarely examined prior to execution of the desired tests (we do not undertake non-parametric analysis in this book). There are instances when these assumptions may not be met. These include small samples and a non-normal distribution. In such cases, non-parametric tests may be appropriate. Also referred to as *distribution-free-methods*, non-parametric tests are not concerned with specific parameters, such as mean in an ANOVA analysis, but with the distribution of the variates (Sokal and Rohlf, 1981). Non-parametric analysis of variance is easy to compute and permits freedom from the distribution assumptions of an ANOVA. These tests are less powerful than parametric tests when the data are normally distributed. Under those circumstances, there is a greater likelihood of committing type II error using non-parametric tests. Some of the guidelines for deciding when to apply a non-parametric test are:

1. fewer than 12 cases
2. the sample is clearly not normally distributed
3. some values are excessively high or low.

However, it is important to bear in mind that non-parametric tests are counterparts to the parametric tests.

If the primary focus is to measure covariation (with no distinction made between dependent and independent variables), one can assign interval scaled values to the categories of the variable to compute the product moment correlation coefficient. The main question addressed here is: how much do the variables vary together (Sokal and Rohlf, 1981)? In Chapter 8, we illustrate this method with the different indicators of nutritional status such as height for age, weight for age and weight for height.

In contrast to correlation, in a regression analysis, a distinction is made between an independent and a dependent variable. If the dependent variable is continuous and one treats the relationship between the variables as linear, then coefficients from the linear regression can predict how much the dependent variable changes with respect to changes in the independent variables. In Chapter 9, we use this method to predict the values of child nutritional status from the values of individual/household and community characteristics.

We then proceed to multivariate analysis of data which allows the user to examine multiple variables using a single technique. While traditional univariate methods such as t -tests and chi-square tests can be very powerful, one can interpret the results based on the analysis of one manipulation variable. Multivariate techniques allow for the examination of many variables at once. There are different types of multivariate techniques that can be used to analyze food security, nutritional status and poverty analysis. Some of these techniques

such as multivariate regression, logistic regression, discriminant analysis, K-mean cluster analysis and factor analysis are used in this book. While these techniques can be very powerful, their results should be interpreted with care. Some techniques are sensitive to particular data types and require that data be distributed normally. Others cannot be used with non-linear variables (for example classification). Thus, while using these techniques, it is important to understand their respective intended uses, strengths, and limitations.

Continuing with our examples, with more than two variables we have the following: if there are more than two variables with a distinction being made between dependent (continuous) and independent variables (and relationship among the variables treated as additive and linear), the coefficients of multiple linear regression with their *t*-statistic will assign to each independent variable some of the explained variance in the dependent variable that the dependent variables shares with other independent variables. This method has been used in examining the role of maternal education and community characteristics on child nutritional status in Chapter 10.

In contrast to multivariate regression, when the dependent variable is categorical (either nominal or ordinal), the coefficients from the ordinal logit regression accompanied with the Wald statistic can tell us the probability associated with being in a particular category of the dependent variable. The idea can be illustrated with our example of determinants of poverty as in Chapter 12 as follows: suppose we want to examine the relationship between assets held by the household and probability of being poor. When the household has a very low level of assets, the probability of getting out of poverty is small and rises only slightly with increasing assets. But, at a certain point, the change of owning more assets begins to increase in an almost linear fashion, until eventually many households hold more assets, at which point the function levels off again. Thus, the outcome variable (in this case, the probability of being poor) varies from 0 to 1 since it is measured in probability.

Discriminant analysis, as introduced in Chapter 11, is used to determine which continuous variables discriminate between two or more naturally occurring groups. In this chapter, we investigate which variables discriminate between various levels of child nutritional status. This approach is particularly suitable, since it answers the questions: can a combination of variables be used to predict group membership (e.g. differentiating between low wasting from severe wasting) and which variables contribute to the discrimination between groups?

However, this method is more restrictive than logistic models, since the key assumption required is multivariate normality of the independent variables and equal covariance structure for the groups as defined by the dependent variable. If the sample sizes are small and the covariance matrices are unequal, then the estimation process can be adversely affected.

The method builds a linear discriminant function that can be used to classify the households. The overall fit is assessed by looking at the degree to which the group means differ (Wilks' lambda) and how well the model classifies. By looking at the correlation between the predictor variables and the discriminant

function, one can determine the discriminatory impact. This tool can help categorize a wasted child from a normal child.

We also explore data reduction and exploratory methods in the chapters of this book. In a cluster analysis, the main purpose is to reduce a large data set to meaningful subgroups of objects or households. The division is accomplished on the basis of similarity of the objects across a set of dimensions. The main problem with this method is outliers, which are often caused by including too many irrelevant variables. Secondly, it is also desirable to have uncorrelated factors. The analysis is especially important for exploring households that can be vulnerable in food insecurity and poverty dimensions. For example, this method can allow the researcher to identify households that are vulnerable in food insecurity dimension alone, households that are vulnerable in dimensions of poverty (such as lack of productive assets) and households that are vulnerable in both dimensions. The rules for developing clusters are, they should be different and measurable.

Finally, when there are many variables in a research design, it is often useful to reduce a large number of variables to a smaller number of factors. There is no distinction between dependent and independent variables and the relationships among variables are treated as linear. In this method, the researcher wants to explore the relationships among the set of variables by looking at the underlying structure of the data matrix. Multicollinearity is generally preferred between the variables, as the correlations are the key to data reduction. The '*KMO-Bartlett test*' is a measure of the degree to which every variable can be predicted by all other variables. This approach is suitable for constructing a food security index, since a large number of variables which are the main determinants of food security can be reduced to a smaller set of underlying components or factors that summarize the essential information in the variables. We use the principal component analysis to find the fewest number of variables that explain most of the variance. The new set of variables is created as linear combinations of the original set. In this procedure, if there were originally 15 variables that affected food security, the procedure can tell us which components explain a substantial percent of variability of the original set of 15 variables and thus reduce the number of factors to say 3. In essence, then, the number of variables to be analyzed has been reduced from 15 to 3.

Learning objectives

Each of the analytical chapters in this book addresses four sets of learning objectives. First, each chapter is theme based. A thematic policy issue is chosen and introduced to provide motivation and discussion for policy analysis. As part of this introduction, students are introduced to selected case studies of policy analysis and research that address the chosen theme from various geographical, eco-regional and policy contexts. Additional literature relevant to the theme is also reviewed.

Second, an appropriate empirical analytical technique to address policy issues of the chosen theme is demonstrated. The learning objective of this part of the chapter includes application of the statistical technique to the real world data by describing the variables, calculation of new variables, development of welfare indicators and applying a statistical model to the data to derive empirical results.

Third, each chapter has its own specific technical appendix that describes in detail the analytical method used in the chapter for implementing the statistical method using the software. Finally, the translation of analytical results into implications for policy and program development is shown relating the results back to the thematic issue introduced in the beginning of the chapter.

In addition, each chapter has its own set of exercises that tests readers' understanding of the issues, concepts and analytical techniques and allows them to explore further the literature. All of the chapters use a single household dataset (the Malawi household dataset) that contains socioeconomic data on several causal factors and indicators of food security, poverty and nutrition. The dataset along with the syntaxes are provided in the publishing company's website.

Section I

Food Security Policy Analysis

Introduction

In this section, we introduce the elements and methods of food security policy analysis. Using basic tools of hypothesis testing and statistical inference, the chapters of this section deal with various issues of food security analysis.

Why study food security policy analysis?

Cutting world hunger by half by the year 2015 is one of the global priorities as set out by the Millennium Development Goals (MDGs) of the United Nations (UN, 2005). Achieving national food security depends on appropriate policies that will ensure availability of adequate food either through local production or through an increase in the volume of international trade. Designing and implementing appropriate food security policies remain a challenge in developing countries. Further, the 'food crisis' of 2008 is a clear indication of how policies undertaken in one country could have ripple effects throughout the world and underpins the importance of analytical based policy decision making.

There has been impressive progress in the world towards food security during the last decade. There were 279 million fewer people living on less than a dollar a day in 2004 compared to 1990, showing a drop in the world's share of poor people from 28 to 18 per cent (Ahmed et al., 2007). The world's population is expected to grow from 5.8 billion in 1997 to 7.5 billion by the end of this decade and such a large absolute increase in population raises serious concerns about whether the world's food production system will be able to feed so many individuals in the face of a stagnant or even declining stock of natural resources. According to the latest estimates of the Food and Agricultural Organization of the United Nations (FAO), the proportion of people suffering from hunger has decreased from 20 to 17 per cent since 1990, implying 19 million fewer food insecure people. Similarly, the global prevalence of malnutrition among preschool children has declined from 30 to 25 per cent during the period 1990 to 2000 which, in absolute terms, implies that 27 million fewer children are malnourished now compared to 1990 (von Braun et al., 2004).

Aggregate trends, however, show that the progress at the regional and country levels was distributed unequally. While East Asia and Latin America saw declining rates and a reduction in the absolute numbers of poor, hungry and malnourished people, the situation in sub-Saharan Africa and Eastern Europe deteriorated, as demonstrated by the recent food shortages in Niger and in Southern Africa. Compared to 1990, sub-Saharan Africa now has 89 million more individuals living on less than a dollar per day, 33 million more people suffering from hunger and an additional 6 million preschool children who are underweight. In Eastern Europe, although the problem is less serious given the initial conditions, the trends suggest serious problems with the region's development process (von Braun et al., 2004). The critical issue for the sub-Saharan African region is thus rapid economic and social development on all fronts to generate income growth for the poor people so that they can have access to food and other basic needs. Given that agriculture is the main source of livelihood in many African countries, this requires a multipronged approach of employment-intensive and rural growth with agriculture as the crucial engine of growth.

If the current trend persists, the proportion of hungry is expected to drop to 11 per cent compared to 9.9 per cent specified by the MDGs. Similarly, the per cent of malnourished children will drop only to 24 per cent compared to the 15 per cent needed. China will remain the main driver towards the progress of MDG goals. At the other extreme, sub-Saharan Africa will either stagnate or lose ground. Projections thus show that 600 million people in the developing world will suffer from hunger in 2015, 900 million people will remain in absolute poverty and 128 million preschool children will be malnourished (FAO, 2005).

Food insecurity and hunger affects developed countries too. In the USA, for example, the prevalence of food insecurity rose from 10.7 per cent in 2001 to 11.1 per cent in 2002 and the prevalence of food insecurity with hunger rose from 3.3 per cent to 3.5 per cent (Nord et al., 2006). During 2005, 11 per cent of all households were food insecure at different times during the year. The incidence of food insecurity in high income countries indicates that income growth alone will not be enough to eliminate hunger and other policies and programs may be necessary to protect the vulnerable population who may be at the risk of starvation during various stages of development of a country.

Understanding determinants of food security and their contribution will help in designing policies and programs to address the challenges of food security. These issues are highlighted throughout the chapters of this section. A brief description of individual chapters of this section is given below.

Chapter 1

This chapter introduces the analytical concepts and measurement issues related to food security. Using a broad conceptual framework the basic determinants, causal factors and indicators of food security are defined. Measuring food security through various approaches is described with examples of real world data.

Chapter 2

Technological change in agriculture and food production is seen as an important tool for reducing hunger and malnutrition. Adoption of new crops, improved varieties of existing crops and new technologies such as biotechnology could improve household food security. In this chapter, Student *t* distribution is introduced for use in inference procedures along with hypothesis tests for the difference in two population means and equality of variances. Statistical inference is applied to food security status of households adopting technology change and those who are not adopting as an inductive procedure to determine 'if adopting new technologies improves food security'. Technological change in rice production in West Africa and adoption of hybrid maize in Zambia are used as case studies. To illustrate policy issues, analytical approaches and research results, a technical appendix on developing a food security index is also presented.

Chapter 3

Moving away from subsistence farming to market-oriented agriculture and shifting from cultivation of traditional food crops to cash crops through commercialization of agriculture are seen as a way to improve food security and nutritional status of the rural households. Using case studies on vegetable production for exports in Guatemala, tobacco cultivation as a cash crop in Malawi and commercialization of fruits and vegetables in Nepal, this chapter addresses the central question: 'is it more likely that a cash crop growing household would be food and nutrition secure compared to households growing traditional crops?' This chapter introduces the use of Pearson's chi-square test in determining the relationship between the types of crops grown and the welfare status of farming households. This chapter, while furthering the exploration of statistical inference procedures, demonstrates important applications of chi-square distribution: testing hypothesis about the variances; Pearson's goodness of fit; and independence between two variables. Since many variables including cash crop production and food security and nutritional status could be mutually exclusive, the simple applications of these tests for food policy analysis are discussed.

Chapter 4

In this chapter, the commercialization theme is extended to determine the implications of gender differences among adopting households. Since adoption of new technologies and commercialization depend on the control of resources within households, and such control has implications of the use of income from commercialization on food and nutrition outcomes, the issues addressed are whether female-headed households are likely to adopt new technologies and whether among adopters of new technology, female-headed households are

likely to become more food and nutrition secure. Using case studies on hedgerow intercropping in Kenya and Nigeria, adoption of improved maize technology in Ghana and hybrid maize adoption in Zambia, this chapter introduces cross-tabulation procedures along with Cramer's V and phi test statistics to test the hypothesis on the relationship between cash crop growing and the gender of the household head.

Chapter 5

Studying food consumption patterns is important as it contains useful information on household welfare and living standards and is an objective way to assess economic performance of countries. From a food security perspective, it is important to understand the changes in food consumption patterns as different income groups can react differently to changes in food imports and changes in food prices in international markets. Using a few studies on changing food consumption patterns in West Africa, an analysis of per capita food consumption patterns in India during the reform period and food consumption patterns in Vietnam, this chapter addresses the question of differences in the share of nutrients from various food groups according to the differences in income levels. The F distribution forms the basis for the analysis of variance technique introduced in this chapter. Describing the underlying assumption of analysis of variance (ANOVA) procedure, the decomposition of total variation is explained.

Chapter 6

Governmental policies that help to liberalize food markets by abolishing state-owned parastatals are expected to encourage private traders to increase the market access to food. However, due to poor infrastructure and lack of market information, the entry of private traders in food markets remains less than expected. The impact of such policies on food security of the households is the theme of this chapter. This chapter uses factor analysis technique to derive factor scores from a subset of highly correlated market related variables. The factor scores are then used in further hypothesis testing about the relationship between food security and market access. Factor analysis technique is demonstrated using the principal component method, computing the observed correlation matrix, estimating the factors, interpreting factors using rotation procedure, computing factor scores for analysis.

This chapter uses case studies on market reform and private trade in Eastern and Southern Africa, transaction costs and agricultural productivity in Madagascar to determine the impact on measures of household welfare.

1 Introduction to food security: concepts and measurement

The World Bank reports that global food prices rose 83% over the last three years and the FAO cites a 45% increase in their world food price index during just the past nine months. The Economist's comparable index stands at its highest point since it was originally formulated in 1845. As of March 2008, average world wheat prices were 130% above their level a year earlier, soy prices were 87% higher, rice had climbed 74%, and maize was up 31%.

Eric Holt Giménez and Loren Peabody, Institute for Food and Development Policy, May 16, 2008.

A common acceptable definition of food security exists. Yet, the concept of food security is understood and used differently depending on the context, timeframe and geographical region in question. In this chapter, we explore the definition and measurement of food security to provide a conceptual foundation to food security policy analysis. First, we introduce a widely used and well-accepted definition along with three core determinants of food security. Second, we explain the measurement of these determinants with examples of global, national and regional datasets that provide information on these determinants. Finally, we explore some alternative approaches to measuring food security indicators.

Conceptual framework of food security

Before examining the determinants of food security, understanding several concepts associated with the definition of food security is necessary. This is because many developing countries continue to suffer from chronic food insecurity and high levels of malnutrition and they are under constant threats of hunger caused by economic crises and natural disasters. Designing policies and programs to improve nutritional status requires an understanding of the factors that cause malnutrition, knowledge of the pathways in which these factors affect vulnerable groups and households and an awareness of policy options available to reduce the impact of these factors on hunger and malnutrition.

A multitude and complex set of factors determine nutritional outcomes. These factors have been identified and their linkages to nutrition have been elaborated on by Smith and Haddad (2000).

The food and nutrition policy-focused conceptual framework presented in [Figure 1.1](#) identifies the causal factors of nutrition security and the food policy linkages to them. It also identifies the points of entry for direct and indirect

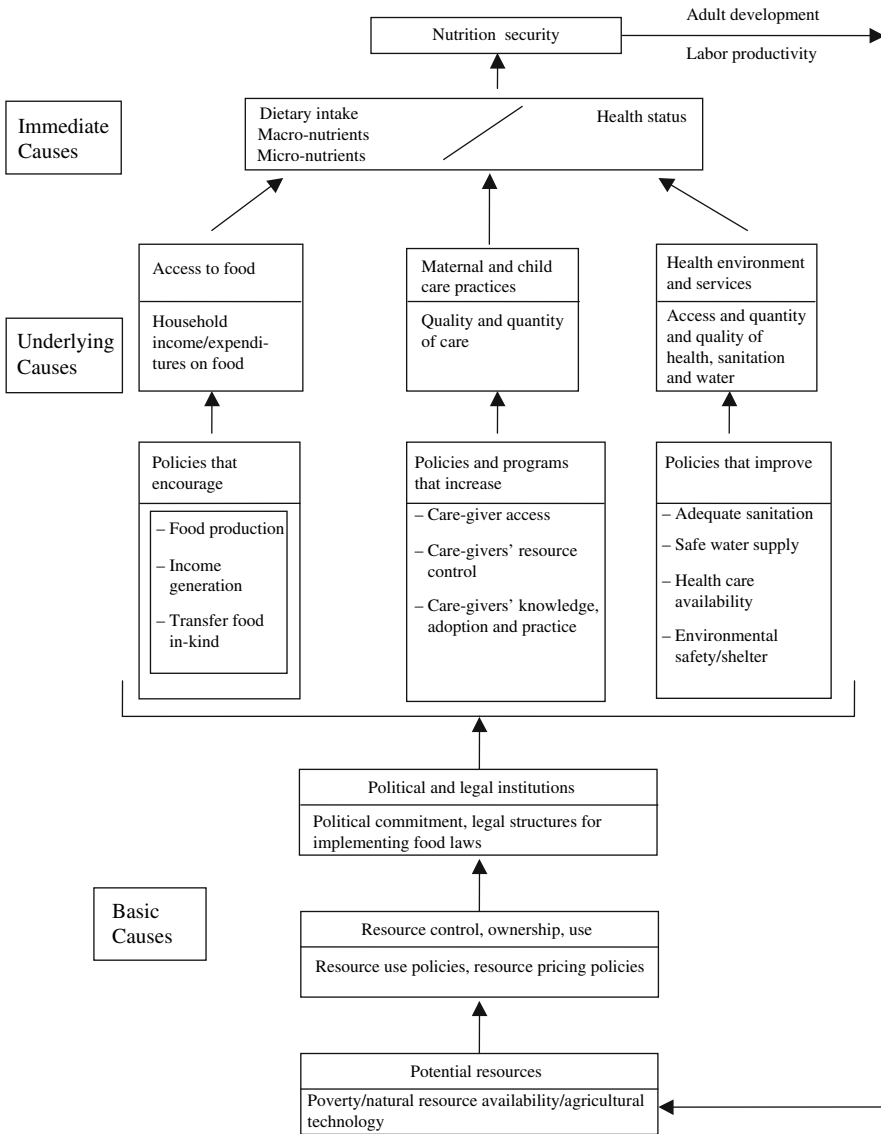


Figure 1.1 Food and nutrition security – a conceptual framework.
 (Source: Smith and Haddad, 2000)

nutrition programs and policy interventions as well as the capacity gaps for analysis and evaluation of food and nutrition policies and programs.

The framework was originally developed and successfully used for explaining child malnutrition (UNICEF, 1998; Haddad, 1999; Smith and Haddad, 2000). It was revised further to incorporate policy and program dimensions (Babu, 2001).

Given the role of nutrition in the human life cycle, this framework attempts to encompass the life-cycle approach to nutrition. In addition, it includes the causes of nutrition security at both the macro and micro levels. As seen earlier in [Figure 1.1](#), achieving food security at the macro level requires economic growth resulting in poverty alleviation and increased equity in the distribution of income among the population. In a predominantly agrarian economy, economic growth is driven by increases in agricultural productivity and, therefore, depends on the availability of natural resources, agricultural technology and human resources. These are depicted as potential resources at the bottom of [Figure 1.1](#).

Agricultural technology and natural resources are necessary but, by themselves, are not sufficient to generate dynamic agricultural growth. Both policies that appropriately price the resources and allocate them efficiently along with stable investment in human and natural resources through political and legal institutions are necessary. These basic factors determine a set of underlying causes of nutrition security, i.e. food security, care and health. These three underlying causes are associated with a set of resources necessary for this achievement. Attaining food security is shown to be one of the key determinants of nutritional status of individuals. Food security is attained when all people have physical and economic access to sufficient food at all times to meet their dietary needs for a productive and healthy life (World Bank, 1986)¹. While this definition is frequently applied at different levels, such as national, subnational and household levels, it is more meaningful to use this concept at the household level. Resources for achieving food security are influenced by both policies and programs that increase food production, provide income for food purchases and establish in-kind transfer of food through formal or informal supporting mechanisms.

Resources for the provision of care depend on policies and programs that increase the caregivers' access to income, strengthen their control of income use and improve their knowledge, adoption and practice of care. Care is the provision by households and communities of 'time, attention, and support to meet the physical, mental and social needs of a growing child and other household members' (ICN, 1992). Child feeding, health-seeking behavior, caring and supporting of mothers during pregnancy and breastfeeding are some examples of caring practices. Resources for health could be improved through policies and programs that increase the availability of safe water, sanitation, health care and environmental safety.

As mentioned earlier, food security that ensures a nutritionally adequate diet at all times and a care and health environment that ensures the biological utilization of food, jointly determines the nutrition security of individuals. Thus, the immediate causes of nutrition security are dietary intake of macronutrients (energy, protein, and fat), micronutrients and the health status of individuals. Adequate nutrition security for children results in the development of healthy adolescents and adults and contributes to the quality of human capital. Healthy female adults with continued nutrition security during pregnancy contribute to fewer incidences of low birth weight babies, thereby minimizing the probability

of the babies becoming malnourished. In the case of adults, improved nutrition security, in terms of timely nutrient intakes, increases labor productivity (given opportunities for productive employment) thus resulting in reduced poverty. Lower prevalence of poverty increases the potential resources needed for attaining nutrition security. The next section examines the measurement and determinants of food security based on the above conceptual framework.

Measurement of the determinants of food security

‘Food security’ is a flexible concept and is usually applied at three levels of aggregation: national, regional and household or individual. At the 1996 World Food Summit, food security was defined as follows: ‘Food security exists when all people, at all times, have physical, social and economic access to sufficient food which meets their dietary needs and food preferences for an active and healthy life’ (FAO, 1996). This definition is well accepted and widely used.

The three core determinants of food security are:

1. food availability
2. food access
3. food utilization.

The measurement of various indicators of food security is a first step in quantifying food security of the population. Various approaches are used to collect and document data on food security indicators. We provide a brief introduction to these measures and their data sources.

Food availability

Information on food availability usually comes from national, regional and subregional food balance sheets. This is obtained from the FAO food balance sheet database for individual countries and regions (<http://faostat.fao.org/site/502/default.aspx>). However, food balance sheets provide no information on consumption patterns and relate only to the supply or availability of food at the national level (Becker and Helsing, 1991). They depict annual production of food, changes in food stocks and imports and exports and describe national dietary patterns in terms of the major food commodities. While they are useful to understand, aggregate indicators (such as macroeconomic and demographic factors) on food consumption, using the national food balance data, do not provide information on food security at the household level.

Measuring food availability

There is a variety of methods for measuring food availability. They are as diverse as participatory poverty profiles, principal component analysis and spatial econometric tools. The small-area estimation method developed by Hentschel et al. (2000) and Elbers et al. (2001) is one of the most common methods in

measuring household food availability. It is a statistical tool that combines survey and census data to estimate welfare or other indicators for disaggregated geographical units (such as rural regions and municipalities). In this method, the first step is to estimate a model of household welfare using the household survey data. In the second step, the parameter estimates are applied to the census data assuming that the relationship holds for the entire population. The household level results are then aggregated by a larger geographical region or area by taking the mean of the probabilities for the area. This allows the researcher to construct maps for different levels of food insecurity disaggregated across geographic units.

Food access

What do we mean by food access? It could be physical access to food in the market or economic access to food at the household level. While food availability at the national and regional levels and the associated infrastructure such as roads and market outlets to buy food determine physical access to food, economic access depends on the purchasing power of the household and the existing level of food prices which could depend on the physical access to food (Thomson and Metz, 1998). A household's ability to spend on food is a good indicator of food access at the household level.

Measuring food access

Household food access is measured through food or nutrient intake at the household level. This is usually reported in 'adult equivalent' units to facilitate comparison among individuals within a household as well as among households. The adult equivalent unit is a system of weighting household members according to the calorie requirements for different age and sex groups. Household income and expenditure surveys that collect information on household composition, household expenditure patterns with a focus on food and non-food items, calorie intake, consumption of major products and socioeconomic characteristics (such as head of the household, household education level, etc.) can be used to assess food access over time, by estimating amounts of food consumed, composition of the diet and nutrient availability at the household and individual levels.

Food utilization

Food utilization relates to how food consumed is translated into nutritional and health benefits to the individuals. In this approach, the consumption of foods both in quantity and in quality that is sufficient to meet energy and nutrient requirements is a basic measure of food utilization.

The relationship between food security and nutrition security is depicted in [Figure 1.1](#). It shows links between nutritional status and other determinants at the household level. In this framework, the nutritional status is an outcome of food intake and health status. However, the underlying causes of health (namely

environmental conditions, health services and caring activities) are shown in different boxes due to their different underlying characteristics and features. A reduced state of health can be due to poor access to health care, poor housing and is possibly worsened by malnutrition, which makes individuals vulnerable to diseases. Thus, distinguishing between health services, caring activities and environmental factors is crucial in selecting appropriate intervention strategies to improve food utilization.

Measuring food utilization

Food intake data, following conversion to nutrient composition, are evaluated by comparing them with recommended intakes of energy and other nutrients. Two terminologies are essential in understanding this approach. *Nutrient requirements* are the levels of particular nutrients in the lowest amount that is necessary to maintain a person in good health. They vary between individuals, although the requirements of a group of similar individuals (age, sex, body size and physical activity) will fall within a certain range. *Recommended intakes* are the levels of nutrients that are thought to be high enough to meet the needs of all individuals within a similar group. WHO and FAO set this recommendation by taking the mean minimum requirement for a nutrient plus two standard deviations. *Dietary guidelines* are the linkages for the general public between recommended nutrient intakes and the translation of these recommendations to food based guidelines.

There is no one method for establishing the minimum requirement levels for nutrients and methods differ depending on the nutrient. Similarly, for the recommended intake levels, the usual guidelines are based on the estimates of the minimum requirements for a nutrient plus a standard additional amount. This amount is usually either two standard deviations or a fixed percentage increment of the mean requirement for the group. Since food balance sheet data are not very useful in describing dietary intake adequacy of a population and household surveys can provide limited information on the dietary adequacy of the household as a whole, the dietary intake approach yields precise application of standards or requirements to individual intake data.

Although food intake includes protein and other nutrients, *energy intake* is one of the main parameters and is extremely important in improving food utilization. Energy requirement for an individual is the amount of dietary energy (through food) needed to maintain health, growth and an appropriate level of physical activity (Torun, 1996). Since energy requirements are derived from data originating in healthy populations, they need to be adjusted in communities that suffer from malnutrition and other debilitating diseases. Estimates of energy requirements are usually based on energy expenditure data, although it is possible to obtain rough estimates on the basis of energy intake data from dietary surveys. For children, there is an additional allowance for growth.

In food security assessment, the group distribution of the individuals' energy and nutrient requirements is assumed to be normally distributed. The

determinants of energy requirements include: basal metabolic rate (constituting between 60 and 70 per cent of total energy expenditure); physical activity; body size and composition; age; climate and ecological factors.

In the basal metabolic factor approach, energy requirement is computed as the product of the basal metabolic rate (BMR) and physical activity level. The basal metabolic rate is the minimal rate of energy expenditure required to maintain life. To calculate BMR, first individual oxygen consumption is measured and then converted into heat or energy output. Physical activity levels have been calculated for various occupational categories. A physical activity level of 1.55 to 1.65 is an average for most developed countries (Shetty et al., 1996).

The estimates of mean per capita energy requirement are thus dependent on the basal metabolic rates, physical activity levels, lactation, pregnancy, climate and the degree of malnutrition. Scientifically, the range varies from 1900 to 2500 kcal per day. The National Academy of Sciences (1995) has arrived at a figure of 2100 kcal per day for use in food emergency situations, which is based on an assumption of light activity.

Alternative approaches in measuring food security

Although the above approaches are the most common ways of measuring food security, some recent alternative approaches are also in vogue in measuring food security depending on context specificity. They are:

1. interaction approach
2. coping strategy/chronic vulnerability approach
3. scaling approach.

The *interaction approach* developed by Haddad et al. (1994) is an overlap technique that seeks to determine to what extent a proportion of households are insecure on a particular dimension given that they are insecure on another dimension. For example, with the above approach one can address: for all individuals that have inadequate drinking water facilities, what percentage is also food insecure. Thus, a combination of various indicators can be an important predictor of food insecurity. While the above approach is useful in combining various indirect indicators to determine household level food insecurity, its main limitation is that such combinations are endless. Thus, the analysis is purely suggestive.

Maxwell (1996) developed a *coping strategy* approach for households in the face of insufficient food consumption. The cumulative food security index is based on six food coping strategies. A scale was developed for the frequency of each individual strategy and was multiplied by the severity weighting factor based on ordinal ranking to derive the food security score. The advantage of this approach is to understand short-term food insufficiency. This approach does not require specialized enumerators or any complex statistical procedures. However, a major disadvantage of this approach is that it cannot differentiate between short-term food insecurity from long-term vulnerability indicators.

A natural way of extending the ‘coping strategy’ approach is to bring in temporal dimensions of food insecurity. The *chronic vulnerability approach* to food security, originally developed by Sen (1981), seeks to identify why households become vulnerable in particular dimensions and thus characterizes a dynamic relationship. It is defined by Riely (1999) as ‘the probability of an acute decline in food access or consumption levels below minimum survival needs’. It can result from both exposure to risk factors – drought, conflict or extreme price fluctuations – or it can result from households having lower ability to cope due to various socioeconomic constraints. According to Riely, vulnerability can be viewed as the sum of exposure to risk and the inability to cope. Vulnerability tends to be higher when the risk of natural disasters increases, adverse government policies result in chronically deficit household consumption or when poorer households rely on a risky source of consumption or income (Scaramozzino, 2006).

Finally, the *scaling approach* assesses how households go through different experiential and behavioral stages and thus become more food insecure over time. This approach is widely used to measure household food security in the USA (Bickel et al., 2000). A core six item set of questions is used to determine a single overall food security scale, with greater values of the index indicating that households are more food insecure. While the food security scale shows that some member or members of the household are experiencing food insecurity, it does not capture other dimensions such as the nutritional status of children.

Conclusions

Measuring food security at the national, regional, community and household levels is important for developing appropriate policy and program options. At the national level, measuring food available for consumption is based on food balance sheets. Food balance sheets provide a comprehensive picture of food supply during a particular reference period (usually one year) and is computed from the annual production of food, change in stocks and imports and exports (FAO, 2001). While the food balance sheet is extremely useful in formulating agricultural policies related to production, consumption and distribution of food, they can also be used in developing appropriate agricultural trade policies (for example, when a country faces a chronic deficit in food). The trends in food consumption over a longer time period at the national level can provide useful information on nutrient intake of the population. However, food balance sheets do not provide general information on nutrient intake within a country or among groups of households and thus should not be usually used in estimating nutritional inadequacy (Jacobs and Sumner, 2002).

At the regional level, targeting through small area estimation in smaller administrative areas improves the cost effectiveness of development spending and reduces geographical disparity of food insecure households. The above food security mapping exercise can be useful in various policy interventions, such as

transfer of food aid throughout a country (as in Sri Lanka) or testing new technologies in a particular food deficient area (such as in Mexico) (Hyman et al., 2005).

Community food security is a natural extension of the food security concept at the community level (Anderson and Cook, 1999). It is defined as ‘all persons in a community having access to culturally acceptable, nutritionally adequate food through local non-emergency sources at all times’ (Winne et al., 1997, p.1). However, the lack of a consensus of a general definition of a community among researchers and practitioners has hindered the measurement of a ‘food insecure community’ and its relationship to household and individual food security. It is thus important conceptually and operationally to define a ‘food insecure community’ for the purpose of survey design in various developing countries. While both contextual and global community factors are critical elements of a community survey, collecting and integrating all these data remains a major challenge in terms of cost-effectiveness.

Finally, household level surveys in conjunction with individual level measures of dietary intake are another set of instruments in assessing food security at the household level. These surveys enable comparison of household food security status by analyzing expenditure patterns on food and non-food items and yields dietary intake patterns of individual members of the household in the context of resource constraints.

Assessment of food security in a community, region or at the national level should be context specific and will depend on the purpose for which the data are collected. For example, emergency interventions may use data from rapid appraisal surveys while a long-term planning exercise will demand comprehensive household surveys. Similarly, monitoring and evaluation of food security interventions may collect a different set of indicators with varying levels of intensity and accuracy. Nevertheless, analysis of and use of data for informing policy and program options require effective conversion of data into useful information for decision making.

A natural question is why is measuring food insecurity important for better program design in developing countries?

The search for better measures of food security still remains a major challenge due to the complex and multidimensional nature of food security. However, the issue remains important as hundreds of millions of individuals and households are affected on a daily basis in both the developing and developed world. The recent food crises in Haiti due to a substantial hike in food prices, the chronic vulnerability of Ethiopian population to famine and the food insecurity of households in the northern region of Malawi due to higher maize prices, all testify to the fact that constructing better measures will remain critical in the coming decades for addressing the substantial challenges posed.

We highlight some of the issues in food security measurement that are relevant for policy analysis. First, the severity of food insecurity cannot be ascertained

only from the national food balance sheet data. Additional household level and dietary intake surveys will be necessary to determine which segments of the population are particularly vulnerable. Second, there is a need to improve the tools and frameworks for targeting various interventions (especially for the vulnerable segments of a population) for achieving optimum resource allocation. This will require precise measures for locating the food insecure households. Third, food availability, accessibility and utilization measures have to be addressed in a holistic manner to develop a gamut of policy and program interventions. Finally, both quantitative and qualitative measures of food security need to be identified in the context of a given resource base, agro-ecological constraints and production and employment opportunities of the communities and households.

Table 1.1 Nationally representative household surveys containing food expenditure data (1990–2007)

Region/country	Year	Sample size	Type
<i>Sub-Saharan Africa</i>			
Ghana	1998/99	5998	World Bank LSMS
South Africa	1993	9000	World Bank LSMS
Tanzania	1993	5200	World Bank LSMS
Ethiopia	1989–97	1477	IFPRI rural household survey
Malawi	2000–2002	758	IFPRI complementary panel survey
<i>South Asia</i>			
India (Uttar Pradesh and Bihar)	1997–98	2250	World Bank LSMS
Nepal	1996	3373	World Bank LSMS
Bangladesh	2000	1120	IFPRI SHAHAR baseline survey
Pakistan	1991	4800	World Bank LSMS
<i>East Asia</i>			
China	1995 and 1997	780	World Bank LSMS
Cambodia	1999	6000	World Bank LSMS
Vietnam	1997/1998	5994	World Bank LSMS
<i>Middle East and North Africa</i>			
Morocco	1991	3323	World Bank LSMS
Egypt	1997	2500	IFPRI
<i>Newly industrializing countries (NIC)</i>			
Albania	2005	3638	World Bank LSMS
Armenia	1996	4920	World Bank LSMS
Azerbaijan	1995	2016	World Bank LSMS
Bosnia and Herzegovina	2001	5402	World Bank LSMS

Exercises

1. Is there a single definition of food security? What are the core determinants of food security? Define each of these. How are these determinants measured?
2. Is food availability in a country the key determinant of food security? Explain.
3. Choose a developing country for understanding the concepts of food security. Using library and web-based resources prepare a food balance sheet of the country for the last year (or latest year for which data are available) and for five years ago. Explain what you infer from the data about food availability in the country including trends in food production, food stocks, imports and exports.
4. What are the advantages and disadvantages of using the coping strategy/vulnerability approaches in measuring food security?

Notes

1. A thorough review of the food security concept and the conceptual frameworks used in the literature for analyzing food security is beyond the scope of this chapter. For such reviews see Maxwell and Frankenberger (1992), Clay (1997) and Von Braun et al. (1992).

2 Implications of technological change, post-harvest technology and technology adoption for improved food security – application of *t*-statistic

By all means, use manure. You can't let it sit around. But if we use only organic fertilizers and methods on existing farmland, we can only feed 4 billion. I don't see 2.5 billion people volunteering to disappear.

Norman Borlaug, Nobel Peace Prize winner.

Introduction

Technological change in agriculture has long been accepted as a necessary condition for accelerating growth in food production. Adopters of yield increasing or post-harvest technology are more likely to experience higher production per unit of land and the associated income benefits at the household level compared to non-adopters. The desired benefits of technological change such as increased agricultural or food production and income are expected to have a positive influence on household food consumption and nutritional adequacy. It is typically assumed that this income-mediated effect on food security and nutritional improvement operates through two main ways. First, increased income can be used for greater food expenditures that directly increase food consumption which, in turn, may improve nutritional status by higher intake of energy and other nutrients. Second, increased income can result in higher non-food expenditures like health and sanitation that, along with food consumption, could indirectly have positive nutrition and health effects. Thus, in order to understand the relationship between technological adoption and food security and nutrition, it is important to answer the following two questions:

1. to what extent adoption of new technologies improves household or individual food consumption and through what mechanisms is such an improvement, if any, achieved?

2. how does technology adoption in agriculture translate into measurable nutritional improvement?

The significance of questions such as the above can be understood in the context of the technological change that was christened as the ‘Green Revolution’ which occurred in many parts of the world – first in USA and Europe during the 1940s and 1950s (Griliches, 1957) and, later, in Asia and Latin America beginning in the 1960s. As pointed out by Conway (2003), ‘the first Green Revolution offered farmers new crop varieties that allowed them to improve agricultural yields’. The new varieties were widely accepted and adopted by farmers in various countries such as India, Pakistan, Indonesia, Mexico and the Philippines during the 1960s and the 1970s. In order to foster such technological change, the Ford and Rockefeller foundations, along with bilateral aid agencies such as the USAID, helped to fund the International Agricultural Research Centers in various parts of the world (see www.cgiar.org). These centers, such as the International Rice Research Institute (IRRI) in the Philippines and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico bred new varieties of rice and wheat respectively and developed new production and post-harvest technologies to accompany them.

The impending food crisis and the need to avert a massive famine in several Asian countries motivated such global action. For example, before the Green Revolution, almost two thirds of South Asia’s rural population was food insecure and hungry and the region depended on food aid for feeding its population. The Green Revolution brought the South Asian region and other Asian countries close to food self-sufficiency with surplus grain stocks available to the vulnerable regions, which could otherwise be affected by famines. Yet, many countries in sub-Saharan Africa continue to struggle to meet the food needs of their populations. Technological change requires increased investment for agricultural research and development which has been declining lately in many developing countries (World Bank, 2008). Recent food price increases caused by short-sighted policies that encourage diversion of food crops to biofuel production, have raised alarm bells and encouraged world leaders to recommit themselves to agricultural development (FAO, 2008; IFPRI, 2008; WFP, 2008).

Adoption of existing technologies that could increase food security depends on supporting programs and institutions. Such support increasingly requires convincing policy makers with empirical evidence on the benefits of technology adoption on human welfare. There is also an emerging international consensus that the adoption of agricultural biotechnology has the tremendous potential for making a substantial impact on many aspects of agriculture – crop productivity, yield sustainability, environmental sustainability, thereby improving household food security in the developing world (World Bank, 2008). Recent advances in molecular biology and genomics can greatly enhance the plant breeder’s capacity and introduce new traits in plants. The commercial applications of agricultural biotechnology have already produced crops such as

Bt-maize, rice, potatoes and sweet corn that can protect themselves against insects and herbicide-tolerant crops such as wheat, maize, rice and onions which allow for better weed management practices (Ozor and Igbokwe, 2007). At the same time, there is growing concern that current investments are increasingly driven by the private sector, which does not address the needs of the poor. There is an urgent need to increase public investments (both at the international and national levels) along with supporting programs and institutions so that the benefits of these technologies do not miss the poor households in developing countries.

This chapter, using the household level data from Malawi, shows how to analyze the impact of adoption of hybrid maize technology on household food security and nutritional situation. Maize remains an important food crop in Malawi. It is the main staple for Malawians and provides over 85 per cent of the total calorie intake (see, for example, Kadzandira, 2003, p.14).

Over the years, research on high and early yielding varieties of maize has achieved remarkable results in terms of yield gains and achieving food security (Smale and Jayne, 2003). This is important for Malawian and other maize-based farming systems, since maize (especially hybrid maize) will remain a crucial component of the food security in two ways: first, by satisfying the basic food requirements of a more diversified rural economy and, second, as a cash crop in areas where it is agro-ecologically suited to provide higher returns.

The relationship between technological change and food security is complex and there are indirect and partial effects of new technology on food security, so that a focused approach has to be taken in order to disentangle the complexities of the relationship.

In this chapter, we introduce a statistical analysis using *t*-test to examine whether hybrid maize adopters and non-adopters are different with respect to their food security status. In other words, we examine whether food security differs between these two groups (adopters and non-adopters) and if this difference is statistically significant. This test is most commonly used for assessing group differences. However, it is also one of the most restrictive tests in its assumptions concerning the underlying data. In general, the data need to be normally distributed and the group variances need to be homoscedastic¹.

In what follows, we present selected case studies that analyze the role of technology adoption in achieving greater food security and a higher nutritional status. A discussion of the issues, data set, methods and results of these case studies serves as motivation for the analytical method demonstrated and policy conclusions drawn from the analysis.

Review of selected studies

The relationship between technology adoption and food security continues to receive wide interest among food policy researchers. This is particularly true in

many African countries, where the threat of famine continues to be real (Levy, 2005). The case study of Zambia reviewed here is useful in developing and testing some of the maintained hypotheses about technology adoption and food security.

Kumar (1994) examined the nature and effects of technological change in maize production on food consumption and nutrition in the Eastern Province of Zambia and suggested a few policy implications. In Zambia, maize is the staple food. To achieve food production growth, the traditional approach has been extensive cultivation – expanding the land under cultivation of maize given the abundant supply of land. However, land expansion (extensive cultivation) alone is not sufficient for a sustained growth in maize production due to diminishing returns from land for a given level of labor supply. Therefore, it is important to increase yield per hectare of land (intensive cultivation). An effective way to do this is through adoption of improved technology. The technology adoption considered in this study is the use of high yielding varieties of seeds – the hybrid maize.

Given the improvement in agricultural productivity through modern technological methods as a worthwhile food security intervention, the study generates some significant policy implications. It is observed that the majority of farmers in the Eastern Province of Zambia grow traditional maize for self-consumption and hybrid maize as a cash crop. The local maize can be easily stored and processed at home, while hybrid maize does not store well and requires processing at mills. The study also observes low adoption of hybrid maize in several areas due to limited availability and poor distribution channels of hybrid seeds and fertilizers. The government thus must encourage and invest in market infrastructure and distribution channels, including the construction of roads, processing and storage facilities and improvement of marketing channels. Government incentives and support to improve on-farm storage capacity and village-level access to milling facilities will encourage the use of hybrid maize for households' own consumption. Policies that offer innovative extension and credit systems will also promote higher production of hybrid maize.

The results indicate that hybrid maize production is more profitable for smaller farms. Also, the positive effect of technology adoption is more pronounced on food consumption of households with smaller farms than larger ones. This can be attributed to larger farms requiring more labor. Since labor costs are high, investing in labor-saving technologies can fulfill the additional labor requirement. This substitution process, however, results in smaller gains to large farms compared to small farms, which are usually managed by a family. Incentives to encourage women's involvement in maize production are thus critical.

The study also finds that the adoption of hybrid maize decreases women's share of income particularly in larger farms. The reduction in income affects both production efficiency and family welfare adversely. The government should therefore offer women easier access to information about farming and agricultural production that results from technological change. Policies that provide

equal access to inputs and credit to women farmers should be brought into effect, since increasing women's income share is associated with better food security and child nutrition.

Technological change or technological adoption and commercialization of agriculture are virtually synonymous in many cases (von Braun et al., 1994). An export-producing cooperative in Guatemala (von Braun and Immink, 1994) enabled its household members to have 18 per cent more expenditure on food per capita on average and significantly improved their calorie consumption. The commercialization scheme under the cooperative resulted in an increase in income and also affected health and nutrition positively in the form of decreased stunting and weight deficiency among the children of the households.

Potato production in the Gishwati forest area of Rwanda (Blanken et al., 1994) resulted in more expensive calories being acquired and made adopters surplus-calorie producers. It also resulted in reduction of malnutrition among adopting households.

Technological adoption for cultivation of tobacco and maize in Malawi (Peters and Herrera, 1994) resulted in a significant increase in calorie intake, especially for those in the top third of income distribution. The study did not find a significant difference in nutritional status between children of adopters and non-adopters.

Bouis (2000) examined the impact of three programs that provided credit and training to women in Bangladesh for the production of polyculture fish and commercial vegetables on micronutrient status of households. The study found a modest increase in incomes for adopting households compared to non-adopting ones. The adoption of polyculture technology did not improve the micronutrient status of members of adopting households.

A report by the International Food Policy Research Institute and International Center for Tropical Agriculture on the use of biofortification for health improvement of poor (IFPRI and CIAT, 2002) states that biofortified crops (crops that are bred for increased nutrient content) are one of the most promising new tools to fight and end malnutrition. However, lack of infrastructure, poor policies, lack of delivery systems for new varieties, low level of investment in research and less demand for such crops in poorest countries, makes it difficult for commercial application and supplementation of such technology.

In a comprehensive study, Minten and Barrett (2008) examine how agricultural technology adoption and crop yields affect food prices, real wages for unskilled workers and key welfare indicators for Madagascar. The novelty of the paper is twofold:

1. it is one of the few empirical studies that examines the linkages between agriculture and poverty in sub-Saharan Africa
2. it relies on spatially explicit data from a complete census of Madagascar's communes – the smallest administrative unit – to under meso analysis. The study examines three distinct pathways through which productivity enhancing technical change affects welfare measures – (a) lower real food prices, thus benefiting net food

consumers; (b) output increases that surpass price declines, thereby benefiting net food suppliers; and (c) increase in real wages, which benefits unskilled workers.

The data for this study originate from three sources: a commune-level census conducted in 2001, the national population census of 1993 and geographical data from secondary sources. The unit of analysis is the commune, which is the smallest administrative unit with direct representation and funding from the central or provincial government. The analysis was undertaken using multivariate regression techniques.

Overall, the results of the study clearly demonstrate that better agricultural performance (as proxied by higher rice yields) is strongly correlated with real wages, as well as rice profitability and prices of staple food. The above results strengthen the conclusion that greater rice productivity reduces food insecurity in Madagascar for all the major subpopulations.

The results of the study show that increased agricultural yields are strongly associated with gains for each of the three subpopulations (net sellers, net buyers and wage laborers) in the rural areas. While greater rice productivity outpaces local market price declines and thus benefits net sellers, higher rice yields benefit the other two subpopulations by driving down food prices and improving unskilled laborers' real wages. The net effect is the presence of fewer food insecure households and shorter lean periods.

Second, cash crop production, but not mining activities, was associated with improvement in welfare outcomes. Finally, the results indicate that no single intervention is effective in improving agricultural productivity and reducing poverty and food insecurity in rural Madagascar. While technology diffusion remains important, equally important are improved rural transport infrastructure, increased literacy rates, secure land tenure and access to extension services.

Post-harvest technology and implications for food security

In many tropical developing countries, agricultural commodities can suffer significant losses after they are harvested and stored. This is often referred to as 'post-harvest crop loss'. Reducing food losses especially in developing countries is considered to be a major constraint in achieving food security (Toma et al., 1991). Crop losses can occur during the post-harvest system at all levels including pre-processing, storage, packaging and marketing. The final level of production is thus adversely affected. Adopting post-harvest technologies can increase better quality of products and extend market opportunity.

Poor grain storage remains one of the most common problems in developing countries and estimates of grain losses range from 33 to 50 per cent (Kader, 2003). The inadequacy of storage accompanied with vulnerability of crops to damage makes middlemen and traders unwilling to store stocks beyond the minimum turnover period (Gabriel and Hundie, 2004). Due to the rapid perishability of food grains, the risk of loss could be quite high in magnitude. Thus, the role of post-harvest management practices becomes critical.

Post-harvest grain management practices can affect household food security through the following channels:

1. output reduction in food grain availability due to physical losses
2. lower income due to lower prices when grains are sold immediately after harvest.

It is important to emphasize that in the above channel, farmers' perception of risk of post-harvest losses and other liquidity constraints can affect the marketing behavior and can produce suboptimal outcomes which result in lower levels of household food security.

As pointed out by Goletti and Wolff (1999), the post-harvest sector can play an important role in achieving higher agricultural growth and improved food security for the following reasons. First, the sector has high internal rates of return². On an average, the rate of return of the post-harvest sector is comparable to that from production research and thus makes an almost equal contribution to income growth. Second, post-harvest research has public good like characteristics and thus will be underfunded by the private sector. In the area of post-harvest research, the International Center for Tropical Agriculture (CIAT) cassava project and the International Rice Research Institute's (IRRI) rice drying technology are examples that can be replicated in many countries. For cassava, the rapid deterioration and perishability of roots increases costs and risks. This leads to considerable losses to wholesale merchants, retailers, processors and consumers. Thus, techniques for storage and processing should be adopted to prolong the root's useful life or in generating other products. If cassava roots can be stored for more than 3 days, the two advantages would be:

1. losses and marketing risks would be fewer, making cassava more acceptable to markets; and
2. managing the possibilities for the processor and consumers will be greater.

Finally, post-harvest research contributes to food security in several ways. Improvement in storage technology reduces the losses and thus increases the amount of food available for consumption. Similarly, reduction of cyanide potential in crops such as cassava has an important effect on food safety and can improve the nutrition situation of a significant proportion of the population in many countries in Africa.

As evident from the above studies, adoption of modern technology can improve both household income and access to resources and, therefore, improve household food security, while its impact on household nutritional status is at best ambiguous. This may be due to gender biased effects, as there is a shift in the control over the crop from women to men with the adoption of new technology. In order to generate similar policy recommendations, this chapter undertakes an empirical analysis based on univariate *t*-test framework. This is done to understand the impact on food security from the adoption of new technology (hybrid maize adoption) using the socioeconomic household survey data of Malawi.

Empirical analysis – a basic univariate approach

As we have seen from the above case studies, policy makers and program managers are keen to know the food security impact of the adoption of new technology. Thus, the main question frequently asked is: do technology adopters and non-adopters have different levels of food security? To answer this question in a comprehensive manner, one needs to know information on household characteristics, such as age and sex, household income and expenditure patterns on food and non-food items and food intakes by the members of the family. The data can be collected in a panel form where the same households are surveyed over time (e.g. before and after technology adoption) or can be gathered from a cross-section of households for a single time period from technology adopters and non-adopters.

In this section, we introduce a statistical technique to study the difference in the food security status of technology adopters and non-adopters. An independent sample *t*-test is undertaken to answer the above question. The key objective of this test is to determine the statistical significance of the observed differences in food security across the two groups, namely technology adopters versus non-adopters. The *t*-test computes sample means for each of two subgroups of observations and tests the hypothesis that the population means are the same between the subgroups. Thus, the hypothesis being tested is that, on average, adopters and non-adopters of new technology have the same level of food security.

In our analysis, the *t*-statistic for testing the above hypothesis (equality of means) is calculated under two different assumptions – equal and unequal variances. These two assumptions imply that either the food security of adopters will vary the same way within themselves as that of non-adopters or adopters and non-adopters will have different within group variances.

In the rest of this section, we use the dataset from Malawi to demonstrate:

1. data description and analysis
2. descriptive statistics
3. threshold of food insecurity by each individual component
4. tests for equality of variances
5. *t*-test.

Data description and analysis

In the first stage, we chose 604 households from regions Mzuzu, Salima and Ngabu out of 5069 households based on whether the household had at least one child as member below the age of 5 (Figure 2.1). These regions were chosen, since detailed data on food consumption patterns for the household and nutritional status of the children are available. Further, they represent varied agro-ecological zones, cropping and livestock rearing patterns, consumption patterns and geographical (northern, central and lakeshore and southern) locations within the country. Out of the 604 households, 197 had information on 304 children (below

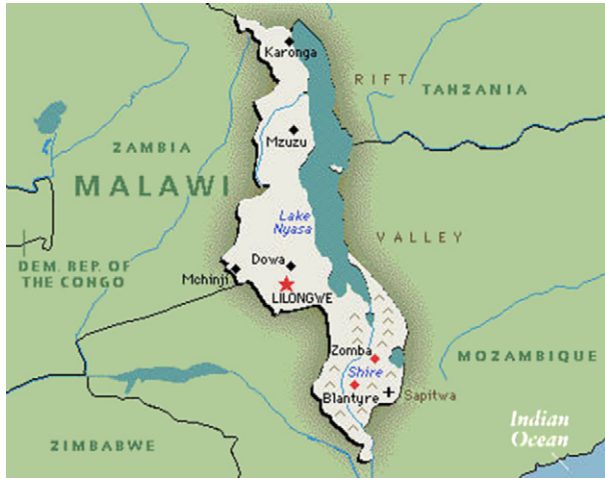


Figure 2.1 Map of Malawi. (iSource:<http://wwp.greenwichmeantime.com/time-zone/africa/malawi/map.htm>)

the age of 5) related to nutritional status and general health conditions. All the households had information pertaining to food intake, quantity harvested for various crops and other socioeconomic information. The aforesaid sampling strategy was adopted in order to understand which households (who had at least one child below the age of 5) suffer from a nutrition insecurity problem. These household level data are rich in content, since they contain not only information on household characteristics such as age, education, sex of the household head, but also expenditure on and share of different food and non-food items consumed. Additionally, the data also contain information on the number of meals consumed by the household on a daily basis (this variable in combination with other variables is used as an indicator of food security) and the time after harvest when the household stock of food runs out.

In the second stage, we sort the data by add-code (agricultural district), epa-code (village cluster), household number and enumerator number. The add-code signifies the main region, whereas the epa-code denotes a subregion within the main region. This is done in order to determine if there are regional variations (for example between the northern and southern regions) in food security between technology adopters and non-adopters. The main variables used in the analysis are as follows:

HYBRID: this variable denotes technology adoption by a household and assumes two values: adoption of hybrid maize (a value of 1); non-adoption (a value of 0).

Two measures of household food security are computed:

1. The first measure of 'food security' is a combination of household dependency ratio and the number of meals that a household consumes. It is thus an interaction

variable on the lines of Haddad et al. (1994). The basic idea is that if a household has a large number of dependents (as measured by variable *Depratio*, the ratio of dependents to total household members, being above 0.5) and consumes less number of meals (*NBR*), say below three per day then the household is relatively more food insecure (a value of 3). On the other hand, if the household has less number of dependents and consumes more meals, then the household is relatively more food secure (a value of 0). This variable is coined as *INSECURE* and is computed on a 0–3 scale to indicate the different degrees of food security. Higher values of this indicator will thus denote that the household is more food insecure. This is computed as follows:

$$\begin{aligned}
 \text{If } \text{Depratio} \geq 0.5 \text{ and } \text{NBR} \leq 2 \text{ then } \text{INSECURE} &= 3 \\
 \text{If } \text{Depratio} < 0.5 \text{ and } \text{NBR} \leq 2 \text{ then } \text{INSECURE} &= 2 \\
 \text{If } \text{Depratio} \geq 0.5 \text{ and } \text{NBR} > 2 \text{ then } \text{INSECURE} &= 1 \\
 \text{If } \text{Depratio} < 0.5 \text{ and } \text{NBR} > 2 \text{ then } \text{INSECURE} &= 0
 \end{aligned} \tag{2.1}$$

2. The second measure of food security combines the income and consumption components into an overall index of food security on the lines of Sharp (2003). The ‘income component’ is determined by total livestock ownership (*LIV-STOCKSCALE*) and measured in tropical livestock units (TLUs). This is an equivalence scale based on an animal’s average biomass consumption. Livestock ownership can be a critical component of food security if assets ensure that household consumption does not fall below a critical level even when incomes are insufficient. During periods of hardship, these assets can be sold to fill in income gaps and, hence, this indicator can serve as a proxy for income levels. The relevant conversion for the types of livestock reported in the questionnaire is given in [Table 2.1](#).

Market prices come as a natural candidate for aggregating livestock resources. However, for a poor country such as Malawi, livestock prices may be highly seasonal and extremely variable from year to year. Additionally, spatial integration of markets is poor in remote regions and thus, under these conditions, even accurate price data are of unreliable quality. Thus, the biophysical scale of TLU is used in aggregating the value of livestock and is consistent with physical measures applied to other assets (such as land for example). For scaling this indicator, we use the minimum value of 0 (for no animals owned), while the maximum is truncated at 6 TLU (i.e. all households with 6 or more have TLUs score 1 on this indicator). Like other assets, livestock ownership is a continuous variable with many possible values.

Table 2.1 Tropical livestock unit values for different animals

Animal type	TLU value
Cattle	0.8
Goat	0.1
Sheep	0.1
Pigs	0.2
Chicken, ducks, and doves	0.01

Source: International Livestock Research Institute (1999).

Table 2.2 Scaled values for livestock owned

Data value of livestock units (TLUs)	Scaled value
6+	1.00
5	0.83
4	0.67
3	0.5
2	0.33
1	0.17
0	0.00

Table 2.2 provides an example of the possible values of livestock owned and their scaled equivalents. The scaling is done so that different indicators can be combined on a scale from 0 to 1. For example, food shortage in months and total livestock units measured in TLU units can be compared and combined. The basic formula for scaling a variable is given by $(X_i - X_{\min}) / (X_{\max} - X_{\min})$, where X_i is the actual value of the variable, X_{\min} is the minimum value of the variable and X_{\max} is the maximum value of the variable. The maximum and minimum values used in the above formulae are from the actual data ranges. For example, if the actual value of a variable is 5, the minimum value is 0 and the maximum value is 6, then using the above formula, we obtain the scaled or normalized value of the variable to be 0.83. This measure of food security can be used across time and space (e.g. between years and between different regions if data are available). Since this variable is continuous, a large number of intermediate values are feasible. The scaled values for livestock owned are given in Table 2.2 using the above approach.

Consumption components of the food security index

The 'consumption components' of the food security index are number of meals (NBR) that the household consumes during a given day and the months when the stock of food runs out (RUNDUM). The number of meals that the household consumes is a strong indicator of household strategies to cope with short-run food insecurity and thus may be a potential measure of vulnerability. However, this measure is less sensitive to changes in situations of chronic food insecurity.

The second component provides an estimate of the number of months per year that households are able to meet their food needs, either through production or purchase. Months of adequate food provision is a relatively simple indicator and, when used in conjunction with the number of meals that the household consumes, provides a clear picture of the vulnerability of the household. Thus, these variables along with the income indicator such as livestock owned, could show why particular households are vulnerable and provide a measure of the severity of vulnerability. The number of months that households are unable to eat enough to satisfy their hunger can be used as an indicator of vulnerability. We measure the number of meals on a 0–3 scale, with 0 denoting that the household

went sometimes without eating in a day, while the maximum value of 3 denoting that the household is food secure (Table 2.3).

Months of adequate provisions or stock of food running out (RUNDUM) was also measured on a 0–3 scale, with the truncation being at the minimum value of 0. In other words, if the stock of food runs out before the enumerating period, the variable assumes a value of 0. For stock of food lasting between 1 to less than 3 months, the variable attains a value of 1. For stock of food lasting between 3 to less than 6 months, the variable assumes a value of 2 while, if the food stock lasts more than 6 months, the variable attains the maximum value of 3. Thus, a higher value of this component indicates that the household is relatively more food secure. Finally, the overall food security index is a weighted average of these three components, namely (1) the number of livestock owned (LIVSTOCKSCALE), (2) the number of meals consumed per day (NBR) and (3) stocks of food running out (RUNDUM). The weights are chosen in proportion to the variance of each component. Thus, if one component has a higher variance relative to another component, it gets a lower weight in the food security index (FOODSEC) (explained in note 3). The rationale for choosing the weights in such a way is to ensure that none of the components dominates the overall ‘food security index’. The overall index is thus computed as

$$FOODSEC = \sum_{i=1}^3 w_i c_i \quad (2.2)$$

where w_i are the respective weights and c_i are the three individual components. For example, with $w_1 = 0.1$, $w_2 = 0.4$, and $w_3 = 0.5$ and with values of $NBR = 0.33$, $RUNDUM = 0.33$ and $LIVSTOCKSCALE = 0.67$, the value of the food security index would be 0.5. The above measure of food security is a continuous variable with higher values of index denoting food secure households. The index ranges between 0 and 1 with 0 denoting completely food insecure households and 1 denoting fully food secure households.

A household’s score of this index has no easy explanation by itself, since it is a mathematical composite of three different factors. Following a common procedure adopted by Filmer and Pritchett (1999), by categorizing the bottom 40 per cent of the population as food insecure, the cut-off value for this index was determined at 0.3. It should be emphasized that the above measure of food

Table 2.3 Scaled values for number of meals per day

Number of meals per day	Scaled value
3	1
2	0.67
1	0.33
0	0.00

security does not capture dietary diversity⁴ or household's perception of food needs such as the food security measurement scale developed in the USA (Staatz et al., 1990).

Descriptive statistics

The independent variable HYBRID is nominal dichotomous variable and FOODSEC, the measure of food security, is a continuous variable. From the analysis, the food security measure is given by:

$$\begin{aligned} \text{FOODSEC} = & 0.2798\text{NBR} + 0.4821\text{RUNDUM} \\ & + 0.2381\text{LIVSTOCKSCALE} \end{aligned} \quad (2.3)$$

where 0.2798, 0.4821 and 0.2381 are respectively the variance⁵ of the components NBR, RUNDUM, and LIVSTOCKSCALE.

The two groups – hybrid maize adopters and non-adopters – are compared in reference to food security. Let us first compare the basic descriptive statistics of food security for adopters and non-adopters (Table 2.4).

From Table 2.4, it is evident that the hybrid maize adopters have a higher mean for food security compared to non-adopters. This suggests that adoption of new technology improves food security given by equation 2.2. Next, we want to investigate whether these differences of mean and variance are statistically significant. In other words, we want to determine if the differences among the sample of technology adopters and non-adopters on food security is relevant for the population too.

Threshold of food security by each individual component

As mentioned before, the problem with a continuous indicator of food insecurity (FOODSEC) is that it does not contain rules or information to identify the food insecure households from the rest. In order fully to understand the households that are food insecure in each of the above components (namely livestock ownership, number of meals consumed per day and the month when the stock of food runs out), it is important to determine the cut-off point for each of the above components. This procedure is explained in the technical appendix of this chapter.

Table 2.4 Group Distribution of FOODSEC

	Hybrid maize adoption	N	Mean	Standard deviation	Standard error mean
FOODSEC	Non-adopters	131	0.3439	0.144	0.01261
	Adopters	43	0.3970	0.152	0.02318

Table 2.5 Threshold of food security components

Indicator	Cut-off point	Cumulative percentage
NBR	0.33	13.4
RUNDUM	0.33	69.8
LIVSTOCKSCALE	0.16	74.7

This is achieved by looking at the cumulative distribution of each component and identifying the cut-off point. Table 2.5 provides the cumulative distribution of households by the cut-off points for the individual components of food security.

Table 2.5 provides some additional interesting insights into the nature of food insecurity in the regions. From the number of meals consumed per day set at a threshold level of 1 or below, we find that about 13 per cent of the population is food insecure. However, looking at the variable when food stock runs out (choosing the threshold value of 0.33, i.e. for RUNDUM < 0.33), we find that almost 70 per cent of the population is food insecure. Additionally, from the number of livestock owned as a measure of asset owned, we find that almost 75 per cent of the population does not own any livestock. As the UN points out, 'households with limited assets are vulnerable, not only because of their relative poverty, but also because they have few items to divest should they be forced to spend money on food or emergencies'. (See for example, the document of the Southern African Regional Poverty Network at <http://www.sarpn.org.za/documents/d0000522/exec.php>.)

Tests for equality of variances

A basic assumption underlying the use of parametric tests such as Student's *t*-test and analysis of variance (ANOVA) is that the variance of variables under study must be roughly equal for multiple samples (groups). Levene's test is used to test the null hypothesis that multiple population variances (corresponding to multiple samples or groups) are equal. The importance of the assumption of equal variances in all groups depends on whether the groups have roughly equal sample sizes. If they do, violation of the equality of variance assumption has little effect on the observed significance levels. If the groups have very different sample sizes and the smaller groups have larger variances, then the chance of rejecting the null hypothesis when it is actually true increases (probability of type I error). On the other hand, if the larger groups have smaller variances, the chances of not rejecting the null hypothesis when it is actually false increase (probability of type II error).

Levene's test follows an *F*-distribution. The *F* ratio test of variance equality is computed by the ratio of the largest to the smallest variance. Assuming a normally distributed population, *F* follows the following distribution:

Table 2.6 Levene's test of equality of variances

Variables	F-statistic	P value
INSECURE	0.566	0.452
FOODSEC	0.174	0.677

$F(n_{max}-1, n_{min}-1)$, where n_{max} is the sample size of the group with the larger variance and n_{min} is the sample size of the group with the smaller variance. If the actual F -value is greater than the critical value, then the variance of the relevant variable is significantly different across groups. If the F -value is non-significant then the variances do not differ statistically. If the Levene's test produces a non-significant result (for example, a P value greater than 0.05), then the t -test that assumes equal variances must be used. However, if the Levene's test produces a significant result (e.g. a P value less than 0.05), then the t -test that does not assume equal variances must be used. In the latter case, the computation includes a correction for the lack of homogeneity of variance (Table 2.6). When the variances are homogeneous, the standard error of the difference is computed by summing the standard deviations and dividing by the square root of the sum of the number of observations in each group. This is also called the standard error of the difference with pooled variance estimates. This is given by equation (2.5).

The hypothesis of equal variance of the interaction measures of food insecurity (INSECURE) and the weighted average of the income and consumption components of food security (FOODSEC) across the two groups, namely the hybrid maize growers and non-growers, is not rejected at the 1 or 5 per cent level of significance.

Student t-test for testing the equality of means

We first introduce a few notations to show how the t -test is undertaken for testing difference of means of variables. Let μ_1 and μ_2 and σ_1 and σ_2 denote the means and standard deviations of technology adopters and non-adopters respectively. These are the population parameters corresponding to the sample statistics. We want to test the hypothesis that

$$\begin{aligned} H_0 : \mu_1 - \mu_2 &= 0 \\ H_1 : \mu_1 - \mu_2 &\neq 0 \end{aligned} \quad (2.4)$$

In other words, the null hypothesis (H_0) asserts that the population parameters are equal. The statistic $(\overline{X}_1 - \overline{X}_2)$, is the difference between the sample means. If $(\overline{X}_1 - \overline{X}_2)$ differs significantly from zero, we will reject the null hypothesis and conclude that the population parameters are indeed different. Since the two random samples are independent, i.e. probabilities of selection of the elements in one sample are not affected by the selection of the other sample, we want to look

at the sampling distribution of the variable $(\bar{X}_1 - \bar{X}_2)$. The standard error of the difference between the two means is given as follows:

$$S_{\bar{X}_1 - \bar{X}_2} = \sqrt{\left(\frac{s_{pooled}^2}{n_1} + \frac{s_{pooled}^2}{n_2} \right)} \quad (2.5)$$

where $s_{pooled}^2 = \text{pooled variance estimate} = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)}$. s_1^2 and s_2^2 are the estimates of the within group variability of the first and second group respectively. The t -test statistic is thus given by:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{S_{\bar{X}_1 - \bar{X}_2}} \quad (2.6)$$

We undertake the t -test of equality of means assuming equal variances. However, we present the results assuming both equal and unequal variances across the technology adopters and non-adopters.

An independent sample t -test is used since different subjects (technology adopters and non-adopters) have been used in each condition. As explained before, Student's t -test for independent samples is used to determine whether the two samples were drawn from populations with different means. The t -test provides a t -statistic along with a corresponding level of significance. If the actual t -value exceeds the critical value at the 1 or 5 per cent level of significance, we reject the null hypothesis of equal means of food security (as measured by either INSECURE or FOODSEC) and conclude that technology adopters and non-adopters have differing levels of food security. On the other hand, if the computed t -value is less than the critical value at the relevant level of significance (1 or 5 per cent), then we do not reject the null hypothesis and conclude that technology adopters (maize growers) and non-adopters (maize non-growers) have the same level of food security (Table 2.7).

The validity of the t -test requires that the samples be drawn from normally distributed populations with equal (population) standard deviations. Levene's test can be used to test the hypothesis of equal variances across populations. If both samples are large then the assumption of equal or unequal variance is not very relevant since the difference in results due to either becomes negligible.

It is important to note that if X_{ij} denotes the original score on a response variable X for case i in group j , the Levene test undertakes a minor transformation of the original scores as $X_{ij} = |X_{ij} - \bar{X}_j|$ before undertaking the hypothesis test of equal group variances. However, as pointed out above, the Levene's test is less robust. This is because if the groups have very different sample sizes and the smaller groups have larger variances, then the chance of rejecting the null hypothesis when it is true increases. In other words, the probability of type I error increases. Under such circumstances (when the variances of the two groups are not equal), it is better to improve the robustness of equality of variance test by applying the Brown-Forsythe test. The Brown-Forsythe test is identical to the Levene's test but uses group j 's sample median in transforming the original data.

Table 2.7 Student's *t*-test for equality of means

Variables	Assumptions	<i>t</i> -statistic	Attained significance (2-tailed)
INSECURE	Equal variance assumed	2.33	0.02
	Equal variance not assumed	2.363	0.019
FOODSEC	Equal variance assumed	-2.064	0.04
	Equal variance not assumed	-2.011	0.04

From Table 2.7, considering the continuous measure of food security (FOODSEC), using equations (2.5) and (2.6) respectively, the mean difference is -0.05307 and the mean standard error difference ($S_{\bar{X}_1 - \bar{X}_2}$) is 0.02571 . Thus, the computed *t*-statistic is given by -2.064 . For 172 degrees of freedom, the critical *t*-value that corresponds to an area of 0.05 (*P* value) in both tails is 1.96. Since the actual value is greater than the critical value, the null hypothesis of equal means of food security for technology adopters and non-adopters is rejected. Thus, food security between these two groups is statistically different and we conclude that hybrid maize adopters are better off in terms of food security. It is important to note here that the degrees of freedom are substantially reduced when the analysis is undertaken with the weighted average measure of food security (FOODSEC). This is because livestock information is available only for 174 households rather than the total sample of 604 households. Since one of the components of the food security index consists of owning livestock, we have only $(131 + 43 - 2) = 172$ degrees of freedom.

Policy implications

The impact of technology adoption on food security and nutrition is still under debate. In many cases cited earlier, adoption of improved technology did not always increase calorie consumption (food security) and/or nutrition. But, in general, there is a consensus that technological change does result in positive production and income effects. Now, it is not always the case that such an income effect is translated into either an increased expenditure on foods giving higher energy intake or an increased expenditure on non-food expenditures related to health and sanitation or both. Such an effect is desirable, since it leads to better food security and nutrition for members of the household.

In addition to increased income, we know from the earlier discussion that there are other determinants that significantly affect the transition from technology adoption to improved nutrition. They are: intra-household labor allocations; equal access for both men and women to credit and technology training; and agricultural policies that improve credit markets, storage and processing facilities, transport infrastructure, research and training and distribution channels.

From the program design and policy intervention perspective, policy makers and program managers need research-based evidence on the role of various factors, such as above, that hinders translation of benefits from technological change into food security and nutrition outcomes. Since much of these outcomes are context specific, the results of the analysis of technological change and adoption should be viewed in a broader policy context.

Reardon et al. (1997) summarize the crucial policy actions that need to be undertaken for a successful implementation of technology adoption:

1. improvement in input access and reduction of unit costs to farmers through infrastructure investment
2. increase in productivity of fertilizer and seed variety by encouraging complementary farm-level investments
3. improvement in distribution and marketing channels of inputs and outputs accompanied by incentives for private sector investment
4. facilitating easy and equal access to credit to both men and women to buy inputs
5. introduction of innovative credit schemes to reduce the farmers' financial risks of investment in inputs
6. evaluation of net economic and social benefits of agricultural support programs, including input subsidies.

The empirical analysis presented from the Malawi dataset is a univariate approach that assesses the role of technology adoption (in the form of growing hybrid maize) on food security. Two measures of food security were constructed: the first being an interaction measure of the combination of the number of meals consumed per day and the proportion of dependents in the household, while the second measure (a broader one) was a weighted average of the income and consumption indicators to understand food access.

Since the above analysis indicates that hybrid maize adopters are better off in terms of food security, policies to encourage technology adoption by growing hybrid maize should be implemented by the government to increase household food security of the rural population. However, the results of such an empirical analysis should be taken cautiously. Though such an exercise is an effective immediate approach, policy makers should recognize that the effects of technology adoption can increase overall household food consumption, thereby satisfying the calorie requirement for the vulnerable sections of the population. However, it can have an ambiguous effect on the nutritional status of adults (especially women) and children. For example, an increased yield of maize could possibly result in increased consumption by the adopting household but could substitute for other purchased foods. This may result in decrease of dietary diversity, which could then lead to micronutrient deficiencies.

Interestingly, the analysis also found that the nature of food insecurity in Malawi may be chronic and long term in duration. This is because, although most of the households are not food insecure as measured by the number of meals consumed per day, they are asset poor and do not have adequate food provisions. Thus, long-term factors and policies encouraging technology adoption in improving food security must take into account income effects, women's

welfare, input and output subsidies, equal access to credit, infrastructural development, efficient marketing and distribution channels and research and training.

A study that was reviewed earlier, on the effects of hybrid maize adoption on food consumption and nutrition in Zambia by Kumar (1994), indicates many pros and cons of technology adoption and outlined different policy implications. The Malawi data used in this chapter come from a very similar agro-ecological region as the Eastern region of Zambia. Thus, the policy implications could be similar to that study. To encourage higher production of hybrid maize by rural households, the study finds it important to promote the development of maize not only as a cash crop, but also for self-consumption. The difficulty involved in processing and storing hybrid maize hinders such promotion. Hence, governments must invest and provide easy credit for private investment in storage facilities and processing mills. The limited availability and poor distribution channels of hybrid seeds and fertilizers constrain the yield levels. To increase the efficiency of yields, governments must invest in infrastructure and transport and communications, in addition to improving marketing channels.

Technical appendices

Constructing the cut-off points for components of the food-security index

As discussed in this chapter, the problem with a continuous indicator such as FOODSEC is that it does not contain any principle of isolating the food insecure households from the rest, since it is a mathematical composite of three different components. Thus, in order to estimate the number of food insecure households, it is necessary to determine a cut-off point between food secure and insecure households. Since it is reasonable to assume that households having less than one meal per day ($NBR \leq 0.33$) and the stock of food lasting less than 3 months ($RUNDUM \leq 0.33$) are relatively more food insecure, we look at the frequency distribution of these variables and the cumulative distribution function of the number of households falling below these threshold values. Since the livestock ownership by the households ($LIVSTOCKSCALE$) is a continuous variable with many possible values, we first looked at the mean of this variable. The mean was found to be 0.164. Thus, the number of households who fell below this threshold value was considered to be food insecure. In other words, we wanted to determine the probability that $LIVSTOCKSCALE \leq 0.164$. By looking at the cumulative distribution function of this variable, we found the percentage of households below this threshold value to be 74.7.

The advantage of this approach is that a researcher can look at the various components of food insecurity and isolate the components from each other. Thus, although the households may not be food insecure by the number of

meals consumed per day, they may be asset poor and may not have adequate food provision to sustain themselves throughout the year. The nature of food insecurity can be long term and chronic and should be captured for policy analysis.

Variable definitions

Dichotomous variable

A variable that categorizes data into two groups is a dichotomous variable. Generally, such a variable is indicated by values 0 and 1 with each representing a different category. For example, sex is a dichotomous variable and can be defined as 1, if female and 0, if male. A dichotomous variable is also called a dummy variable or indicator variable. Most importantly, one must always understand that, in the case of a dichotomous variable, each of the two numbers (e.g. 0 and 1) represents a qualitative category and in no way can they be used as quantities.

In general, a variable that categorizes data into two or more groups is a *nominal* or *categorical* variable. In the present chapter, HYBRID is a dichotomous variable, while INSECURE is a nominal or categorical variable. Thus, a dichotomous variable is just a special case of a set of nominal or categorical variables.

Interval variable

These variables are also known as continuous variables. They are measured on a scale that changes values smoothly rather than in stepwise fashion. They can be ordered in ascending or descending fashion. For such a class of variables, distances between the values are known and these distances have meanings. In the present chapter, FOODSEC is an example of a continuous variable.

Exercises

1. Based on the studies presented in this chapter, discuss the main findings related to effects of technology adoption on food consumption and nutrition. Discuss the policy implications of promoting technology adoption among rural households.
2. Compute the FOODSEC index with the following weights as variances of each individual component: $NBR = 0.2$, $RUNDUM = 0.45$ and $LIVSTOCKSCALE = 0.35$. Undertake an independent sample *t*-test to determine if there are significant differences among technology adopters and non-adopters in generating food security. Also, undertake a Levene test to determine if the null hypothesis of equal variances across populations holds true.
3. The climatic conditions in southern parts of Malawi are not very favorable for maize production, while the northern regions are more productive in adopting hybrid maize technology. Write a syntax for the *t*-test that examines the impact of adopting hybrid maize on food insecurity and regional variations in production of maize. In other

words, undertake an independent sample t -test to determine if there are significant differences among technology adopters and non-adopters in generating food security and productivity in the northern and southern regions.

Hint: use the dummy for the northern (dnorth) and southern regions (dsouth) as the test variables in your analysis.

4. Check the food balance sheet for your country from the FAO website and prepare a commentary on the food availability for the past decade.
5. Read the paper by Staatz et al. (1990) and describe how the food security index is constructed in their paper. What would be the impact of technology adoption in Malawi on food security using that index?
6. Do hybrid maize adopters have lower incidence of child malnutrition than non-adopters in Zambia? Explain.

Notes

1. For testing the equality of group variances, SPSS provides the Levene test, which is a homogeneity of variance test. This test is less dependent on the assumption of normality than most other tests. For each observation, the program computes the absolute difference between the value of that observation and its cell mean and performs a one-way analysis of variance (ANOVA) on those differences.
2. The internal rate of return is the interest rate that makes the present value of an investment's income stream equal to zero. In other words, the costs and benefits add up to zero.
3. The first step in measuring dietary diversity is to collect information on local consumption patterns to identify a diet that signifies food security. When this indicator is used as a measure of food security, foods are grouped not by economic value but by nutritional composition.
4. The first step in measuring dietary diversity is to collect information on local consumption patterns to identify a diet that signifies food security. When this indicator is used as a measure of food security, foods are grouped not by economic value but by nutritional composition.
5. The individual weights were computed from the variances as follows: suppose, that for any three series, X , Y , and Z the variances are: $V(X)$, $V(Y)$ and $V(Z)$, with $V(X) > V(Z)$. Then, the weight of X is given by $\frac{V(Z)}{\sum V(Z)}$, while the weight of Z is given by $\frac{V(X)}{\sum V(Z)}$. In other words, we give a higher weight to the series with a lower variance and a lower weight to the series with a higher variance. This procedure ensures that none of the series dominates the overall index.

3 Effects of commercialization of agriculture (shift from traditional crop to cash crop) on food consumption and nutrition – application of chi-square statistic

Diverse cropping systems, rather than monocropping, is also much more suited to the harsh conditions in which most farmers in Sub-Saharan Africa operate.

Second report from Working Group on Climate Change and Development, June 20, 2005.

Introduction

Growing cash crops in lands where food is traditionally grown can have a profound impact on food security. Effects of this shift, known as commercialization of agriculture, on food consumption and nutrition vary; a number of studies have documented disastrous effects, while others found a positive or neutral effect. Critics of commercialization of agriculture contend that if the resources that are used to produce agricultural export crops were used instead to produce food for the local economy, the problem of malnutrition in many countries could be reduced. Proponents, on the other hand, argue that by exploiting comparative advantage, commercialization could raise farm incomes and improve nutrition (see, for example, von Braun et al., 1994 and Bouis and Haddad, 1994).

The emphasis on cereal production over the past three decades in many developing countries has resulted in low output prices and profitability and has dampened agricultural growth (the growth in cereal production was 2.3 per cent during the period 1965–1980 and declined to 1.9 per cent per year during the period 1996–2000; (see, for example, Barghouti et al., 2004)).

Additionally, investment in the agricultural sector has also declined during the past three decades. In order to reverse this trend, agricultural commercialization has been identified as one of the strategies by the donor agencies (World Bank, 2002a; DFID, 2002). Commercialization is seen as a common and powerful

means to increase rural household income and food access, as well as diversify production and reduce risks of income and food shortfalls (Ali and Farooq, 2003).

von Braun et al. (1994) emphasize that the process of commercialization raises income. Increased incomes further improve welfare, food security and nutritional status – all of which could have been worse in the absence of commercialization of agriculture for rural populations. Recent studies (see, for example, Govereh and Jayne, 2003) have also demonstrated that commercialization of agriculture can lead to improved productivity of other crops through household level synergies and regional spillover effects, thereby improving food security.

In order to conclude about the positive benefits of agricultural commercialization on food security and nutrition, it is important to answer a few specific questions: Is commercialization of smallholder agriculture a legitimate policy tool for improving food and nutrition security? As commercialization proceeds, which social and economic groups benefit from higher wages and incomes? In other words, what does the distribution of average income look like – is it skewed towards specific economic or social groups and, if so, towards which group? Which socioeconomic group adopts commercialization and what are the implications for resource ownership and sharing? Does higher household income from commercialization result in improved food consumption and better nutrition for all household members?

The issue is critically important since cash crops contribute to livelihood diversification and improve food and nutrition security by directly increasing the farm household's income earning potential which, in turn, increases the household's spending potential. Second, since most cash crops tend to be labor-intensive, cash cropping entails a substantial expansion of the demand for hired labor. This employment effect for households that hire out labor may represent significant livelihood improvement (Masanjala, 2006). Third, the introduction of cash crops contributes to the development of rural financial markets, which partially relieves the cash constraints (Goetz, 1993). Finally, cash cropping opportunities are also accompanied by improved technology.

However, there are also reasons to suspect that the impact of cash crop liberalization on the welfare of households may be more limited than is generally acknowledged (Orr, 2000). First, a critical assumption made is that as farm households earn more income, the market will widen the scope for its welfare maximization since increases in income will assure household food security by increasing the farm household's access to food through the market. However, this impact chain is not at par with the empirical evidence from the food security literature, which suggests that cash cropping is associated with missed opportunities for improving household welfare. The income and employment benefits of commercialization are not spread equally between households due to imperfect or missing factor markets. Second, due to weak financial markets for expenditure and consumption smoothing, when cash cropping opportunities increase household incomes, allocating more income to

food purchases is not automatic as the literature seems to suggest (Paolisso et al., 2001).

In light of the above set of issues, this chapter examines the relationship between cash crop growing and household food security and nutrition situation using a chi-square statistical technique. The purpose of a chi-square test is to compare the observed frequencies with the expected frequencies derived under the hypothesis of independence. It is appropriate in examining the relationship between two bases of classification, since we are examining the relationship between cash crop growers and food security of the household and then determining the independence between cash crop growers and children's nutritional status. The chi-square procedure can be legitimately applied only if the categories in which the observations are sorted are independent of each other, i.e. only if the placement of each observation into a particular category does not depend on the placement of any of the other observations. In other words, the categories must be both exhaustive and mutually exclusive – each observation must fit into one or another of the categories and no observation fits into more than one. This procedure is appropriate to use since food security, cash crop production and nutritional status variables can be classified into mutually exclusive and exhaustive cases.

A discussion of the concepts of commercialization and its impact on food consumption and nutrition and an overview of some of the main studies serves as a motivation for the empirical analysis. We conclude with a few policy implications from the results of this chapter.

A few concepts

What is commercialization?

Commercialization of agriculture is mainly a process of production of cash crops. A cash crop is simply a crop produced for sale. Agricultural commercialization can be defined as the 'proportion of agricultural production that is marketed' (Govere et al., 1999). Commercialization of agriculture involves moving from subsistence-oriented patterns to increasingly market-oriented patterns. The underlying assumption behind this shift is that markets allow households to increase their incomes by producing those commodities that generate the highest returns and then use the cash to buy household consumption items (Timmer, 1997). Recent trends in globalization of smallholder agriculture including connecting smallholder farmers with domestic and international market chains is a clear indication that commercialization of smallholder agriculture will continue to increase in the developing world (von Braun, 2005).

Commercialization of smallholder agriculture by bringing the resource poor farmers to markets is not entirely a new phenomenon. Many agricultural processes have been implemented in developing countries for production of cash

crops. Abbott (1994) provides a few examples in the context of commercialization in developing country agricultural development:

Hanapi and Sons enterprise for rice production in Malaysia: this enterprise specializes in mill-polished rice, bran, very fine rice, broken rice and husk from paddy.

Corn Products Corporation International enterprise for maize production in Kenya and Pakistan: this enterprise converts maize to starch, sweeteners, oil-and-gluten feed and flour for livestock.

Siam Food Products enterprise for pineapple in Thailand and Rose's Lime Products enterprise for limes in Ghana: these enterprises specialize in canning of pineapples, processing of limes into limejuice, lime oil etc.

Dabaga Fruit and Vegetable Canning Company for fruits and vegetables in Tanzania: the main activities are processing products (fruits and vegetables) into jams, pickles, juices and soups.

Commercialization of agriculture can also include dairy farming enterprise such as the successful Anand Dairy Cooperative Union in India that processes and markets milk, butter, milk powder, ice cream and other dairy products.

Recent cases of commercialization

1. Supermarket chains have opened in China, especially in the rural areas. The government of China is actively encouraging the development of rural retail networks, including the transformation of rural market fairs into modern supermarkets (USDA, 2005). The commercialization of Chinese agriculture has been accompanied by an improvement in calorie and protein intake, which is consistent with evidence from other developing countries. Thus, food insecurity is a relatively rare phenomenon in rural China.
2. With the opening of the Indian industrial sector during the early 1990s, the Punjab Agro-Industries Corporation in 1988 went into a joint venture with Pepsi (a US multinational corporation) with the third partner being Voltas, a domestic corporate firm (Kumar, 2006). The entry strategy of Pepsi was to procure and process certain fruits and vegetables grown in the state. By the early 1990s, these activities led to the emergence of contract farming for tomatoes. Also, another local entrepreneur named Nijjer entered the market with financial support from the Punjab Financial Corporation and set up a tomato processing plant and began processing and procuring tomatoes from the farmers under contract farming. Presently, Pepsi is procuring chilli and basmati rice and plans to enter the business of ginger and garlic paste and the processing of several fruits such as mango, guava, orange and other citrus fruits. FritoLay, which is a subsidiary to Pepsi, is procuring potatoes from the farmers under contract farming, while Hindustan Lever Limited (HLL), a subsidiary of Unilever, is contracting farmers to procure basmati rice for exporting it abroad (Kumar, 2006).

Two types of contract farming can be distinguished: the first type consists of firms that have a direct contract relationship with the farmers and they are responsible for providing inputs/extension services. These firms procured the end product directly from the farmers. Examples include Pepsi/FritoLay; Hindustan Lever Limited; Chambal Agritech Limited and A.M.Todd. The second type of firm was operating through the Punjab Agro Foodgrains Corporation (PAFC). PAFC tied up with three types of companies for providing inputs and extension services to the farmers and to

buy back their contracted crops¹. Thus, in the latter type there was a tripartite agreement between the farmer, the PAFC and the companies providing seed, extension services and a buy back guarantee to the farmers on behalf of PAFC.

Out of these two types of contract farming, it was found that the former was operating efficiently. The extension services provided were up to the mark in the case of firms having direct contract with the farmers. Similarly, the buy back guarantee was honored at the pre-determined procurement price in the case of direct contract firms. In the case of the PAFC model, although there was a written contract between the farmers and the service providers, there was a lack of commitment on the part of service providing companies. In most cases, no extension services were provided to the farmers and, as a result, farmers were forced to sell their commodities in the open market. Thus, the system of contract farming was heavily skewed towards medium and large farmers and the smaller farmers were the losers.

Additionally, the productivity data clearly showed superiority of contract farmers over their counterpart non-contract farmers in all size classes and this was clearly dominant in the case of crop productivity. One can conclude that the experiment of contract farming in Punjab has generally benefited the farming community. However, the system is heavily skewed towards the medium and the large farmers and the small farmers were net losers in the process.

Commercialization as a process is not limited to cash crop production. It extends beyond cash crops and may also include traditional crops (grown for self-consumption) if one markets the produced surplus or adopts a purchased input technology. There are also instances where farmers have retained significant produce of a cash crop for home consumption, such as groundnuts in West Africa. Moreover, commercialization of agriculture does not necessarily mean commercialization of the rural economy. There are rural settings where there is negligible production of cash crops but a high level of non-farm and non-agricultural employment. An example of such a setting could be a village that produces traditional crop for household consumption and derives its income mainly from non-agricultural commercial activities such as production of handicrafts or employment in textile mill for instance (von Braun et al., 1994).

Commercialization effects

The effects of commercialization on income, consumption, food security and nutrition are very complex in nature and mainly depend on household preferences and intrahousehold allocations (von Braun et al., 1994).

Some of the exogenous factors of commercialization are population change, adoption of new technologies, infrastructure and market based development and macroeconomic and trade policies. The endogenous factors of commercialization mainly depend on three characteristics of intrahousehold decision making: first, the household determines the proportion of income spent on food and non-food (mainly health and sanitation) expenditures. Second, the household determines the allocation of food expenditure among the various types and quantities of foods. Third, the household decision maker also

determines how the food and other consumption items are distributed among the household members. There are other endogenous consequences of commercialization, most important of which are the gender allocation of time, labor and control of income.

Effects of commercialization of agriculture on food consumption

The decision of intrahousehold allocations, i.e. how to allocate household resources like land, labor, time and capital towards production activities and how to share household income among members can have a significant impact on household food consumption (Haddad et al., 1997). Since household food availability determines food consumption, it is important to evaluate the impact that commercialization of agriculture has on household food availability. Such an impact can be either positive or negative on the individual members of the family depending on who controls the household income and how they are allocated to food consumption and non-food items among the members.

On the positive side, commercialization can produce considerable real income gains, thus enhancing a household's capacity to acquire food. However, the income–food consumption relationship is not so direct. It is influenced by many factors such as who controls the income, the proportion of money spent on food and non-food items and whether the increased income results in higher intake of calories or intake of more expensive calories.

Furthermore, if the household shifts from a traditional crop production to cash crop production (particularly a non-food cash crop with a long growing cycle), it allocates the majority of its land resources to such a commercialization process. In the absence of non-farm income, the household's food supply may be affected negatively in the short and medium term. However, in the presence of non-farm income, the household can compensate for such a loss by purchasing foods. In the worst-case scenario, non-farm income is not available and trading of cash crops takes place in the presence of unfavorable production conditions. This can adversely affect the household's food consumption and nutrition. The findings of studies on how commercialization affects rural food consumption in various developing countries are presented in later sections.

Effects of commercialization of agriculture on nutrition

The complexities involved in commercialization and food consumption relationship are also applicable to the commercialization and nutrition relationship (Peters and Herrera, 1994). The nutritional effect of commercialization can be attributed to the impact commercialization has on an individual's nutrient intake. There are important factors other than diet that need to be considered in analyzing the effect of agricultural commercialization on human nutrition, particularly on the nutritional status of women and children. The effects of commercialization on children's welfare are partly mediated through the income–consumption link,

since increased incomes are found favorably to affect children's nutritional status. The effect of commercialization on non-food expenditures can influence the health and sanitation environment positively which, in turn, improves children's nutritional status. At the same time, the additional time allocated by women in pursuing productive activities can adversely affect the child's nutritional status as less time is allocated to child-care.

The general view is that the commercialization of agriculture increases household income which, in turn, influences food consumption and nutritional adequacy. It is typically assumed that this income-mediated effect on nutritional improvement operates through two main pathways. First, increased income can be used for increased food expenditures that directly increase food consumption which, in turn, may improve nutritional status by higher energy and nutrient intake. Second, increased income can result in increase in non-food expenditures like health and sanitation that indirectly have positive health effects (Kennedy and Haddad, 1994).

Review of selected studies

von Braun and Immink (1994) examined the impact of export-oriented vegetable production on household food security and nutritional status in Guatemala. Vegetable production appeared to be a promising option because of rising foreign demand during the 1980s, for two main reasons. First, for the small-holder sector, such production created opportunities for adoption of labor-absorbing production techniques. Second, the decline in market prices of traditional exports, an increasing external debt and contracting foreign exchange reserves prompted the government to undertake policies towards production of vegetable crops to reduce the risk factors that are associated with declining income and food insecurity of farm households.

The cooperative was formally formed in 1979 with 177 farmers. Its membership rose to 1600 in 1989 comprising eight villages. In 1985, the cooperative farmers were cultivating almost 300 hectares of export vegetables, mainly snow peas, cauliflower, broccoli and parsley. The results of the study are based upon household-level surveys conducted in 1983 and 1985 in six villages of the Cuatro Pinos region in the western highlands of Guatemala. The cooperative was active in all these six villages and the survey constituted of two rounds (1983 and 1985) in the same season with the same households.

In examining the impact of commercialization on income, the study found that export crop producing households earn higher income than others and food expenditure as a share of total expenditure decreases with an increase in income levels. In addition, the calorie intake was increasing with the rise in incomes across all households. While the cooperative households, on average, increased their calorie intake by 2.8 per cent with 10 per cent more income compared to 4.4 per cent by non-members, this difference in calorie intake was not significant.

Overall, although the favorable effect of an export producing commercialization scheme is not very significant in the short term, it had a significant positive impact in the long run. Increase in incomes decreased stunting and weight deficiency, but the effect was less pronounced at higher income levels. Women-controlled income affected children's nutrition significantly. Finally, higher export crop income share did not have adverse effects on children's nutrition.

Based on the above findings, the authors conclude that production of export crops had a positive effect on household income, food security and nutrition of farmers in Guatemala. However, commercialization is not risk free and increases the small farmer's dependence on market conditions for both inputs and outputs. In the absence of appropriate financing, such risks may be hard to bear. The production of export crops has the potential for significant losses if market prices are unstable, the crop fails, marketing institutions break down or export markets collapse. In addition, government's fiscal, monetary and foreign trade policies can have a significant effect on the revenues from export crops in either direction (positive or negative). The study suggests a few policy implications of commercialization effects.

To attain a sustained income growth from export crop production, the policy structure should consist of:

1. increasing the efficiency of domestic and international marketing channels through investment in infrastructure, transportation facilities and development of effective marketing organizations.
2. easier access to rural credits and innovation of credit schemes that address the specific needs of small and large farm households.
3. macroeconomic and foreign trade policies that encourage production of export crops and a simplified export licensing structure.
4. development of rural financial and social institutions that provide easier access to extension programs, savings schemes and financing of community development projects.

The above policy structure accompanied by simultaneous and complementary social investments in health, environment and sanitation, can not only attain sustainable income growth for rural farmers, but can also reinforce the positive effect of increased income on food security and nutrition.

Peters and Herrera (1994) conducted a study in the Zomba district of Southern Malawi to evaluate the impact of commercialization of tobacco on household food security and nutritional status. The sample consisted of households that were tobacco growers and non-growers. Household consumption of maize (which is the main staple food) came mainly from own farm production.

The research site was located in the southern part of Zomba district, which was about 15 miles from the town of Zomba. The area was covered by one of the largest white-owned estates in the Shire Highlands – the Bruce Estates. A sample of 210 households was selected with 148 of them being non-tobacco growing households, while the remaining were tobacco growing households.

The results of the study indicated that income was positively correlated to nutritional adequacy, with per capita income and per capita expenditures being the most important determinants of child nutrition. Interestingly, though, tobacco growers had both higher per capita incomes and expenditures and their children were not significantly different in nutritional status from non-growers. Overall, the study does not find a significant effect of cash cropping on children's nutrition.

Since Malawi is a very poor country, any agricultural initiative that guarantees an income increase for the rural population is encouraged. This is corroborated by the findings that income plays a significant role in influencing household food consumption and nutrition. As most of the tobacco growers in the sample, on average, still produce maize as the main crop, the cash crop component of income is not a significant part of production and income plans. Policy makers must address the important risks that small farmers face when recommending cash crop production at higher levels.

An effective policy plan should include development of efficient distribution and marketing of inputs (such as fertilizers, seeds, etc.) and outputs (processed tobacco), an easy access to credit, training programs and policies that promote a sustainable and stable market for cash crops. In addition to market risks, farmers also face risks related to food security. Policy plans to encourage commercialization must consist of measures that reform the food supply inefficiencies.

Paolisso et al. (2001) address how the commercialization of the vegetable and fruit cash crop program (VFC) affects male and female time allocation and thereby child nutrition in Nepal. The overall goal of the VFC program is to increase the commercial value of vegetable and fruit production and raise household incomes of targeted farmers. The program also provides production inputs, training and technical assistance to both men and women farmers.

The data came from three communities that represented different agro-ecological zones, ethnic groups and cultural practices. A sample of 264 households was chosen using a random spot observation method by recording the activity of the households within the 6:30 to 18:30 time period. The activity of the households was recorded during the above time period by visiting them randomly 30 times during a 12-month period.

The study addressed three questions. First, what factors determined household participation in the VFC program. Second, how male- and female-headed households allocated time among various activities depending on their VFC participation status and third, how VFC participation affected male- and female-headed households' labor allocation to various activities after controlling for a number of individual and household characteristics. A probit analysis² was undertaken to estimate the likelihood that a household would have received VFC training.

The study used an instrumental variable estimation strategy to address the impact of VFC participation on time allocation by male- and female-headed households. The main result is that VFC participation increased the time allocated in the production of fruits and vegetables by both men and women; less

time was allocated to cereals and livestock and greater time was devoted to care of children less than 5 years by women. At the same time, men spent moderately less time caring for children. Although, the study does not measure nutritional status of the children directly, it seems that participation in the VFC program by women gives them additional time to allocate for child-care. This in turn possibly improves the nutritional status of preschoolers.

A study by Govereh and Jayne (2003) examined how agricultural commercialization affects food productivity through household level synergies and regional spillover effects for a northern district in Zimbabwe called Gokwe. Household level synergies occur when a household's participation in a commercialized crop scheme enables it to acquire resources that otherwise would not be available. For example, Strasberg (1997) points out that under credit and input market failures in northern Mozambique, cotton outgrower schemes were the primary method of acquiring cash for use in food production. Regional spillover effect occurs when commercialization schemes attract investments to a region that generate benefits to all farmers regardless of whether they engage in that commercialization scheme. The study examined the determinants of cotton commercialization at the household level and the contribution of commercialization to food crop yields and production. The data come from a survey of 480 rural households in 1996, using a stratified sampling approach. Gokwe district was selected since it was a major cotton producing area.

The study used an instrumental variable estimation approach to address how commercialization affected food productivity. The results showed that the effect of households adopting commercialization had a positive and significant impact on food productivity. This can possibly be attributed to cotton producers having access to key inputs such as credit and training through the cotton schemes that are either not accessible to non-participating farmers or simply not available to them at all. Second, farm size had a negative and significant impact on yields, which suggests that smaller farms are more productive than larger farms. Third, regional spillovers had a positive and significant impact on food productivity and an additional cotton input retailer in the area boosts maize grain output significantly. This is mainly because cotton retailers provide a range of services for farmers growing food crops, including inputs used in maize production. Thus, commercialization of cotton appears to be associated with higher grain productivity.

The main implication of the study is that cash crop production may not come at the expense of household food security. Participation in cash crop programs may allow farmers to overcome failures such as access of inputs and credit supply. The author thus suggests that synergies between cash crops and food crops research extension programs may have important implications for promoting smallholder food crop productivity growth and thus alleviate the problem of food insecurity significantly.

From the above studies, it is apparent that the impact of commercialization on food security and nutrition is income mediated. Research findings (Govereh et al., 1999) also point to the synergies between commercial cash crop

production and food crop production, which can improve food crop productivity and thus have a positive impact on household food security. Commercialization at the household level can also contribute to farm capital formation, which is an additional source of productivity growth. However, for commercialization to be successful, investment in specific areas are necessary, such as irrigation and drainage, science and technology, rural infrastructure and changing the policy and institutional environment. All these investments cannot be expected to come from the public sector. Thus, national governments have to create an enabling environment for the private sector to provide inputs and services so that farmers can have the incentives for commercialization.

In order to generate similar policy recommendations, this chapter undertakes an empirical analysis based on the chi-square test to determine if cash crop adoption by rural households in Malawi has a positive impact on food security and nutrition of children.

Empirical analysis

Since policy makers are keenly interested in knowing whether commercialization creates multiplier effects by changing opportunities created by new production technology or market signals, it is important to understand whether this improved productivity leads to households being more food secure (especially the marginal farmers) after a commercialization scheme is launched.

Thus, the central questions addressed are as follows:

- is it more likely for a cash crop growing household than a traditional crop growing household to be food secure?
- is it more likely for a cash crop growing household than a traditional crop growing household to have children with adequate nutrition, i.e. absence of malnutrition?

To answer the above questions, one needs information on household characteristics such as incomes by family members, expenditure on food and non-food items, demographic characteristics of the members and food intake by family members. Additionally, one also needs suitable measures of the children's nutritional status. Pearson's chi-square test is used to determine whether the observed relationship between the nominal or categorical variable is statistically significant or is due to random variability. A brief description of the Pearson's chi-square test is presented in the technical appendix.

Data description and analysis

We use the household-level data for Malawi as before. The variables used in the analysis are as follows:

CASHCROP: tobacco, groundnuts, cotton and plantain are the major cash crops in Malawi. The variable is defined as $CASHCROP = 1$ if the household grows at least one of these four major cash crops and 0 otherwise. CASHCROP will thus represent commercialization of agriculture at the household level.

Two measures of household food security are computed:

1. The first measure of ‘food security’ is a combination of dependency ratio and the number of meals that a household consumes as defined in Chapter 2.
2. The second measure relies on per adult equivalent calorie intake for households. Food security is defined as households being able to satisfy at least 80 per cent of the requirement for calorie intake. This variable is coined CALREQ. If a household’s daily per adult equivalent calorie intake (CALADEQ) is at least 80 per cent of the requirement, 2200 kcal, then the household is qualified as ‘food secure’³. The variable is defined as CALREQ = 1, if the household is food secure and CALREQ = 0, otherwise.

CALREQ is computed as follows:

$$\text{PCALMET} = \left(\frac{\text{CALADEQ}}{2200} \right) \times 100 \quad (3.1)$$

CALREQ is then defined by

$$\text{CALREQ} = \begin{cases} 1 & \text{if PCALMET} \geq 80 \text{ (Indicating food security)} \\ 0 & \text{otherwise (Indicating food insecurity)} \end{cases} \quad (3.2)$$

The following three nutrition measures are also used:

ZHANEW, ZWANEW, and ZWHNEW: the Z-scores that identify malnutrition in children ZHA (height for age Z-score), ZWA (weight for age Z-score) and ZWH (weight for height Z-score). The details of computing the Z-scores are given in Appendix 6.

ZHANEW indicates presence or absence of stunting, ZWANEW indicates if the child has low weight for age and ZWHNEW indicates the presence or absence of wasting. These three variables are constructed as follows:

1. All the Z-scores that are above 5 and below -5 are excluded. By rule of thumb, all the Z-scores above 5 and below -5 are considered outliers and are excluded from the analysis.
2. The three indicators of malnutrition are defined by creating two categories, one with Z-score less than -2 and the other with Z-score greater than or equal to -2 , i.e.

$$\begin{aligned} \text{ZHANEW} &= \begin{cases} 1 & \text{if ZHA} \geq -2 \text{ (Normal Z-scores indicating absence of stunting)} \\ 0 & \text{otherwise (Low Z-scores indicating presence of stunting)} \end{cases} \\ \text{ZWANEW} &= \begin{cases} 1 & \text{if ZWA} \geq -2 \text{ (Normal Z-scores indicating absence of under weight)} \\ 0 & \text{otherwise (Low Z-scores indicating presence of under weight)} \end{cases} \\ \text{ZWHNEW} &= \begin{cases} 1 & \text{if ZWH} \geq -2 \text{ (Normal Z-scores indicating absence of wasting)} \\ 0 & \text{otherwise (Low Z-scores indicating presence of wasting)} \end{cases} \end{aligned} \quad (3.3)$$

Descriptive analysis: cross-tabulation results

First, we investigate the relationship between CASHCROP, which is the independent variable, and the two food security measures. Later, we will

investigate the relationship between CASHCROP production and child nutritional levels. It is important to note that all the above variables are nominal or categorical variables. The hypothesis is that there is no relationship between commercialization (CASHCROP) and food security (CALREQ and INSECURE). This is tested using cross-tabulation procedures (Table 3.1).

The cross-tabulation results indicate that 35.9 per cent of the cash crop growing households are food insecure (as measured by CALREQ) compared to 64.1 per cent of the non-cash crop growing households. It is likely that growing cash crop generates additional income for the household, who can sell these crops at local markets. This in turn allows them to purchase more food. Next, we investigate the relationship between CASHCROP and INSECURE (the second measure of food security) (Table 3.2).

From Table 3.2, it is evident that cash crop growers are relatively more food secure compared to non-cash crop growers. This is possibly because the household's participation in a commercialized crop scheme enables it to acquire resources that otherwise would not be available.

Next, we want to investigate whether cash crop production results in achieving higher nutritional levels for the children as well as increased food security for the household members. We undertake cross-tabulation tests for CASHCROP and ZHANEW, ZWANEW and ZWHNEW. All the above variables are dichotomous nominal variables. The hypothesis is that there is no relationship between commercialization (CASHCROP) and child nutrition as measured by the above indicators. Tables 3.3–3.5 show the relationship between them.

The cross-tabulation results indicate that 53.7 per cent of preschoolers of the households not growing cash crops are stunted, while 46.3 per cent of preschoolers for households growing cash crops are stunted. It is likely that the extra income generated through sale of cash crops achieves greater income, which helps in moderating food insecurity of the household. Household members can obtain higher energy intake as well as greater dietary diversity. The higher energy intake results in better child nutritional status.

The incidence of underweight preschoolers was 55.1 per cent for households who did not grow cash crops and 44.9 per cent for households who grew cash

Table 3.1 Cross-tabulation results of cash crop growers and CALREQ

		CASHCROP		Total
		No	Yes	
CALREQ	No	225 64.1%	126 35.9%	351
	Yes	169 66.8%	84 33.2%	253
	Total	394	210	604 = <i>n</i>

Table 3.2 Cross-tabulation results of cash crop growers and INSECURE

		CASHCROP		Total
		No	Yes	
INSECURE	Secure	49 65.3%	26 34.7%	75
	Moderately insecure	64 73.6%	23 26.4%	87
	Highly insecure	116 60.1%	77 39.9%	193
	Totally insecure	165 66.3%	84 33.7%	249
	Total	394	210	604 = <i>n</i>

Table 3.3 Cross-tabulation results of cash crop growers and height for age
Z-scores for children under 5 years

		CASHCROP		Total
		No	Yes	
ZHANEW	Low	66 53.7%	57 46.3%	123
	Normal	54 55.7%	43 44.3%	97
	Total	120	100	220 = <i>n</i>

Table 3.4 Cross-tabulation results of cash crop growers and weight for age
Z-scores for children under 5 years

		CASHCROP		Total
		No	Yes	
ZWANEW	Low	97 55.1	79 44.9%	176
	Normal	44 53.7%	38 46.3%	82
	Total	141	117	258 = <i>n</i>

Table 3.5 Cross-tabulation results of cash crop growers and weight for height Z-scores for children under 5 years

		CASHCROP		Total
		No	Yes	
ZWHNEW	Low	121 57.08%	91 42.92%	212
	Normal	7 31.82%	15 68.18%	22
	Total	128	106	234 = <i>n</i>

crops. The results indicate that underweight children are less likely to occur in cash crop growing households relative to non-cash crop growing households.

The cross-tabulation results of cash crop production and wasting are given in Table 3.5. It is evident that households who grew cash crops had a lesser incidence of wasting (42.9 per cent) compared to households who did not grow the crops (57.1 per cent). However, from the above results, we cannot conclude if the results were significant or only due to random variability. Thus, we undertake chi-square tests to determine this.

Chi-square tests

Similar to the cross-tabulation tests, we first investigate whether the relationship between CASHCROP and food security (Table 3.6) is significant and then determine whether the relationship between CASHCROP and nutritional indicators (such as ZHANEW, ZWANEW, and ZWHNEW) are significant or if it is just due to random variability. For the sake of brevity, we will just concentrate on one food security measure, namely per capita adult equivalent calorie intake falling below 2200 kcal per day.

The null hypothesis is given by H_0 : no relationship exists between growing cash crops and food security, i.e. incidences of observed food insecurity among households are not statistically different between cash crop growers and non-cash crop growers. The value of Pearson chi-square is 0.471 with significance level (P value) of 0.492⁴. The P value is the smallest level of significance for which the observed data indicate that the null hypothesis should be rejected. Since the significance level is greater than 0.1, the null hypothesis cannot be rejected at the 10 per cent level. It is important to report the P value, since it gives more information to the reader than stating whether the null hypothesis was rejected or not for some level of significance (for example, $\alpha = 0.05$) chosen by the researcher. The incidence of food insecurity is not statistically different between cash crop growers and non-growers. Although we find that cash crop growers have better food security using the cross-tabulation tests, we cannot infer that this relationship is statistically significant. Next, we undertake

Table 3.6 Chi-square tests between CASHCROP and CALREQ

	Value	<i>P</i> value
Test statistic	0.471	0.492
Number of valid cases	604	

Table 3.7 Chi-square tests between CASHCROP and height for age Z-scores for children under 5 years

	Value	<i>P</i> value
Test statistic	0.089	0.766
Number of valid cases	220	

chi-square tests between cash crop growers and the various indicators of nutrition in order to determine whether the observed relationship is statistically significant or is simply due to random variability.

It is evident from [Table 3.7](#) that the *P* value of the test statistic is quite high (0.766). Thus, we are unable to reject the null hypothesis and infer that there is no observed pattern of relationship between cash crop growing and stunted preschoolers. Although, from the cross-tabulation results we find that cash crop growing reduces stunting, this relationship is not significant and is only due to random variability.

It is apparent from [Table 3.8](#) that the *P* value of the chi-square test statistic is 0.827 and is greater than 0.1. Thus, the null hypothesis that there is no observed pattern of relationship between cash crop growing and underweight preschoolers cannot be rejected. Hence, the incidences of underweight preschoolers are not statistically different between these two groups.

We find that the *P* value of the chi-square test statistic is 0.023 ([Table 3.9](#)) and is significant. It can be reasonably concluded that cash crop growing reduces the incidence of wasting among preschoolers. This is probably because the weight for height Z scores (WHZ) are a short-term indicator of nutritional status and, at least in the short run, cash crop growing can benefit households by generating greater income and achieving food security. Improvement in food security status leads to greater distribution of food and other resources at the intra-household level which, in turn, alleviates the problem of malnutrition for preschoolers.

Conclusion and policy implications

‘Commercialization of agricultural systems is a universal and irreversible phenomenon that is triggered by economic growth’ (Pingali and Rosegrant,

Table 3.8 Chi-square tests between CASHCROP and weight for age Z-scores for children under 5 years

	Value	P value
Test statistic	0.048	0.827
Number of valid cases	258	

Table 3.9 Chi-square tests between CASHCROP and weight for height Z-scores for children under 5 years

	Value	P value
Test statistic	5.131	0.023
Number of valid cases	234	

1995). The rate of commercialization differs across countries and its impact on food security and nutrition are also different. Agricultural commercialization has complex linkages with food security and nutrition. The relationship operates through its effect on household income, expenditures and intrahousehold labor and resource allocations. Each of the above three factors can be broken down into further important categories.

Commercialization in agriculture has a significant impact on per capita income, income of men and income of women. A positive effect on either of these variables has different effects on food consumption and nutrition. The income available per household member for consumption is a better measure than income. Men spend relatively more on non-food expenditures that include nutrition-enhancing items like health and sanitation in addition to alcoholic drinks. On the other hand, women on an average spend a higher share of their expenditures on food, which directly affects children's nutrition (see, for example, Peters and Herrera, 1994).

Similarly, household expenditures constitute food expenditures (more specifically, quantity and quality of calories), non-food expenditures (especially health, sanitation and education) and investments in agricultural inputs. Though higher income in many cases has resulted in higher food related expenditures by rural populations, it is critical to understand the nature of these expenditures. Higher intake of calories by purchasing more staple food, say maize, may not have the similar effect on nutritional adequacy as by purchasing more expensive calories like fish, fruit, meat, etc. The effect of commercialization will obviously be more beneficial if the increased income is used to spend more on health and sanitation than on alcoholic drinks. Since a shift to cash crop from traditional crop requires investment in technology and various other inputs that are not easily affordable to small farmers, they look for access to the credit markets. Channeling a proportion of increased income to reduce debt and future investments in better

technologies can also have significant effects on household food security and nutrition in the long run.

From the cross-tabulation and chi-square tests, we find that cash crop growing is usually beneficial to the household both in achieving greater food security and higher nutritional status for children. This is possibly mediated through higher incomes as well as the additional synergy of access to greater credit for the cash crop growers. However, undertaking the chi-square tests, we find that, except for weight for height Z-scores, there is no observed pattern of relationship between cash crop growing and food security and between cash crop growing and nutritional status of children in general. This does not imply that cash crop growing has no benefits to the household at all. In the short run, cash crop growing can benefit households by generating greater income and achieving food security. Increase in food security leads to better distribution of food and other resources at the intrahousehold level, which can reduce the problem of malnutrition.

A few critical policy implications must be emphasized concerning the impact of commercialization on food security and nutrition. An efficient domestic and international marketing channel, easier and equal access to credit markets, macroeconomic and foreign trade policies that simplify export licensing and encourage export production and promotion of a sustainable and stable domestic market for cash crops are vital for commercialization to work. Food security is a primary concern for small farmers in allocating land for cash crops. The policies advocating commercialization for increasing rural incomes and those reforming food supply inefficiencies must be juxtaposed. Most importantly, simultaneous and complementary social investments in health and environment can not only attain sustainable income growth for rural farmers but can also reinforce the positive effect of increased income on food security and nutrition.

Policy makers should also encourage women's participation in the commercialization process by providing incentives that hinder gender bias in decision making and income sharing. Governments should offer easier information access to women about farming and agricultural production of cash crops. Policies that provide equal access to inputs and credit for women farmers should be brought into effect, since increasing women's income is associated with better child nutrition (Spring, 2000).

The nature of agricultural commercialization, socioeconomic environment and agro-climatic conditions specify a certain policy structure. Thus, a generalized plan cannot be prescribed for all commercialization processes. The adverse impact of cash crop production on food consumption and nutrition is not necessarily the result of inherent fallacies in commercialization opportunity but can be due to bad policies or underinvestment in specific sectors such as rural infrastructure, irrigation and drainage. Government actions, such as unnecessary trade constraints, inaccessible credit markets for rural poor and absence of appropriate price supports for inputs and outputs, can be disadvantageous for the commercialization process to work effectively.

Technical appendices

Pearson's chi-square (χ^2) test of independence

The Pearson chi-square is the most common test for significance of the relationship between nominal variables. The purpose of the χ^2 test is to answer the question by comparing observed frequencies with the expected frequencies derived under the hypothesis of independence. The test statistic is given by $\chi^2_{\text{statistic}} = \sum (f_0 - f_t)^2 / f_t$, where f_0 is an observed frequency and f_t is the expected frequency. The expected frequencies are computed as follows:

$$f_t = \frac{(\text{Row total})(\text{Column total})}{\text{Total Sample Size}(n)}.$$

For example, from Table 3.2, the expected frequencies for each of the four cells are computed as follows: for households who are cash crop growers and have food security, the expected frequency is given by $\frac{(394) \times (351)}{604} = 228.96$. Similarly, for the households who are not cash crop growers but are still food secure, the expected frequency is given by $\frac{(351) \times 210}{604} = 122.03$. For the households who are cash crop growers but are not food secure, the expected frequency is 165.03. Finally, for the households who are not cash crop growers and who are food insecure, the expected frequency is given by 87.96.

The number of degrees of freedom must be determined in order to apply the above test. In this example with a 2×2 table, the degrees of freedom $v = (2 - 1)(2 - 1) = 1$. In general, for r rows and c columns, the number of degrees of freedom is $(r - 1)(c - 1)$. For example, the chi-square value between cash crop growing and food security was 0.471. The critical value at the 0.01 level of significance is $\chi^2_{0.01, 1} = 6.635$. Since the actual value is less than the critical value, we are unable to reject the null hypothesis of no observed pattern of relationship. The chi-square test measures the discrepancy between the observed cell counts and what one would expect if the rows and columns were unrelated.

The main assumptions underlying the use of the chi-square test are that the sample is randomly selected and expected frequencies are not very small. The reason for the latter assumption is that the chi-square inherently estimates the underlying probabilities in each cell of the cross-tabulation – when the expected cell frequencies fall below 5, those probabilities cannot be estimated with sufficient precision. In our analysis, none of the cells in the cross-tabulations has a frequency below 5.

Student's t-test versus Pearson's chi-square (χ^2) test

When the primary concern is the dependence or independence rather than the absolute difference in mean between variables, the χ^2 test should be employed. This distinction becomes somewhat elusive sometimes. In fact, when the test for difference in means involves nominal (categorical) variables, both t -test and

χ^2 tests can be applied. In general, however, the difference between the two is that a t -test is more applicable with the difference in means between variables, whereas the χ^2 test is designed to test the independence between variables (Lowry, 2003).

The χ^2 test should also be distinguished from various statistical procedures that measure the association between variables. While the former tests if there is dependence relationship among variables, the latter is intended to quantify such dependence, if it exists.

Limitations of the chi-square procedure

Although chi-square procedures are computationally simple, they rest on a complex logical structure and thus impose certain limitations. First, chi-square procedures can be applied when the N observations are independent of each other, i.e. putting one observation in one particular category does not depend in any way on placement of any of the other observations. The categories must be exhaustive and mutually exclusive. Second, validity of the chi-square tests is greater when the value of f_t , the expected frequencies within the cells, are fairly large. Although statisticians do not always agree where to draw the line between 'large enough' and 'too small', chi-square procedures can be applied if $f_t \geq 5$. For the special case of 2×2 contingency tables, this limitation can be avoided using the Fisher exact probability test (Lowry, 2003).

Exercises

1. Based upon the literature listed in the analysis, discuss the main findings related to effects of agricultural commercialization on food consumption and nutrition. Discuss the policy implications of promoting commercialization among rural households.
2. Write a chi-square syntax to examine the relationship between CASHCROP and INSECURE. Is the test statistic significant? How many degrees of freedom does the test statistic have?
3. Recollect the food security index developed in Chapter 1. Can a chi-square test be applied between CASHCROP and this index? Discuss your answer in detail.
4. From the empirical results of this chapter, is it more likely for a cash crop growing household than a traditional crop growing household to be more food secure in Malawi? Discuss the findings critically.
5. Is it more likely for a cash crop growing household than a traditional crop growing household to have children with adequate nutrition? Discuss the results with reference to Malawi.

Notes

1. The first set were seed companies, the second set were consultant companies providing consulting services on agronomic practices, while the third set belonged to the buyers/export companies who

were tied up for a buy back guarantee to contract farmers and for providing forward linkages for their produce.

2. A probit analysis uses a transformation where each observed proportion is replaced by the value of the standard normal curve (z value) below which the observed proportion is found. Probit coefficients represent the difference a unit change in the predictor makes in the cumulative normal probability of the outcome, i.e. the effect of the predictor on the z value for the outcome. This probability depends on the levels of the predictors. For example, a unit change at the mean of the predictor has a different effect on the probability of the outcome than a unit change at the extreme value of the predictor.
3. The percent intake of the average energy requirement is used as a means of examining calorie adequacy. Individual energy requirement is estimated according to the age-sex specific recommendation of the joint FAO/WHO/UNO committee. The standard for an adult male equivalent is 2200 kilocalories.
4. The P value for the chi-square test is $P(\chi^2 \geq X^2)$, the probability of observing a value at least as extreme as the test-statistic for a chi-square distribution with $(r-1)$ ($c-1$) degrees of freedom. The P value was similarly computed for the t -distribution in the previous chapter.

4 Effects of technology adoption and gender of household head: The issue, its importance in food security – application of Cramer's V and phi coefficient

Women in developing countries need to be involved in policy making and planning to ensure the most productive and efficient use of land and water resources to meet present and future food and agriculture demands. Women farmers need to be part of the planning and implementation of land and water management programs, with full access to inputs and organizational arrangements. Equally important is the increased participation of women in training and extension activities that deal with soil resources and land-use planning, and in water conservation and development.

A Women in Development Technical Assistance Project, USAID, 2000.

Introduction

It is increasingly recognized that women could effectively improve food access and availability if they are empowered with capabilities and resources within the household. Women produce more than half the food grown in the developing countries (Stringer, 2000). Women farmers in sub-Saharan Africa produce more than three-quarters of the region's basic food, manage about two-thirds of the marketing and at least one-half of the activities for storing food and raising animals (Saitio, 1994). In Asia, women account for more than two-thirds of food production, while they contribute to about 45 per cent of production in Latin America and the Caribbean (FAO, 2000). Nonetheless, findings suggest that male-headed households are more likely to adopt a new technology or participate in a commercialization scheme than female-headed households (see, for example, von Braun, 1988; Kumar, 1994; David, 1998; Doss and Morris, 2001).

Most farmers in general and women in particular face limited choices and constraints at the household level. The gender differences in technology adoption rates can be attributed to two main reasons (Doss and Morris, 2001). Men and women may inherently have different preferences towards technology, women may be more risk averse.

The market-orientation could be different between men and women, with women growing food for household consumption and men for commercial sale. Even perceptions about tastes, appearance and storage of crops can explain the difference in preferences between men and women. Second, even if men and women have the same preferences towards technology choices, their access to complementary inputs, such as land, labor and credit and extension services, may be unequal. Understanding how gender affects farmers' access to land, labor and other inputs and how this changing access affects the adoption of new technology and commercialization processes will help in designing gender-mediated policies and programs that improve food security (Quisumbing and Otsuka, 2001).

Additionally, the benefits of technological adoption are not always distributed equally among males and females. Such biased effects can have serious adverse implications for family welfare and nutrition of children. Men tend to spend relatively more on non-food expenditures, which also include tobacco and alcoholic drinks. On the other hand, although women spend more on clothes, they also spend relatively more on food items that directly affect children's nutrition (see, for example, Kumar, 1994; Peters and Herrera, 1994; Lilja and Sanders, 1998).

Intrahousehold allocations and production structure in agriculture are the driving forces behind the gender-biased effects of agricultural innovations such as technological change (Kumar, 1994). The household characteristics that influence the allocation of resources are mainly women's share of resources (crop ownership) and household head's gender, education and age. These factors combined with other household characteristics, such as time spent in household activities by men and women, access to protected water and health and sanitation conditions, are the key determinants of children's nutritional status (World Bank, 2007).

Since the effects of commercialization or technology adoption vary greatly by gender, it is critically important to understand the linkages between the two. The main issues addressed in this chapter are:

1. are male-headed households more likely to be technology adopters than the female-headed households?
2. among technology adopters, are male-headed households more likely to be food-secure than female-headed households?

Addressing the above issues can help in program and policy design since gender differences in technology adoption rates have significant implications for agricultural productivity and food security.

The next section presents some case studies that examine critically the role of gender in technology adoption on household resource allocation and thus on household food security and nutrition. The third section presents the empirical analysis, while the final section draws some conclusions and implications.

Review of selected studies

In an extensive study, Kumar (1994) examined the gender effects of technological change in maize production in Zambia and the role of gender in food

consumption and nutrition. Maize is a staple food crop in Zambia and the traditional maize growers primarily rely on increasing the available land to improve productivity. Increasing the land area by itself is not sufficient for sustained growth in maize production. Thus, adoption of new technology is critical in improving yields. The technology adoption considered in this study is the production of high yielding hybrid maize.

The Eastern Province of Zambia is one of the major agricultural regions and provides about 90 per cent of household income through production or employment on farms. Additionally, the majority of the households derive food consumption from their own farm production. Maize is the most important crop grown in the province, with 83 per cent of overall land devoted to its production. Local maize constitutes about 60 per cent of land devoted to production, with the remaining land allocated to hybrid maize production.

The rate of hybrid maize adoption is 34 per cent for male-headed households compared to 22 per cent for female-headed households. While this is true for small farms with farm sizes between 1 and 3 hectares, female-headed households had a higher adoption rate for farm sizes between 3 and 5 hectares. Interestingly, a 100 per cent adoption rate is observed for all female- and male-headed households with farm sizes above 5 hectares. The study concluded that male-headed households have a higher likelihood of adoption of hybrid maize than female-headed households after controlling for other important observable factors. This was concluded after conducting logistic and two-stage regression models. The results implied that if there were two households with all observable characteristics and their decision to adopt new technology was equal and they differed only in respect to the gender of the household head, then the male-headed household is more likely to adopt hybrid maize production than their female counterpart.

The study found that the smaller farms are resource constrained on average. However, it is more likely that women would adopt new technology compared to men when the constraints are mitigated. The lower adoption rates for female-headed households can possibly be explained by women's tendency to be more risk averse about new technologies. It could also imply that access to critical inputs (such as land and labor) and other inputs such as training and credit is harder for women to obtain.

Agricultural innovations such as technological changes and commercialization have complex linkages with food security and nutrition and are determined mainly by their effect on household income, household expenditures and intrahousehold labor and resource allocations. A gender perspective plays an important role in analyzing such effects. The fundamental intrahousehold processes of labor and income allocation are gender-specific and they differ significantly between adopters and non-adopters (Katz, 1995).

Since the early 1970s, hedgerow intercropping (also known as alley cropping)¹ has been a major agro-forestry technology promoted by the various CGIAR (International Institute for Tropical Agriculture (IITA), International Livestock Center for Africa (ILCA), International Livestock Research Institute

(ILRI) and the International Center for Research in Agroforestry (ICRAF) centers. It is crucial that extension agents take into account the impact of adopting this technology on intrahousehold decision-making processes, given the complex nature of this technology due to its composite nature and multiple outputs.

Based on a study in southern Nigeria and western Kenya, David (1998) observes that the gender division of labor and decision making determines not only whether the household adopts a new technology or shifts to a cash crop production, but also the distribution of its benefits among the household members. Women's active role in agricultural commercialization (either as a household head or as a co-decision maker) tends to increase household food security. The adoption of hedgerow intercropping was more widespread and lasting in the south-western part of Nigeria relative to the south-eastern part. In the south-western part, male-headed households adopted the new technology. In contrast, in the south-eastern part, gender-related decision making was clearly the prominent factor that constrained the diffusion of new technology. The reason behind the low diffusion rate was that women farmers were not happy about mixing fodder trees with food crops – especially cassava.

For western Kenya, on the other hand (an area characterized by subsistence level mixed crop farming system), most of the households are female-headed due to the high rate of male emigration. An estimated 30 to 60 per cent of households were female-headed. Since a high percentage of households are female-headed and women are responsible for most of the farm work, male emigration constitutes an important constraint in the adoption of hedgerows. The authors cite two main reasons behind this low rate of adoption:

1. women were unable to find additional labor (labor availability constraint) for cutting hedges and small trees for firewood
2. the task generally involves male participation, since coppicing and spreading the mulch involve physical strength.

In a comprehensive study for Ghana, Doss and Morris (2001) examined the following set of issues:

1. does gender add any additional understanding of the technology adoption process?
2. to what extent are the observed differences in the rates at which men and women adopt technology attributable to gender-linked differences in access to complementary inputs, such as land, labor and extension services?

The above questions have significant practical implications, since men and women could have fundamentally different preferences in technology adoption and access to complementary inputs, which prevent them from adopting technology at the same rate.

The case study is undertaken for maize production in Ghana, since it is the most important cereal crop both in terms of production and consumption. Data were collected on the adoption of modern varieties (MV) and chemical fertilizer using a three-stage randomized procedure. A sample of 420 maize farmers located in 60 villages in the country was selected. A two-stage probit model was

specified, where adopting MV and chemical fertilizer were related to each other with a vector of explanatory variables that explain technology adoption. The explanatory variables were gender of the farmer, farmer's age, farmer's education, amount of land owned by the farmer, level of infrastructure and household size measuring labor availability.

Overall, the results indicated that technology adoption decisions depended critically on access to resources, rather than on gender per se. The above finding should be interpreted with caution, since it does not necessarily mean that MV and fertilizer adoption are gender-neutral technologies. This is because if adopting MV and fertilizer depends on the critical access to resources (such as availability of land, labor and extension services) and men have better access to resources than women, then under these conditions technologies will not benefit men and women equally.

The use of gender of the household head as a proxy can be effective for two main reasons. First, the data are readily available from most surveys. Second, it is usually the case that the majority of decision making is vested on the household head. Posel (2001) observed that for female-headed households, in particular, heads have a final say over the majority of the decisions even when they may not be earning most of the income in South Africa. In fact, the study argued that the highest income earner is usually a worse predictor of decision making than the household head. The gender of the household head is thus very useful in distinguishing households on their access to economic resources and hence their welfare outcomes. Given that the impact of technology adoption on food security and nutrition is essentially mixed and is highly dependent on variables such as the nature of the crop, the control of production and income, the allocation of household labor, the maintenance of subsistence production, land tenure policies and prices of food and cash crops, it is important to understand the gender dimension of the technology adoption process on household food security and nutrition. It is the intervening factors and not crop choice that appear to be crucial in understanding the impact of technology adoption on nutrition. From a policy perspective, food and agricultural policies and programs that target the most vulnerable segments of the population are most likely to have a positive benefit on food security and nutrition.

In this chapter, we investigate whether commercialization and technology adoption varies by gender and how such a decision influences household food security and nutritional status through Cramer's V and phi coefficient statistical technique.

Empirical analysis

To evaluate empirically the impact of agricultural innovations on the gender of the household head, one needs to address the following questions:

- are male-headed households more likely to be technology adopters than the female-headed households?

- among technology adopters, are male-headed households more likely to be food secure than female-headed households?
- is cash crop commercialization more likely to be adopted by male-headed households than female-headed households?

The first question investigates if men are more likely to be adopting new technology than women. The second question investigates if the effects of technology adoption are gender-biased, i.e. if they favor men more than women. The final question addresses whether male-headed households are more likely to undertake commercialization than producing for home consumption.

We again use the ‘cross-tabulation procedure’ (similar to Chapter 3) in order to address the above set of issues. This method is appropriate since the relationship between two or more categorical variables² can be established with cross-tabulation. Cramer’s V and phi test statistic will be introduced in addition to cross-tabulation and chi-square test statistic in this chapter. This is because we are investigating if male- or female-headed households are more likely to be technology adopters, whether the different households (male or female) are more food secure and finally we want to determine if male- or female-headed households are more likely to commercialize crops and thereby receive greater income from the proceeds.

Data description and analysis

The main variables used in this analysis are as follows:

1. HYBRID: whether a household grows hybrid maize (HYBRID = 1) or not (HYBRID = 0) and represents technological adoption at the household level.
2. FEMHHH: whether the household head is male (FEMHHH = 0) or female (FEMHHH = 1) and hence represents gender of the household head.
3. CASHCROP: tobacco, groundnuts, cotton and plantain are the major cash crops in Malawi. The variable is defined as CASHCROP = 1 if the household grows at least one of these four major cash crops and 0 otherwise. CASHCROP thus represents commercialization of agriculture at the household level.
4. CALREQ: the measure of food security³ used relies on per adult equivalent calorie intake for households. It is defined as households being able to satisfy at least 80 per cent of the requirement for calorie intake. This variable is coined CALREQ. If a household’s daily per adult equivalent calorie intake (CALADEQ) is at least 80 per cent of the requirement, 2200 kcal, then the household is qualified as ‘food secure’⁴. The variable is defined as CALREQ = 1 if the household is food secure and CALREQ = 0 otherwise.

Descriptive analysis: cross-tabulation results

We initially investigate the relationship between FEMHHH (the gender of the household head), which is the independent variable, and HYBRID (growing hybrid maize), which is a measure of technology adoption. Later, we will also examine the relationship between FEMHHH and food security and the relationship between FEMHHH and CASHCROP (a measure of agricultural

commercialization). Examining the above relationships will help us in determining through what channels gender linkages affect technology adoption and commercialization process in agriculture. It is important to note that all the above variables are nominal or categorical variables.

Table 4.1 reports the cross-tabulation results of technology adopters by household head. The results indicate that almost 82 per cent of the male-headed households are technology adopters compared to 18 per cent of female-headed households. This result confirms to the existing literature that the male-headed households are more likely to adopt new technology relative to female-headed households. It is not possible to determine from the data why this is the case. One possibility is that female-headed households, on average, are generally risk averse in adopting new technology or they may not have critical access to the inputs required to adopt new technology such as land, labor and credit. It is also likely that a combination of risk aversion and access to critical inputs are detrimental factors for women in adopting hybrid maize. Next, we examine the relationship between gender of the household head (FEMHHH) and food security measure (CALREQ) to understand which groups of households are relatively more food secure.

About 28 per cent of the households grow hybrid maize in the sample. Among them, only 18 per cent of the households are female headed. The cross-tabulation results in Table 4.2 indicate that, among hybrid maize growers, almost 86 per cent of male-headed households are food insecure compared to 13.6 per cent of the female-headed households. This interesting result indicates that, although a higher proportion of male-headed households adopts hybrid

Table 4.1 Cross-tabulation results of technology adopters and gender of household head

		FEMHHH		Total
		Female	Male	
HYBRID	No	128	305	433
	Yes	31	140	171
	Total	159	445	604 = <i>n</i>

Table 4.2 Cross-tabulation results of food security and gender of household head

		FEMHHH		Total
		Female	Male	
CALREQ	INSECURE	39	247	286
	SECURE	22	140	162
	Total	61	387	448 = <i>n</i>

maize technology, a lower proportion of female-headed households among the adopters is food insecure. Next, we examine whether female-headed households are also less likely to adapt to cash crop commercialization just as the literature predicts.

Cramer's V and phi tests

The value of the chi-square itself is difficult to interpret, since it is a function of the sample size, the degree of independence between the variables and the degrees of freedom (Hamburg and Young, 1994). To overcome this difficulty of interpretation, several statistics have been created that measure the 'degree of association' between any two nominal variables. Two of these measures, namely phi and Cramer's V, are based on the chi-square itself and the value of these statistics is the same for any sample size. Since the above measures are all based on the chi-square statistic, the significance level is also based on the significance of the chi-square statistic. In Tables 4.3–4.5, we want to determine if the relationship among the variables (the cross-tabulation results) is significant or if it is just due to random variability. The null hypothesis is given by: H_0 : no relationship between technology adoption and gender of the household head, i.e. incidences of hybrid maize adoption are not statistically different between the male- and female-headed households.

Since the significance level (P value) is less than 0.01, the null hypothesis is rejected at the 1 per cent level of significance. Thus, we conclude that the incidences of hybrid maize adoption are statistically different between the male- and female-headed households. Although the value of the phi coefficient is low (-0.117), it is statistically significant at the 1 per cent level.

Table 4.3 Tests between technology adopters (HYBRID) and gender of household head (FEMHHH)

	Value	P value
Phi	-0.117	0.004
Cramer's V	0.117	0.004
Number of valid cases	604	

Table 4.4 Tests between food security (CALREQ) and gender of household head (FEMHHH)

	Value	P value
Phi	-0.001	0.987
Cramer's V	0.001	0.987
Number of valid cases	448	

Table 4.5 Tests between cash crop commercialization (CASHCROP) and gender of household head (FEMHHH)

	Value	Significance
Phi	-0.097	0.017
Cramer's V	0.097	0.017
Number of valid cases	604	

Next, we want to examine the null hypothesis of the relationship between food security and gender of the household head for hybrid maize growers. This is given by: H_0 : no relationship between food security and gender of the household head for hybrid maize growers, i.e. both male- and female-headed households are not statistically different in regard to food security.

Since the significance level (for both Cramer's V and phi statistic) is greater than 0.1, the null hypothesis cannot be rejected even at the 10 per cent level. For both groups of households (male- and female-headed), the incidences of food security are not statistically different among hybrid maize growers. We find no pattern of relationship emerging between gender of the household head and food security for the technology adopters for this sample. One cannot conclude that technology adoption has a gender-biased impact on household food security.

Finally, we examine the null hypothesis of the relationship between cash crop growing and gender of the household head. This is given by: H_0 : no relationship exists between cash crop growing and gender of the household head, i.e. incidences of cash crop commercialization or adoption are not statistically different between male- and female-headed households.

Since the significance level (both Cramer's V and phi statistic) is 0.017, the null hypothesis cannot be rejected at the 5 per cent level. The incidences of cash crop commercialization are statistically different for both the groups of households (male- and female-headed). We can conclude that the incidences of cash crop commercialization are statistically different between male- and female-headed households. Although the value of the phi coefficient is low (-0.097), it is statistically significant at the 5 per cent level.

Conclusion and policy implications

As pointed out by Doss (2001), understanding the linkages between female-headed households and technology adoption/commercialization are inherently complex. The African farm household is a multifaceted entity that undertakes various agricultural and non-agricultural activities and operates with different accessibility to various inputs, such as land, labor, credit and extension services. It is clear, however, that gender matters in new technology adoption and commercialization patterns. The gender role and responsibilities may change in

response to change in agricultural technology or urbanization, but gender remains an important analytical concept. Many interventions and projects that were designed to improve the conditions of rural women in Africa failed, since these projects did not consider the complex role women played in households and communities in adopting the new technology (Doss, 2001). Identifying the technologies that are beneficial to improve the economic conditions of women thus remains a challenge to researchers and policy makers in developing countries. This is because new technologies can have both positive and negative impacts as they may increase output but, at the same time, may increase women's labor input.

From the recent studies that examine the conditional relationship between gender of the household head and technology adoption decision, the evidence is generally mixed (World Bank, 2007). After controlling for other relevant characteristics, female-headed households in general are less likely to adopt new technology compared to male-headed households (Asfaw and Admassie, 2004; Chirwa, 2005). Very few studies find that female-headed households are more likely to adopt new technology than male-headed households (Bandiera and Rasul, 2006).

From the empirical analysis in this chapter, it is evident that male-headed households in Malawi have a higher propensity to adopt new technology and sell cash crops to earn more cash revenues than female-headed households. The former (greater propensity to adopt new technology) is possibly due to men having greater access to key inputs such as land and labor as well as availability of complementary resources such as credit and more information from extension services. The latter (cash crop commercialization) is probably because men tend to specialize in cash crop production for earning greater cash revenues and providing income for the members of the household, while women specialize in subsistence production (maize and other food crop production) to improve the nutritional status of children. Additionally, we find no relationship between the gender of the household head and food security for the technology adopters. It is more likely that technology adoption has no gender-biased impact on household food security.

A few lessons and programmatic implications for the agricultural research community deserve special attention (Doss, 2001). First, there is no silver bullet that will resolve all agricultural productivity issues in Africa. Instead, new technologies will have a differential impact on men and women farmers depending on their access to the critical inputs. Second, researchers and extension agents must continually interact with local farmers to understand how adoption of a new technology may affect the dynamic within the household and community members. Third, it is also crucial to understand the patterns of labor and land allocation and how that affects individual members of the household before and after the introduction of a new technology. Fourth, technology that has a more direct impact on women's welfare should be taken into consideration in program design. This is because innovations that decrease women's labor hours in the farm can actually improve women's well-being. Finally, in addressing the gender dimension of new technologies, it is important to

understand why women do not adopt certain technologies – is it because they have preferences in growing certain crops or is it the case that they face different constraints relative to men? The policy solution might be to address those constraints. It is evident that the simple dichotomies such as men’s crops and women’s crops, cash crops and food crops, male- and female-headed households will not provide sufficient insight by themselves.

Technical appendices

Phi coefficient and Cramer’s V

While the chi-square test is useful for determining whether there is a relationship, it does not tell us the strength of the relationship. Symmetric measures such as phi coefficient and Cramer’s V attempt to quantify this relationship and are based on the chi-square statistic that controls for the sample size. They are designed for use with nominal data and with chi-square they jointly indicate the strength and the significance of a relationship. While these measures give some sense of the strength of the association, they do not, in general, have an intuitive interpretation (Lowry, 2003).

Phi coefficient (Φ)

The phi coefficient is a measure of the degree of association between two binary variables. Phi is the ratio of the chi-square statistic to the total number of observations, i.e. $\phi = \sqrt{\chi^2/N}$. The range of phi varies between -1 and $+1$ for 2×2 tables. Conceptually, phi is the application of the Pearson r to dichotomous variables. If one ran Pearson r on these data, they would get exactly the same result. Since phi has a known sampling distribution, it is possible to compute its standard error and significance. SPSS and other major packages report the significance level of the computed phi value.

The general rule of thumb for phi coefficient of correlation is:

- -1.0 to -0.7 strong negative association
- -0.7 to -0.3 weak negative association
- -0.3 to $+0.3$ little or no association
- $+0.3$ to $+0.7$ weak positive association
- $+0.7$ to $+1.0$ strong positive association.

It is the most ‘optimistic’ of the symmetric measures and, unlike most association measures, does not have a theoretical upper bound when either of the variables has more than two categories.

Cramer’s V

Cramer’s V is usually appropriate for tables that are larger than 2×2 . Cramer’s V is a rescaling of phi so that it varies between 0 and 1. The formula for Cramer’s V is $V = \sqrt{\chi^2/N(k-1)}$, where N is the total number of observations and k is

the smaller of the number of rows and columns. For 2×2 tables, Cramer's V is equal to the absolute value of the phi coefficient. This is because since $k = 2$, the $(k - 1)$ term becomes 1.

Exercises

1. Recollect the food security indicator INSECURE developed in Chapter 2. Undertake a cross-tabulation procedure and determine which households are more insecure. Is there any relationship emerging between gender of the household head and the INSECURE variable?
2. After studying the paper by Doss (2001), carefully examine how gender affects technology adoption among African farmers. What are the main challenges that women farmers face? Suggest policy measures that can benefit the adoption of new technology for women farmers.
3. From the empirical results of the present chapter, discuss critically the role of gender in technology adoption process. Discuss whether male-headed households are more likely to be food secure than the female counterparts. What can you infer of the role of gender in cash crop commercialization from the results?

Notes

1. Hedgerow intercropping involves the planting of nitrogen fixing trees in a hedge environment with the purpose of using foliage as mulch on crops planted between the hedges. The main objectives of this technology are as follows: (i) continuous cropping on depleted soils by introducing trees that help in preventing soil erosion; (ii) add nutrients to the soil through nitrogen fixation, nitrogen recycling and mulch. Unlike other technologies, it links three components of the farming system: crop production, land and soil management and livestock husbandry.
2. Categorical variables are those where distinct categories exist, such as gender (female, male), ethnicity (Whites, Asian, Hispanic) and cash crop commercialization (commercialize, do not commercialize) etc.
3. Since the major focus of the present chapter is to understand the gender dimension of new technology adoption and commercialization, we concentrate our analysis on only one measure of food security, namely per capita adult equivalent calorie intake falling short of 2200 kcal per day.
4. The percent intake of the average energy requirement is used as a means of examining calorie adequacy. Individual energy requirement is estimated according to the age-sex specific recommendation of the joint FAO/WHO/UNO committee. The standard for an adult male equivalent is 2200 kilocalories.

5 Changes in food consumption patterns: The issue and its importance to food security – application of one-way ANOVA

The real issue is not consumption itself but its patterns and effects. Inequalities in consumption are stark. Globally, the 20% of the world's people in the highest-income countries account for 86% of total private consumption expenditures – the poorest 20% a minuscule 1.3%.

UNDP, *Human Development Report 1998*.

Introduction

Increase in household incomes could result in an increase in average daily food intake. The average global calorie intake had reached 2800 kcal (kcal/person/day) at the end of 2000 with the developing country average expanding by more than 30 per cent (based on a study by Pingali and Stringer, 2003). The substantial increase in food consumption can be attributed to a combination of economic growth, increased use of irrigated land, long-term declines in food prices and rapid growth of imports from developed economies. However, not all countries have shared the benefit of the increase in consumption. In sub-Saharan Africa, the intensity of food insecurity¹ remains a serious challenge during this century². Recent food insecurity data are greatly worrisome and estimates from FAO suggest that 43 countries will have average food consumption levels of less than 2500 kcal/day by 2015, with the number of actually undernourished increasing by 9 million (Pingali and Stringer, 2003). Most of this food insecurity is a result of food shortages caused by civil unrest, wars and other natural calamities and recent food price increases are likely to exacerbate the situation. As rising food prices affect the poor directly, the greatest concern are their impact on food consumption. The short-term impacts are alarming, with income falling by 25 per cent and food consumption by almost 20 per cent (Overseas Development Institute, 2008). In the light of chronic food shortages, changes in food consumption patterns can have important implications for achieving food security.

The study of consumption patterns is important for a number of reasons. First, since total consumption accounts for more than two-thirds of national

income in many countries, it is the largest macroeconomic aggregate, having great significance for the state of the economy as a whole and business conditions (Clements and Selvanathan, 1994). Second, the pattern of consumption contains useful information regarding economic welfare and living standards and, thus, is an objective way of measuring and assessing economic performance. Finally, understanding the price responsiveness of consumption is critical for a number of microeconomic policy issues, which include the measurement of distortions, optimal taxation and the treatment of externalities.

From a food security standpoint, understanding the trends in food consumption patterns is extremely crucial since policy makers may be interested in knowing whether an increase in average per capita food availability is due to an increase in domestic production or imports. Food security can be thought of as improving when per capita food consumption increases due to an increase in domestic production or food imports. On the other hand, if per capita food consumption decreases due to a decline in domestic production or food imports, the situation may be unsustainable for long-run food security. Dependence on food imports can create a food insecurity problem at the national level if a country faces difficulty in paying for these imports, thereby losing valuable foreign exchange earnings³. From a policy perspective, it is crucial to understand how different socioeconomic groups (especially the poorest segments) in the population are affected by changes in food imports and changes in food prices in the international markets.

Along with the increase in per capita availability of food, a change in the composition of diet can affect food security. These changes occur due to demographic and epidemiological transitions (Popkin, 2003). While the demographic transition occurs due to a shift from a pattern of high fertility and mortality to one of low fertility and mortality, the epidemiological transition occurs due to a shift from a pattern of high prevalence of infectious disease associated with malnutrition, to one of high prevalence of chronic and degenerative disease associated with urban lifestyles (Olshansky and Ault, 1986). The consequence of these transitions is reflected in nutritional outcomes, such as changes in body composition and morbidity. In the developing world, changes in the diet pattern are occurring at a very rapid pace. While the share of cereals and roots and pulses declined, the share of vegetables, meat and poultry and vegetable oils has increased remarkably during the past decade. Mittal (2008) estimates that for India, with a 9 per cent GDP growth over the next two decades, the demand for edible oil is likely to increase almost three-fold by 2026. The growing dietary diversity in many Asian and Latin American economies can be attributed to an increase in incomes. However, diet in sub-Saharan Africa has changed only marginally with cereals, starch roots and pulses (the low cost foods) comprising 70 per cent of the region's calorie consumption, while the share of meat and dairy products (higher cost foods) continues to be very low. A recent research report by Smith et al. (2006) from a sample of 12 countries in sub-Saharan Africa found that the problems of diet quality are widespread in most of the countries. While low diet diversity

appears to be relatively minor for West African countries, prevalence is higher in the East and Southern African countries, with the highest incidence found in Mozambique. The average per capita income in the region was around \$500 per year during 2003 and the distribution of income is extremely skewed. Inequality in purchasing power adversely affects the food security and nutritional status in the region. In order to raise food consumption and achieve a greater dietary diversity (especially for the poorest segments of the population), it is critical to promote policies that accelerate agricultural productivity and improve distribution in income.

In order to determine whether food security is sustainable or not requires an understanding of the trends of per capita food consumption (i.e. whether the increase in consumption is due to increased domestic production and falling imports). In the next section, we examine the determinants of food consumption and its linkages to food security and nutritional status. The third section provides a brief review of the selected studies (both regional level and country-specific studies) that examine the linkages between food consumption on food security and nutritional status. The fourth section presents the empirical analysis using the one-way analysis of variance (ANOVA) approach. This approach is an extension of the two-sample *t*-test (Chapter 2). The last section makes some concluding remarks and draws policy implications of the results.

Determinants of food consumption patterns and its importance to food security and nutritional status

Determinants of food consumption patterns

Food consumption refers to the quantity and quality of food intake by households or individual members. It is conceptually closer to ‘food intake’ as measured by calories or broken down into different nutrients. Household-level food consumption is often proxied by calorie or nutrient availability.

As economic development proceeds over time, average per capita income and expenditure exhibit an increasing trend. This typically shifts the consumption patterns of the population. In other words, the food consumption basket changes from commodities with a low quality dietary content to food commodities with a higher quality dietary content. In the first phase, consumption of coarse cereals and starchy root crops increases, followed by a second phase of increase in staple foods such as wheat and rice based products (Timmer et al., 1983). In this phase, the relative consumption level of starchy root crops exhibits a declining trend. In the final phase, consumption of cereals falls and there is a shift towards higher dietary value (such as protein food, fruits and vegetables, etc.). Other factors, apart from income and expenditure, which may significantly affect food consumption are rural–urban migration, changes in demographic structures and improvements in education, transport and communications, and marketing infrastructure. The recent surge in

urbanization has increased the demand for animal based products. Huang and Bouis (1996), using cross-sectional data for Taiwan (disaggregated by rural and urban area) over the period 1981–1991, found that demand for food substantially changed not only by increase in incomes and price changes, but also by the relative increase in urbanization. They found that per person consumption of rice fell by 35.3 kg for rural areas. This is because income and urbanization worked in opposite directions. However, income and urbanization worked in a similar direction for meat. Total per person consumption rose by 24.2 kg, with 18.2 kg contributed from income effects and the remaining effect came from urbanization.

Impact on food security

Trends in per capita food availability can have important consequences for food consumption patterns in developing countries. FAO data indicate that food availability improved over the period 1990 to 1999 for the least developed economies of sub-Saharan Africa. For 18 out of the 22 countries, the undernourished population declined during the above time period. (The countries where the proportion of undernourished actually increased were Botswana, Morocco, Senegal, and Uganda.) Per capita food consumption also depends on how income is distributed among the population. If a significant percentage of the population earns less income (more inequality in the distribution), then it is more likely that per capita food consumption may not reflect how food is distributed among the population. Thus, a large section of the population may remain food insecure (although with the yardstick of per capita food consumption it may seem that households are not food insecure). Additionally, from a food security standpoint, it is crucial to understand how dietary pattern is changing over time. If a significant percentage of the population is deriving calories out of meat, dairy products and fruits and vegetables instead of cereals and other root crops, then it can be inferred that the country is relatively more food secure. Thus, dietary diversity, which occurs as result of income changes and rapid growth in urbanization, can be a suitable proxy for understanding food security over time.

Review of selected studies

One of the earlier studies of changes in food consumption patterns was by Delgado and Miller (1985). They studied the aggregate trends in production, consumption and net imports of food grains and examined the determinants underlying consumption shifts for West African countries over the period 1960 to 1980. The analysis on cereal trends showed that rice was gaining rapidly as a staple food with production lagging behind consumption growth. Thus, imports were required to close the gap between domestic supply and demand.

The major factors that explained substitution towards rice and wheat consumption were per capita GDP growth and high rates of urbanization. Additionally, relative prices for cereals were an important factor in the substitution process. The results demonstrated that governments in many West African countries kept the prices of rice and wheat artificially cheaper compared to coarse grains. The distortion in relative prices was a result of policies to subsidize urban consumption. These countries imported grains at overvalued exchange rates that made it cheaper relative to domestically produced coarse grains. The study identifies other policy factors that explained the consumption shift. First, advertising trends in West African countries made consumption of wheat and rice more 'fashionable'. Second, wheat and rice typically made up a large proportion of food aid, which introduced new irreversible dietary habits in the population.

The authors suggested some policy measures that could slow down the rate of consumption shifts and reduce the volume of imports from abroad. They were as follows:

1. income transfers
2. consumer taxes
3. tariffs and quotas
4. food aid policies.

Income transfers improve food security by taxing the wealthier segments of the population. Consumer taxes on food grains alter the relative price of coarse grains and superior cereals in favor of the former and thus affect the food consumption of poorer households. Tariffs and quotas on wheat and rice imports are an effective means of raising the domestic prices. Tariffs are analogous to direct taxes on food imports, revenues of which pass to the government. Quotas, on the other hand, can be an instrument to generate rents for government officials involved and may not be an effective instrument in improving the welfare of the poorer households. Appropriate food aid policies can also help in slowing down consumption shifts. In non-emergency situations, prices of superior cereals, such as rice or wheat, can be kept high and the revenues used to subsidize coarse grain production. The above policy instruments can be optimally designed to achieve a greater variety of cereals and a better distribution of per capita availability.

Ray (2007) examined the changes in the nature and quantity of food consumption in India during the reform decade of the 1990s and analyzed their implications for calorie intake and undernourishment. The analysis is motivated by the failure of expenditure and income based poverty magnitudes that do not truly depict the food and nutrition security situation in a period of rapid changes in food consumption patterns. The study provides evidence at both the state and all India levels on the magnitude and trends in food consumption. The prevalence of undernourishment in both the urban and rural areas is estimated using calorie intake.

The data sets used for the analysis were from the 43rd (July 1987–88), 55th (July 1999–2000) and 57th (July 2001–2002) rounds of the National Sample Survey (NSS). The results of the study can be summarized as follows: first, cereals consumption was generally much higher in the rural than in urban areas, mainly due to higher consumption of rice by the rural household. However, for vegetables and fruits, meat and eggs, per capita consumption was higher in urban areas. Second, there has been a marked decline in the consumption of all cereal items over the period 1987–88 to 2001–02 in nearly all states – the reduction being particularly sharp in the case of insignificant cereals, such as barley, maize, etc. Third, consumer preferences had shifted from cereal items to non-cereal items such as meat and fish and fruits/vegetables, with the above trend holding true for the whole country. The above trend clearly demonstrates that the food share in total expenditure registered a sharp decline, especially in urban areas. The significant decline in calorie consumption can be attributed to the switch from calorie intensive cereals to non-cereals due to an increase in food prices during this period.

In examining the prevalence of undernutrition during the 1990s, the study found that the prevalence of undernutrition was especially acute in rural areas. At the all India level, the prevalence of undernutrition increased from 57.6 per cent in 1999–2000 to 66.9 per cent in 2001–02. An important result of the study was that a significant number of households, even in the top expenditure decile, were unable to meet their daily calorie requirement.

Since a significant number of households, even in the top expenditure deciles, suffer from undernourishment, a reassessment of the strategies of directing the Public Distribution System (PDS) exclusively to households below the poverty line cannot be rationalized. By providing subsidized rice and wheat through the ‘fair price shops’, there is more room for designing a more effective strategy for the PDS to target households above the poverty line.

Another implication of the result is that, despite a sharp decline in the expenditure of rice and wheat during the 1990s, both these cereals continue to provide the dominant share of calories, especially for the rural poor. Thus, it is important to go beyond the money metric measure of welfare to assess the changes in the living standards of households during a period of rapid structural change in the economy.

In a recent study, Chand (2007) estimates the future demand for basic food in India. The study also provides the demand projections for food grains towards the end of the eleventh Five-year Plan by 2020–21 and examines its impact on food security.

Food grains are important for household food and nutrition security for four main reasons:

1. as cereals and pulses are staple foods, there is no possibility of substitution between staple foods and other foods
2. increased consumption of other foods fills dietary deficiency due to the inadequate level of intake of almost all foods by the poor

3. food grains are the cheapest source of energy and protein compared to other foods, which has implications for food and nutrition security for the low-income classes
4. as increased production and consumption of livestock products resulting from an increase in per capita incomes are usually used as feed for livestock, food grains still remain the main source of food security. Any decline in production in food grains results in price shocks, which consequently affects consumption adversely.

As the demand for cereals and pulses is expected to grow by almost 2 per cent during the next two decades owing to increase in population growth and rise in indirect demand, it is imperative that growth in production keeps pace with it. The demand for food grains has outpaced supply and this has created serious imbalances between domestic production and supply, with the consequence that it has cut down the stocks and exports of food grains. The implication is that if the growth rate in domestic production of food grains does not keep up with increased demand for food grains, it could eventually led to an increased dependence on imports of essential food grains, such as wheat and rice.

Le Dien et al. (2004) examined the food consumption trends, prevalence of stunting (low height for age) for children below 5 years age and women's nutritional status using a body mass index (BMI) criterion for the urban Vietnam region. The comparison was made based on the Vietnam Living Standards Survey (VLSS) during 1988 and 1998. From 1989 onwards, Vietnam's transition to a market economy resulted in massive output gains in food production. For example, paddy production increased from around 23 million tons in 1993–94 to more than 30 million tons in 1999.

The main trend in consumption was a decrease in the consumption of rice and substitution towards consumption of other cereals, mainly wheat. While roots and tubers showed a declining trend, the consumption of animal products increased appreciably. Second, the study found that food consumption outside the home represents about 20 per cent of food expenditure in urban areas compared to only 5 per cent in the rural areas. The main reason behind this pattern of consumption was time savings, low price and choice of variety. Third, in regard to the nutritional status, although stunting in children decreased substantially, there was an increase in obesity among adult urban women. However, this situation was not homogeneous across regions. Regions in the south had higher levels of income but still had a high rate of stunting. Thus, in spite of a remarkable growth in food supply, the nutritional status was still unsatisfactory due to health-related problems.

In a recent study, Asfaw (2008) examines the patterns and determinants of fruits and vegetable (F&V) availability for human consumption in Latin American and Caribbean (LAC) countries during the period 1991 to 2002. As inadequate intake of F&V is a leading cause of micronutrient deficiency, obesity and chronic diseases, understanding the trend and determinants of F&V consumption is important to find effective solutions for the low level F&V consumption and the related health problems.

The data came from FAOSTAT of FAO and the World Development Indicator of the World Bank. A panel data analysis was undertaken to understand the

determinants of F&V availability for human consumption in LAC countries during the above time period.

The results of the study indicate that overall mean availability of F&V in LAC countries was 167.24 kg/capita/year, with the amount of F&V available large enough to meet the WHO's F&V intake level if no wastage was assumed. However, there was substantial variation in F&V available by countries, with some countries having significant shortages – notably countries such as Nicaragua, El Salvador, Panama, Peru, Honduras and Uruguay – with others having surpluses. The policy implications of these results are that for countries where F&V availability is in serious shortage, public policy should focus on encouraging production and trade. In contrast, for countries where the apparent availability levels are higher than the recommended level, such as Belize, Costa Rica, Mexico and Chile, nutrition education and distribution issues should be given higher priority.

Generally, the results of the study demonstrate substantial scope for promoting the consumption of F&V in LAC countries through economic incentives, such as reducing the relative price of F&V and/or decreasing poverty and inequality.

In order to generate similar policy implications, we examine the determinants of food consumption across various food groups and for the different expenditure brackets using a statistical technique called the one-way ANOVA approach. This approach is appropriate since we want to test whether the means of the share of calories across various food groups differ across expenditure brackets or if they are identical.

Empirical analysis and main findings

The main question addressed is as follows:

- does the share of calories from the various food groups differ across households at different expenditure brackets?

The above question addresses whether the population means of any calorie source differs across households at different expenditure quartiles. This is important since we want to know if households at different expenditure levels are deriving calorie intake (a measure of dietary energy supply) from the same source or from different sources.

Data description

The variables used to address the above question are per capita expenditure (PXTOTAL), quartile of per capita expenditures (NPXTOTAL) and percent share of calories from various food groups. Per capita expenditure was derived by dividing total household expenditure by the number of members in the household. This is done in order to control for the number of household members as member

size varies widely in the sample. Expenditure quartiles were obtained by dividing the sample into four equal subsamples based on annual per capita expenditures and ranked into four socioeconomic quartiles, namely poor, lower middle, upper middle and highest. The share of calories from major food groups was calculated by dividing total calories from each food group by the total calories consumed and then the ratio multiplied by 100. Based on this, the share of calories consumed from seven food groups were constructed: the seven groups were maize (PCALMZ), other cereals (PCALCR), roots/tubers (PCALRT), meat/fish/eggs (PCALMT), milk (PCALMLK), vegetables (PCALVEG) and pulses (PCALPUL).

Analysis method

Since we want to compare if households at different expenditure brackets derive the same calories from the various food groups, an ANOVA analysis is appropriate. This is because we want to test whether the means of the share of calories across various food groups differ across expenditure brackets or if they are identical. The null hypothesis is that means of the share of calories derived from various food groups are identical across all expenditure groups, while the alternative hypothesis is that they are not all equal. The ANOVA procedure is also appropriate since we are examining the variability of the sample means to draw conclusions about the population means.

Results

Table 5.1 shows the mean and standard deviations of the food shares from the various groups. As a proportion of the total household calorie intake, the mean share of maize was almost 64 per cent, which is not an unexpected finding. This is because maize is the dominant staple food crop in Malawi. Next in importance are roots and tubers (cassava, plantains and sweet potato), which constitute about 16.5 per cent of total calorie intake, followed by other grains such as rice and sorghum.

Table 5.1 Food group shares (%) of household calorie intake for Malawi

Food group	Mean share	Standard deviation
Maize	63.66	38.71
Other grains	9.76	21.91
Roots/tubers	16.54	27.01
Meat, fish & eggs	4.91	16.43
Milk	1.56	7.73
Vegetables	1.98	9.92
Pulses	0.76	5.24

Note: The mean share of calories does not sum to 100 per cent since the calories from other food are not available.

Table 5.2 shows that most of the calories consumed by households (across all expenditure groups) originate from maize. Roots and tubers occupy the second place as a source of calorie followed by other grains (such as rice, sorghum). This is possibly because maize has been the major food crop in terms of the policy agenda and hectares of plants. For the hybrid maize variety, both poor and non-poor households retain most of it for home consumption. Additionally, a greater percentage of the population retains local maize compared to hybrid maize. Thus, consumption preferences show that most of the produce is used for consumption by all quartiles of the population. From Table 5.2 we can also infer that, for the higher expenditure groups, the share of calories from maize, which is a staple diet, declines while the share of calories from animal products, vegetables and dairy products increases. This is possibly because with increase in incomes, households substitute a better variety of food (in calorie and dietary content) compared to maize, which usually has lower dietary value.

Next, we investigate our central question whether the share of calories consumed from the various food groups differs across expenditure groups. This is done through a one-way ANOVA analysis. The null hypothesis is: H_0 : population means of the share of calories from various food groups are identical for all the expenditure groups.

The alternative hypothesis (H_1) is that population means of the share of calories are not identical for the income groups. The ANOVA procedure utilizes an F -test with $(k-1)$ and $(N-k)$ degrees of freedom, where k is the number of groups and N is the total number of observations. Whenever the observed F ratio is large enough, we would reject the null hypothesis that the share of calories is identical for all the four income groups in favor of the alternative hypothesis that the share of calories is not identical.

From Table 5.3 we can reject the null hypothesis that the shares of calories from maize for the four expenditure groups are the same at the 5 per cent level. Additionally, we also reject the null hypothesis that calorie shares of roots and tubers and meat, fish and eggs for households in all the expenditure groups are the same at the 5 and 1 per cent levels respectively. The groups for which the null hypothesis cannot be rejected are other grains, milk, vegetables and pulses.

Table 5.2 Mean share of calories from various food groups by expenditure brackets

Per capita expenditure quartiles	Maize	Other grains	Roots/tubers	Meat, fish and eggs	Milk	Vegetables	Pulses
1 (Lowest)	62.12	11.10	15.03	8.64	1.51	1.05	0.42
2 (Lower middle)	72.17	6.75	13.52	3.64	0.64	1.73	0.36
3 (Upper middle)	64.8	8.11	15.45	4.43	2.75	1.88	1.58
4 (Highest)	57.3	12.3	21.97	1.97	1.27	3.40	0.72
Total	63.67	9.77	16.55	4.91	1.57	1.98	0.76

Table 5.3 One-way ANOVA for share of calories across expenditure quartiles

	<i>F</i>	Sig.
Maize	3.565	0.014
Other grains	1.97	0.117
Roots/tubers	2.837	0.037
Meat/fish/eggs	5.09	0.002
Milk	1.82	0.142
Vegetables	1.59	0.191
Pulses	1.66	0.174

In other words, the share of calories for the above food groups is identical across all the expenditure groups. If we reject the null hypothesis, this implies that at least one of the means is different. However, the ANOVA method does not tell us where the difference lies.

Conclusion and policy implications

From a food security standpoint, understanding the trends in food consumption is extremely important since we want to know whether the increase in average per capita availability of food is due to an increase in domestic production or imports. Dependence on food imports, especially for developing economies, can create a food security problem at the national level if a country has difficulty in paying for these imports, thereby losing valuable foreign exchange earnings. Many countries, especially in sub-Saharan Africa, lack the purchasing power to meet their needs fully. Unless new actions are taken, the gap between demand and supply may widen, resulting in less per capita availability of food. These actions can be improving long-term agricultural productivity, sound and consistent trade and macroeconomic policies, property rights to land and other natural resources, improving rural infrastructure and various other incentives for small farmers. It is also critical to improve women's access to land and mitigate labor supply constraints, since these factors affect agricultural productivity directly. From a policy perspective, it may be crucial to understand how different socioeconomic groups (especially the poorest segments) in the population are affected by changes in food imports and changes in food prices in the international markets.

At the same time, studying urban consumers' purchasing behavior and food consumption patterns may be very fruitful, since an increasing proportion of the developing world's population will be located in the urban areas in the next quarter of a century. Urbanization affects dietary and food demand patterns by increasing opportunity cost of women's time, changes in food preferences due to increased income and a more diversified diet. A consumption shift from basic

cereals, such as sorghum and millet, to other cereals, such as rice and wheat, milk and livestock products, fruits and vegetables is a result of rapid urbanization. This dietary diversity is not only an indicator of enhanced food security but may also be an indicator of improved nutritional status of the population (especially women and children).

From our present analysis on the trends of consumption across households in different regions of Malawi, we find that most of the households consume maize as part of a staple diet in order to derive calories. From the ANOVA analysis, we find that calorie shares of maize for households in different expenditure groups are not the same. This implies that poorer households derive most of the calories from cereals such as maize. As income of the households increases, there is greater substitution towards vegetables, milk and meat, fish and eggs. Thus, there is a tendency towards greater dietary diversity as income increases.

Technical appendices

One-way ANOVA

The analysis of variance technique (ANOVA) uses sample information to determine whether three or more treatments⁴ yield different results. Let us introduce some useful notations from the exercise conducted in this chapter. (This section is largely based on Lowry (2003), available at <http://faculty.vassar.edu/lowry/overview.html>.) Let X_{ij} be the share of calorie (say, for example, maize) of the i^{th} household from the j^{th} expenditure group, where $i = 1, \dots, 600$ and $j = 1, 2, 3, 4$. Since there are four expenditure groups, the totals of the columns are denoted as ΣX_{i1} , ΣX_{i2} , ΣX_{i3} , and ΣX_{i4} respectively. The subscript i indicates the total of each of the columns summed over the respective row. Let the means of the four columns be denoted by \bar{X}_j . Finally, we denote the grand mean \bar{X} as the mean of all the observations. \bar{X} is thus the sample mean of $\bar{X}_1, \bar{X}_2, \bar{X}_3$, and \bar{X}_4 respectively. The null hypothesis is given by: $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$. The alternative hypothesis is that the population means are not all equal. We want to determine if the differences among the calories consumed (maize) by the various expenditure groups can be attributed to chance error of samples from the population having the same means. If the sample means differ significantly, we conclude that maize consumption differs across households from different expenditure groups.

Underlying assumptions in the ANOVA procedure

The main assumptions are as follows.

1. Normality: the samples are assumed to be drawn from normally distributed populations.

2. Independence: the samples are independent. This implies that the share of calories obtained from maize by one expenditure group does not affect the share of calories obtained by another expenditure group.
3. Homoscedasticity: the populations have equal variances.

Decomposition of total variation

The term 'variation' in statistics is referred to as the sum of squared deviations or simply sum of squares. When a measure of variation is divided by the appropriate number of degrees of freedom, it is referred to as variance or mean square. There are two kinds of variation in an ANOVA framework:

1. Between treatment variation: this is calculated as follows:

$$SSB = \sum_j r(\bar{X}_j - \bar{X})^2 \quad (5.1)$$

where r = sample size involved in the calculation of each column mean. \bar{X}_j and \bar{X} have been defined earlier. In our example, SSB for maize is 15825.60.

2. Within treatment variation: this is a measure of the random errors of the individual observations around their column means. It is computed as:

$$SSW = \sum_j \sum_i (X_{ij} - \bar{X}_j)^2 \quad (5.2)$$

where X_{ij} denotes the value of the observation in the i^{th} row and the j^{th} column. The double summation means that the squared deviations are first summed over all sample observations and then summed over all columns. In our example, for maize, the SSW is 881963.9. The total variation (TSS) is computed by adding the squared deviations of all the individual observations from the grand mean \bar{X} . The formula is given as:

$$TSS = \sum_j \sum_i (X_{ij} - \bar{X})^2 \quad (5.3)$$

In our example, the TSS is 897789.5.

Number of degrees of freedom

The next step in the procedure is to determine the number of degrees of freedom with each of the measures of variation. The number of degrees associated with SSB is $(k-1)$. This is since there are k groups; there are k sums of squares involved in measuring the variation of these column means around the grand mean. Since the sample grand mean is an estimate of the unknown population mean, we lose one degree of freedom. Thus, there are $(k-1)$ degrees of freedom. The total number of degrees of freedom associated with SSW is $(N-k)$, where N is the total number of observations. Since in the present illustration N is 600 and $k=4$, the degrees of freedom for SSW is 596. The total number of degrees of freedom for TSS is $(N-1)$, which is the sum of degrees of freedom for SSW and SSB.

F-test and distribution

The comparison of the SSB with the SSW is done by computing their ratio denoted as F . It is given by:

$$F = \frac{SSB/(k - 1)}{SSW/(N - k)} \quad (5.4)$$

Under the null hypothesis, the population means are equal. If the computed F exceeds the critical F (at 1 or 5 per cent level of significance), we will reject the null hypothesis that population means of the share of calories from various food groups are identical for all the expenditure groups. We can determine how large the test statistic F needs to be in order to reject the null hypothesis by looking at the probability distribution of the random variable F . In the case of maize, the computed $F = \frac{15825/3}{881963.9/596} = 3.565$. Since the critical value of F at 5 per cent level of significance is 2.60, we can reject the null hypothesis that the population means of the share of calories from maize are identical for the various expenditure groups.

Relation of F to t-distribution

Since the F -test is just an extension of the t -test for more than two groups, the relation between them are as follows.

With two groups, $F = t^2$, and this applies to both the critical and observed values. For example, consider the critical values for degrees of freedom (1, 15) with $\alpha = 0.05$, $F_{crit(1,15)} = t_{crit(15)}^2$. Then, obtaining the values from the respective tables, we obtain $4.54 = (2.131)^2$. Since the t -test is a special case of the ANOVA and will almost always yield similar results, most researchers prefer ANOVA, since the technique is more powerful in complex experimental designs.

Exercises

1. Recall Levene's statistic which tests the null hypothesis that several population variances are equal. Write the syntax for Levene's statistic. For which food groups can you reject the null hypothesis that population variances are equal?
2. Recall the food security variables CALREQ and INSECURE developed in Chapter 2. Write an ANOVA syntax for CALREQ and per capita expenditure quartiles and INSECURE and per capita expenditure quartiles. Does food security differ across the different expenditure groups? Interpret the results.
3. Select member number = 3 as the unit of analysis, which denotes children. Write the syntax with member number = 3 as the unit of analysis. Define a new weight for height variable (ZWHNEW) such that if the weight for height variable falls below 2 standard deviations, the variable assumes a value of 1 or the child is wasted. Otherwise, the variable has a value of zero. Write a syntax relating ZWHNEW with per capita expenditure quartiles using ANOVA. Does wasting differ across different

- expenditure groups? Interpret your results in the light of whether food security translates into nutrition security.
4. From the Delgado and Miller (1985) study, identify the main factors behind the consumption shift in West African countries.
 5. What are the determinants of food consumption patterns? What are the linkages between food consumption patterns and nutritional status?

Notes

1. FAO's primary indicator of food security is the number of people who consume sufficient number of calories for a healthy diet. This indicator is based on a combination of country level estimates of average per person dietary energy supply (DES) from local food production, the number of calories required by different age and gender groups and country-specific coefficients of income/expenditure distribution.
2. A recent study by IFPRI (2008) estimates that the increase in crop prices resulting from expanded biofuel production is accompanied by a net decrease in both food availability and access to food for all regions. For sub-Saharan Africa, calorie availability will decline by more than 8 per cent if biofuels expand dramatically.
3. A recent study by Rosen and Shapouri (2008) of the USDA finds that with the sharp increase in food prices, prospects are not so bright for the 70 low-income, highly import-dependent countries. Any decline in import capacity arising from increase in food prices can have significant food security implications.
4. The term treatment is used in agricultural experimentation in which treatments may be different types of fertilizer applied to plots of land, feeding methods for animals, etc.

6 Impact of market access on food security – application of factor analysis

Structural adjustments have been implemented in most developing countries over the past two decades. They have generally led to the elimination of public intervention in the agricultural sector, including state-led institutions such as marketing boards which, in the past, supported small-scale farmers through credit, inputs and facilitation of market access. Structural adjustments have also encouraged the concentration of agricultural trade and production, which excludes small-scale farmers from business and growth.

Frederic Mousseau, Oakland Institute, October 2005.

Introduction

During the past two decades, donors and international lending agencies have strongly advocated the reduction of direct state intervention in agricultural marketing and pricing in developing countries. The objectives of such policies were to redress the bias against producers and enhance economic development (World Bank, 1981). A wide body of empirical literature has demonstrated the impacts of food market reforms, which includes both the withdrawal of state agencies from pricing and marketing activities and the relaxation of regulatory restrictions on private trade (Kherallah et al., 2002). These reforms have led to increased entry of private traders into food trade, increased producer prices and have improved market integration (Barrett, 1994; Jones, 1996). However, the question that still lingers on is whether the entry of these private traders has increased productivity and improved food security.

The rationale for entry of private traders to function efficiently was not only for direct intensification of agriculture by smallholder farmers in poor rural areas, but also ways through which production, consumption and investment linkages can be promoted. In this chapter, we examine the role private traders (a measure of market access) in the agricultural food markets and how their participation affects food security.

The issue is critically important, since an efficient marketing system can play an important role in supplying yield enhancing modern inputs at reasonable prices and in assuring remunerative prices for farmers. Second, there is a broader consensus that agriculture in these countries is responsive

to economic incentives, yet incentives fail when the risks are quite high. For example, a shift to high value crops entails higher risks and failure of production could prove fatal to the livelihoods of small and poor farmers, consequently affecting their food security. Private traders could improve the efficiency of output and input markets by generating greater market information for small farmers, thereby reducing the price risks that they face.

In this chapter, we use a multivariate statistical technique called ‘factor analysis using principal components’ to study the impact of market access on food security. The main purpose of using the factor analysis approach is to reduce a large number of variables, which are the main determinants of food security, to a smaller set of underlying components or factors that summarize the essential information in the variables. The derived factors will thus be linear combinations of sets of original, highly correlated variables. Factor analysis is undertaken for two main reasons:

1. since household food security is determined by a complex set of variables, such as food availability, assets of the household, technology indicators, market access variables, it is important to condense the information contained in a large number of variables which are bundled into a smaller set of factors representing the underlying dimensions
2. since the set of variables used in the analysis is linearly related, the Kaiser-Meyer-Olkin (KMO) measure (a measure of sampling adequacy and should be greater than 0.5) indicates that factor analysis is an appropriate technique to use. Both the summarization and data reduction are achieved for analyzing household food security with this analysis.

In what follows, we first introduce the basic concepts of market reforms and their linkages to food security. Next, we review a few case studies that investigate the role of food market reforms on food security during the past two decades. A discussion of the methods and the results of these studies serve as motivations for the analysis presented next.

Assessing the linkages of market reforms on food security and productivity

Agricultural market reforms occur within the context of domestic and external political economy interests, global economic trends and macroeconomic adjustments (Kherallah et al., 2002). Understanding the process and impact of these reforms cannot be viewed in isolation from these important linkages. Reforms need to be examined in terms of actors, influences and outcomes. During the process of a reform, national governments and other interest groups come in either cooperation or conflict with external actors, such as bilateral donors, lending agencies and non-governmental organizations. This, in turn, influences the pace and scope of reforms as well as the timing and sequence of the reform process. [Figure 6.1](#) depicts the mechanism through which market

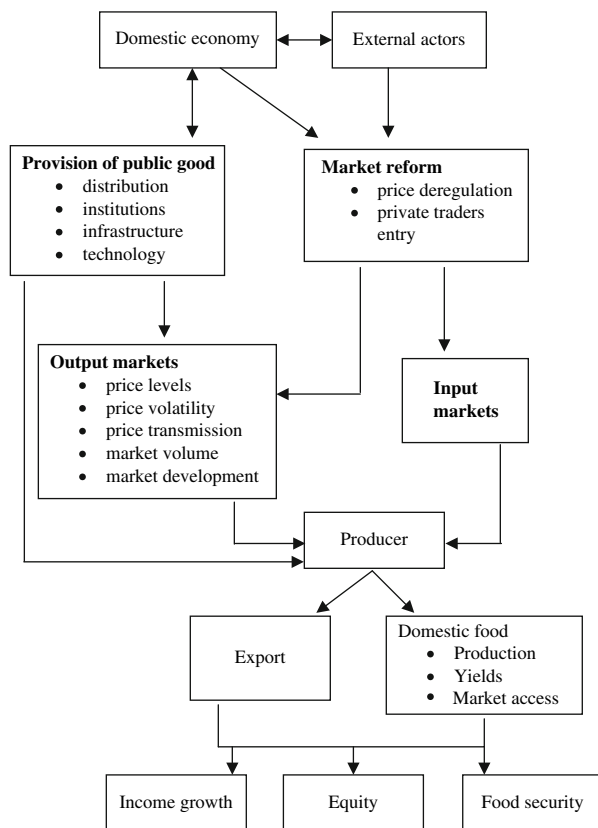


Figure 6.1 Agricultural market reform linkages to market outcomes.
(Source: Adapted from Kherallah et al., 2002)

reforms affect market outcomes. Abandoning price controls by state agencies, allowing private sector entry into agricultural trading activities and eliminating or easing trade restrictions are some of the reforms undertaken during the past two decades. The main issue is what the outcomes of this reform process were.

Kherallah et al. (2002) point to the outcome process at three main levels. First, the liberalization of agricultural markets affected the nature and efficiency of the market itself. The liberalization process affected the agricultural price levels, the extent of price transmission across markets, the stability of market prices and investments by private traders so as to improve the functioning of markets. Second, the impact of market reforms has to be evaluated in regard to changes in supply levels and agricultural productivity. Third, these reforms need to be assessed in terms of welfare changes. There are gains and losses associated with privatization to both producers and consumers, through price changes. Besides, the impact of reforms on food security can be assessed by looking at changes in the marketed

surplus of food and access to food supplies (both domestic and imported). It is also important to determine the resulting increase or decrease in producer's income due to changes in producer prices after a liberalization program is initiated.

As Kherallah et al. (2002) point out, the outcome of market reforms needs to be examined in light of the changes in the provision of public goods. Withdrawal of the public sector can have significant implications on the positive functions that it carries out, namely information dissemination, law enforcement, product standardization and investments in infrastructure and other social services. Reforms that might reduce the provision of public goods include dismantling the operation of state marketing boards, loss of quality control and the increased transaction and price risks faced by producers due to abandonment of the public buffer stock schemes (see Kherallah et al., 2002, pp. 24–25 for further details). In light of the above, we investigate some selected case studies that examine the impact of agricultural market reforms on price stabilization, productivity and food security. In particular, we look at one aspect of this reform process, namely the entry of private traders on the food security outcomes.

Review of selected studies

We first examine some of the cross-country studies that study the role of agricultural market reforms on the outcome variables, namely price stabilization, productivity and food security and later look at the country-specific studies for the sub-Saharan African region. The case studies provide the motivation for the subsequent empirical analysis.

Beynon et al. (1992) examined the impact of market reforms (removal of controls over food pricing and marketing) on food production and private sector development. The authors distinguished Eastern and Southern African (ESA) countries into two broad groups based on their policy stance. In the first group were countries whose policy stance has been generally favorable to food production, but marketing reforms have been incremental. The second group comprises of countries whose pre-reform marketing and pricing policies were biased against food production. For this group, liberalization of the private sector has been associated with the collapse of the public or state agencies (as prices have left them uncompetitive). Thus, the role of market reforms on private sector development is unclear. The first group of countries is Kenya, Malawi, Zimbabwe and Zambia, while the second group consists of Somalia, Ethiopia and Tanzania. The main policy implication that emerges is that price reforms should be the starting point rather than market liberalization for a viable public sector marketing institution to exist after liberalization.

Stifel et al. (2003) examined the impact of transaction costs on household consumption (a measure of poverty) and agricultural productivity for Madagascar. The data were collected during the period September to November 2001 for a sample of 5080 households. 'Transaction cost' in this

paper was defined by transportation costs (and proxied for isolation). It was captured using three measures:

1. travel time to the nearest primary urban center
2. cost of transporting a 50 kg sack of rice to the nearest primary urban center
3. a remoteness index, which was the result of a factor analysis on the various measures of access, or lack of it.

A major implication of the study was that, although little can be done with respect to distances to markets, policy interventions could substantially improve road quality (for example, through building new roads and maintaining existing ones). Such an investment in infrastructure would reduce marginal transaction costs and is likely to have a positive impact on market integration, productivity and poverty.

In one of the major reports, IFPRI and CSR (2003) assessed the impact of ADMARC (the state-led marketing body of Malawi) marketing activities on household welfare in Malawi. ADMARC is a parastatal organization, which was created in 1971 to assist the development of the smallholder agricultural sector through marketing activities and investments in agro-industry enterprises. Besides, it was mandated to generate food security (particularly in the maize markets) through its role as a buyer and seller in remote areas. To achieve this marketing mandate, ADMARC developed an extensive network and infrastructure of markets across the country. The market infrastructure included regional offices, divisional offices, area offices, parent markets, unit markets, and seasonal markets.

Small farmers had traditionally depended on ADMARC for the purchase of inputs and marketing of crops. However, since the late 1980s, the dependence of smallholders on ADMARC started declining due to two main reasons:

1. ADMARC's maize trading activities started declining from the early 1990s
2. ADMARC began experiencing financial problems in the early 1980s due to deterioration in the terms of trade, changes in government pricing policy and the liberalization of agricultural marketing to private traders in 1987 (Scarborough, 1990).

ADMARC was restructured several times during the 1990s in response to the liberalized environment. However, the impact of these reforms (such as entry of private traders) is not clear on smallholder farms.

In order to address whether reforms improved household welfare, the study used a multivariate regression model, where the data were collected over a 12-month period during 1997/98 and 2002 for 6586 households. The dependent variable was the logarithm of per capita expenditure, while the explanatory variables were non-labor assets, household labor characteristics and several dummy variables representing ADMARC facilities. The hypothesis tested was that the presence of ADMARC facilities would have a positive impact on per capita household consumption.

The results of the study were highly unusual. First, improvement in household welfare between the two time periods was strongly and significantly affected by

changes in the size of the household and changes in cultivated land area. Second, proximity to ADMARC had no impact on household expenditure. This result is striking as it suggests that proximity to ADMARC is less important in remote areas. Thus, differential access to ADMARC facilities did not have any impact on changes in household welfare, although simply looking at level regressions ADMARC does have a significant impact on household welfare.

From the above studies one can reasonably conclude that the incidence of food insecurity increases with market isolation and decreases with improvement in market access. In addition, productivity of crops tends to decline as one gets farther from the markets which, in turn, can have an adverse impact on food security. In order to understand the critical determinants of food security, it is important to construct a subset of underlying factors from the original set of factors (such as food indicators, asset indicators, technology indicators, market access indicators and household level determinants). This can be accomplished with factor analysis, which tries to construct a subset of the underlying factors from the set of original factors to derive the determinants of food security.

Empirical analysis

The main objective of the present chapter is to derive factor scores (which can be used for further hypothesis testing) from a subset of highly correlated variables from the original set of variables, while there is very little correlation between the factors. Each factor then comprises a group of variables that represents a single construct, responsible for the interrelationships between the variables. For example, if there are p variables, X_1, X_2, \dots, X_p , factor analysis aims to find a group of variables F_1, F_2, \dots, F_k , (which are the factors) where $k < p$ to describe the interrelationship between the original variables. Thus, the main aim of the analysis is as follows:

- extract the factors
- compute the scores for each factor
- interpret the factors.

Thus, a good factor analysis must be simple and interpretable. A factor analysis involves the following steps. First, based on the correlation matrix for all variables, the appropriateness of the factor analysis is evaluated. Second, it is necessary to decide which factor model should be used, the number of factors to be extracted and to assess how well the model fits the data. The criteria used to extract the factors can be maximizing variance or minimizing residual correlations. The main techniques available in many statistical software packages, such as SPSS, are:

1. principal components (PC): proportion of variance accounted for by the common factors
2. principal axis factoring (PAF): the communality of a variable is estimated from its correlation with other variables

3. maximum likelihood: produces estimates that are most likely to have produced the observed correlation matrix.

The technical concepts and analysis of this chapter largely follows from Hair et al. (1998).

Technical concepts

Eigenvalues and eigenvectors

Suppose that S is a symmetric matrix of order p . If v is also a column vector of order p and λ is a scalar such that $Sv = \lambda v$, then λ is called the eigenvalue (also called characteristic root) of S and v is the corresponding eigenvector (also called characteristic vector) of S . If $v'v = 1$, then v is said to be the standardized eigenvector of S . The eigenvalues can be arranged as diagonal entries in a diagonal matrix D (a square matrix where all the diagonal elements are zero) with the corresponding eigenvectors arranged as columns in V . Matrix V is orthogonal meaning:

$V'V = I$. Thus, the eigenstructure of S can be written in matrix form as:

$$SV = VD \tag{6.1}$$

Additionally, it is also the case that:

$$S = VDV' \tag{6.2}$$

Equation (6.1) is also known as the eigenequation.

Properties of eigenvalues

1. If all the p eigenvalues of a symmetric matrix S are positive, then S is termed positive definite.
2. If any eigenvalue is zero, then S is singular.
3. The sum of diagonal elements of a symmetric matrix S is equal to the sum of its eigenvalues.

The most frequently used method for factor analysis is principal component factor extraction and it is used in the present analysis. The number of factors to be extracted is somewhat arbitrary but can be based on the following for principal components.

- Eigenvalue ($\lambda_j > 1$), i.e. factors with a variance less than one are no better than a single variable.
- Scree test criterion: this is done by plotting eigenvalues against the number of factors in their order of extraction. The number of extracted factors is determined by the point on the curve where the slope becomes horizontal. This point indicates the maximum number of factors to be extracted.

It is important to interpret the factors. This is done through a factor rotation procedure, which simplifies the factor structure giving more insight into each factor. The simplest case of rotation is the orthogonal procedure in which the axes are maintained at 90 degrees. Varimax is one common rotational method

under the orthogonal procedure and maximizes the sum of the variances of the required loadings of the factor matrix. Table 6.1 shows guidelines that are usually used for significant factor loadings based on sample size.

Finally, the standardized variables Z_1, Z_2, \dots, Z_p can be formed as linear combinations of the factors F_1, F_2, \dots, F_k . The magnitude of each of these coefficients in the factor loading matrix is a weight measuring the importance of the j^{th} variable Z_j to the k^{th} factor F_k . Scores on factors can be estimated once the factor loading matrix is available. These scores are standardized to have zero mean and unit standard deviation.

Data description and methodology

Figure 6.2 helps in understanding how we can derive a food security indicator from the underlying variables that are highly correlated and derive the underlying factors which explain the relationship among the original variables.

Figure 6.2 shows a comprehensible mechanism through which food security is affected, which can include various food-related indicators, such as staple food left in storage, number of meals that the household has on a daily basis, expenditure by the household on food, assets of the household – land area owned, livestock owned, other physical assets, yield or technology indicators – quantity harvested per household size, adoption of hybrid maize, use of modern chemical inputs such as fertilizer use, market access indicators, such as road quality, distance to an agricultural marketing facility for buying or selling and household characteristics such as education of the household head, age of the members, whether the household is headed by a female. Some of these indicators may be highly correlated. The purpose of factor analysis is to compute a linear combination of the original variables (called factors) from which factor scores can be constructed. The following variables are used in undertaking the present analysis.

Table 6.1 Significance of factor loadings based on sample size

Factor loading	Sample size needed for significance*
0.30	350
0.40	200
0.45	150
0.50	120
0.55	100
0.60	85
0.65	70
0.70	60
0.75	50

*Significance based at 0.05 level.

Source: extracted from computations made with soft power analysis (Hair et al., 1998)

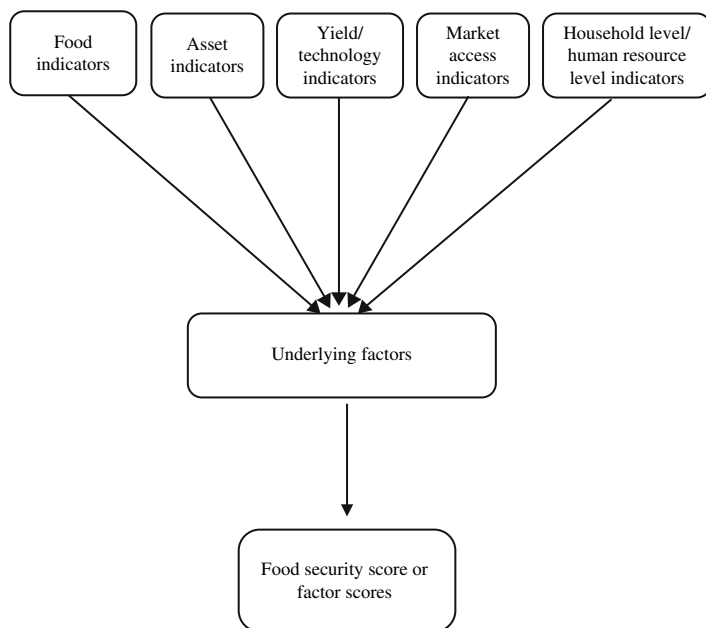


Figure 6.2 Variables and underlying factors.

Food indicators

The following indicators are used: per capita expenditure in food (PXFOOD), defined as the ratio of the total expenditure by the household on food to household size. Additionally, staple left over (STAPLEFT) is also another indicator of vulnerability. This is a dichotomous variable assuming two values 0 and 1; 1 indicates whether some staple is left over for the household for own consumption and 0 indicates no food left.

Asset indicators

Two asset indicators are used, namely: size of land owned (LANDO) – a categorical variable, assuming values from 0 to 5. Higher values indicate that the household has more land. For example, food crops such as maize require a lot of land, as land is an essential input in the production system and is directly related to food security. Second, we also use LIVSTOCKSCALE as an additional variable for asset ownership by the household.

Yield/technology indicators

Three indicators are used to measure technology. Fertilizer use (FERTILIZ) is an essential input in the production of both food and cash crops. Thus, its use

can be considered a pathway to modernizing production systems. FERTILIZ is a dichotomous variable assuming two values 0 and 1, with 1 denoting that the household uses chemical fertilizer as an input in the production process. Second, hybrid maize adoption (HYBRID) is a dichotomous variable and denotes whether the household adopts new technology. The ratio of total quantity harvested of local maize (LNPRODLMAIZ) to household size is considered as a measure of yield (since local maize is the main crop produced and consumed in Malawi) and the natural logarithm of this variable computed.

Market access indicators

Proximity to market is an important aspect of market access. Various indicators can be used to measure market access such as distance to the local market, distance of the household from ADMARC – the parastatal agency – and the distance of the household to the private traders’ selling point. The closer the households are to roads, the more likely it is that transaction costs can be reduced, since food crops can be bought and sold. Since the main focus of the present analysis is to understand the role private traders play in enhancing food security, we consider the distance of the household to a private traders’ selling point (SELPOINT) as a measure of market access. This is a categorical variable ranging from 0 to 5, with higher values indicating that the household is farther off from a private traders’ selling place.

Household level characteristics

Finally, human resources of the household like age of the household head, gender, education/skills and household size can play a critical role in food security. We consider two household level characteristics for the analysis: female-headed households (FEMHHH), which is a dichotomous variable with a value of unity indicating that the household head is a female and 0 otherwise. There is some evidence that, as females are usually discriminated against in the labor and land markets compared to males, their wages are lower relative to men and thus reduced income can affect food security adversely. The next characteristic that we consider is education of the spouse (EDUCSPOUS). Since higher levels of education can translate into higher income, improving the levels of education can have implications on food security. This variable is also categorical in nature, ranging from 1 to 7, with 1 denoting no education.

Factor analysis by principal components

We now undertake factor analysis with each of the steps discussed above.

Step 1: Computing the observed correlation matrix

Computing the observed correlation matrix is the first step. [Table 6.2](#) shows the observed correlation matrix for the eight selected variables in the present

Table 6.2 Matrix of observed correlation coefficients

Variables	LNPRODLMAIZ	FERTILIZ	SELPOINT	LANDO	LIVSTOCKSCALE	HYBRID	EDUCSPOUS	STAPLEFT
LNPRODLMAIZ	1.00	0.238 [*] (0.00)	-0.023 (0.254)	0.212 [*] (0.00)	0.269 [*] (0.00)	0.246 [*] (0.00)	0.07 ^{**} (0.02)	0.137 [*] (0.00)
FERTILIZ		1.00	0.547 [*] (0.00)	0.193 [*] (0.00)	0.322 [*] (0.00)	0.355 [*] (0.00)	0.365 [*] (0.00)	-0.47 [*] (0.00)
SELPOINT			1.00	0.093 [*] (0.004)	0.121 [*] (0.00)	0.048 (0.089)	0.413 [*] (0.00)	-0.58 [*] (0.00)
LANDO				1.00	0.324 [*] (0.00)	0.323 [*] (0.00)	0.107 [*] (0.001)	-0.039 (0.133)
LIVSTOCKSCALE					1.00	0.423 [*] (0.00)	0.111 [*] (0.001)	-0.112 [*] (0.001)
HYBRID						1.00	0.171 [*] (0.00)	-0.06 ^{**} (0.036)
EDUCSPOUS							1.00	-0.428 [*] (0.00)
STAPLEFT								1.00

*Denotes significant at the 1 per cent level.

**Denotes significant at the 5 per cent level.

analysis. For lack of space, we do not report the correlations of female-headed households and per capita expenditure of households with the remaining variables.

Since the sample size is reasonably large in the present analysis, most of the coefficients are statistically different from zero. However, we are interested in groups of variables that are correlated to each other. The largest correlation coefficient is between selling point and staple left, -0.58 (third row, last column). This is possibly because approximately 40 per cent of the households live at a distance of more than 15 km from the private traders' selling point and it is likely that they have less access to markets, which increases their vulnerability to food insecurity.

In order to understand if the set of variables is linearly related, the Kaiser-Meyer-Olkin (KMO) measure is computed (Hair et al., 1998). This is an index that compares the size of the observed correlation coefficients to the sizes of the partial correlation coefficients. The KMO measure of sampling adequacy is defined as:

$$KMO = \frac{\sum_{i \neq j} \sum r_{ij}^2}{\sum_{i \neq j} \sum r_{ij}^2 + \sum \sum a_{ij}^2} \quad (6.3)$$

The numerator is the sum of all the squared correlation coefficients (r_{ij}), while the denominator is the sum of all the squared correlation coefficients plus the sum of all of the squared partial correlation coefficients (a_{ij}). If the ratio is close to 1, the partial correlation coefficients are small and indicate that the variables are linearly related. Small values of the KMO measure will thus show that the factor analysis of the variables may not be a good idea, since observed correlations between pairs of variables cannot be explained by other variables. The Bartlett test is done to test the null hypothesis that observed data come from a multivariate normal population in which all the correlation coefficients are zero. This test requires the assumption of multivariate normality and is sensitive to deviations from this assumption.

Table 6.3 gives the KMO value to be 0.732, which is closer to 1 and thus we can undertake factor analysis.

Table 6.3 KMO-Bartlett test

Kaiser-Meyer-Olkin measure of sampling adequacy	0.732
Bartlett test of sphericity	
Approx chi-square	1669.045
Df	45
Significance of Bartlett	0.00

Step 2: Estimating the factors

Once it is established that the variables are related to each other, we are ready to look at the factors that explain the observed correlations. One of the assumptions of factor analysis is that the observed correlations between the variables result from sharing of these factors. The general model in a factor analysis is of the following form:

$$X_i = A_{i1}F_1 + A_{i2}F_2 + \dots + A_{ik}F_k + U_i \quad (6.4)$$

where X is the score of a typical household i , F_s are the common factors, U is the unique factor and the A s are the coefficients of loadings used to combine the k factors (Rencher, 2002). The unique factors are uncorrelated with each other and with the common factors. The factors in turn are inferred from the observed variables and are estimated from the linear combination of the variables. For example, a factor k can be expressed as:

$$F_k = W_1X_1 + W_2X_2 + \dots + W_pX_p \quad (6.5)$$

It is possible that all the variables contribute to factor k , but we expect only a subset of variables to have large coefficients. The W s are known as *factor score coefficients* (Rencher, 2002).

Principal components analysis

There are different algorithms for extracting factors from a correlation matrix (see for example, Tabachnick and Fidell, 2001). The simplest method is called principal components analysis. We will discuss this approach in some detail in the technical appendix at the end of the chapter. For additional technical details, the reader can consult Tabachnick and Fidell (2001). In this approach, linear combinations of the observed variables are formed. The first principal component is the combination that accounts for the largest variance in the sample. The second component accounts for the next largest amount of variance and is uncorrelated with the first. Successive components thus explain progressively smaller portions of the sample variance and are uncorrelated with each other. In this chapter, we will use principal components to extract factors, with the output labeled as components, instead of factors. Factor analysis analyzes shared variance among the variables, while principal components just restructure all of the observed variance by forming linear combinations of the observed variables. However, for simplicity, the terms are used interchangeably.

Since one can calculate as many principal components as there are variables, the researcher does not gain any additional insight if all the variables are replaced by their principal components. Thus, one needs to determine how many factors are needed to represent the data, i.e. to reproduce the original correlations.

There are two main criteria for deciding how many factors to extract. They are as follows.

Examining eigenvalues

A criterion of eigenvalue greater than 1 suggests that only factors that account for variances greater than 1 should be included. Factors with a variance of less than 1 are not better than individual variables, since each variable has a variance of 1. From [Table 6.4](#), we find that almost 57 per cent of the total variance is explained by the first three factors and thus three factors can be retained for the analysis. We will name these factors later in the chapter.

Scree plot

The eigenvalues are plotted against the number of factors in their order of extraction. The number of extracted factors is determined by the point on the curve where the slope becomes horizontal. This point indicates the maximum number of factors to be extracted.

Figure 6.3 depicts the scree plot of the eigenvalues against the factors. The graph is useful for determining how many factors to extract. It can be seen that the curve begins to flatten between factors 3 and 4. Thus, only the first three factors are retained.

Now, in order to determine how the variables and factors are related (using the coefficients produced by the factor extraction method), one can express each variable as a linear function of the factors. The component matrix in [Table 6.5](#) shows the relationship between the variables and the underlying factors.

For example, we have:

$$\begin{aligned} \text{LANDO} &= 0.370(\text{factor1}) + 0.496(\text{factor2}) - 0.416(\text{factor3}) + U_{\text{LANDO}} \\ \text{SELPOINT} &= 0.710(\text{factor1}) - 0.440(\text{factor2}) + U_{\text{SELPOINT}} \end{aligned}$$

The coefficients are called ‘factor loadings’ as they determine how much weight

Table 6.4 Explained common variance

Component	Initial eigenvalues			Sum of squared factor loadings		
	Total	Percent of variance	Cumulative per cent	Total	Percent of variance	Cumulative per cent
1	2.814	28.144	28.144	2.814	28.144	28.144
2	1.828	18.275	46.419	1.828	18.275	46.419
3	1.015	10.149	56.568	1.015	10.149	56.568
4	0.985	9.846	66.414			
5	0.770	7.702	74.117			
6	0.690	6.895	81.012			
7	0.636	6.363	87.375			
8	0.530	5.303	92.678			
9	0.393	3.928	96.606			
10	0.339	3.394	100.00			

Extraction method: principal component analysis.

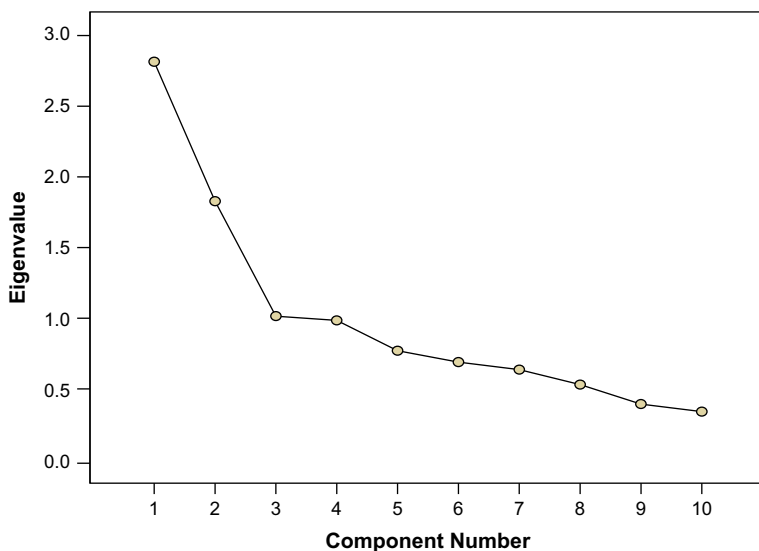


Figure 6.3 Scree plot of eigenvalues.

Table 6.5 Component matrix

Variables	Component		
	factor 1	factor 2	factor 3
FERTILIZ	0.815		
SELPOINT	0.710	-0.440	
STAPLEFT	-0.660	0.472	-0.104
EDUCSPOUS	0.631	-0.151	0.174
LIVSTOCKSCALE	0.538	0.483	
LNPRODLMAIZ	0.251	0.603	0.241
HYBRID	0.478	0.559	-0.138
LANDO	0.370	0.496	-0.416
FEMHHH	0.304	-0.329	0.115
PXFOOD		0.349	0.840

Extraction method: principal component analysis. Three components extracted.

is assigned to each factor for each variable. If the factors are orthogonal (uncorrelated with each other), the factor loading coefficients can be interpreted as the correlation coefficients between the factors and the variables. Thus, the variable LANDO has a correlation of 0.37 with *factor 1*, 0.496 with *factor 2* and -0.416 with *factor 3*. Similarly, the variable SELPOINT

(households' distance to a private traders' selling point) has a correlation of 0.71 with *factor 1*, 0.44 with *factor 2*, and is independent of *factor 3*.

Once a smaller number of factors are extracted, we can evaluate how well these three factors describe the original variables. In other words, we want to determine the proportion of variance of each variable that is explained by the three common factors. This is also known as *communalities*. Since the factors are uncorrelated, the total proportion of the variance explained for a variable is just the sum of the variance proportions explained by each factor. Table 6.6 shows the communalities of each variable.

As mentioned before, the proportion of variance explained by the common factors is known as *communality* of the variable. Communalities can range from 0 to 1, with 0 denoting that the common factors do not explain any of the variance, while 1 denotes that all of the variance is explained by the common factors. The variance that is not explained by the common factors is attributed to the unique factor for each variable. If there are variables that have very small communalities, it implies that they cannot be predicted by the common factors. Thus, it is reasonable to remove them from the analysis as they are not linearly related to the other variables. Again, considering the variable LANDO as an example, we find that the communality can be calculated as:

$$(0.37)^2 + (0.496)^2 + (0.416)^2 = 0.556(\text{rounded}).$$

Step 3: Making the factors easier to interpret: rotation procedure

From the component matrix in Table 6.5, we find that some of the variables are more correlated with a few factors than others. Ideally, we want to see the groups of variables with large coefficients for one factor and small coefficients for the others. This will enable us to assign meaning to the factors. The purpose

Table 6.6 Communalities table

	Initial	Extraction
LNPRODLMAIZ	1.00	0.485
FERTILIZ	1.00	0.666
SELPOINT	1.00	0.698
LANDO	1.00	0.556
LIVSTOCKSCALE	1.00	0.527
PXFOOD	1.00	0.829
HYBRID	1.00	0.561
FEMHHH	1.00	0.214
EDUCSPOUS	1.00	0.451
STAPLEFT	1.00	0.670

Extraction method: principal component analysis.

of rotation is to identify the factors that have large loadings in absolute value for only some of the variables so that we can differentiate the factors from each other. If several factors have high loadings on the same variables, it is difficult to determine how the factors differ.

There are two kinds of rotation: orthogonal and oblique. If the axes are rotated and are perpendicular to each other, the rotation is called orthogonal. However, if the axes are not maintained at right angles, the rotation is called oblique. The consequence of an oblique rotation is that the factors are correlated and thus makes them difficult to interpret. The factor axes are rotated so that variables with the largest correlations are associated with a smaller number of factors (Kline, 1994).

Varimax orthogonal rotation

The VARIMAX method of rotation is the most frequently used rotation method (Hair et al., 1998). It minimizes the number of variables that have high loadings on a factor, so that the factors can be interpreted more easily. The relationship between the test points remains the same as before. However, the axes are altered to interpret the factors more easily. It is similar to describe people's position in the classroom in relation to the walls. The people retain the same relative position to each other but the description of their position changes.

Table 6.7 presents the rotated component matrix. We report only the correlations above 0.5. In order to make it easier to identify the factors, we find that the use of inputs such as fertilizer, human capital inputs, staple left and distance of the household to the private traders' selling point are highly correlated with *factor 1*. Similarly, ownership of livestock, land owned and growing hybrid maize is clearly correlated with *factor 2* and per capita expenditure on food is correlated with *factor 3*. Since, for the first factor, both input use, household

Table 6.7 Rotated component matrix

Variables	Component		
	VA	ASSETTECH	FOOD
FERTILIZ	0.691		
SELPOINT	0.820		
STAPLEFT	-0.815		
EDUCSPOUS	0.635		
LIVSTOCKSCALE		0.696	
LNPRODLMAIZ			
HYBRID		0.741	
LANDO		0.716	
FEMHHH			
PXFOOD			0.909

Extraction method: principal component analysis. Three components extracted.

characteristics, market access and staple left over have higher loadings, it is difficult clearly to name this factor. However, since the absolute magnitude of private traders' selling point and staple left over are greater, we will call this factor *vulnerability and access* (VA). Similarly, we can call the second factor as *assets and technology adoption* (ASSETTECH). Finally, the third factor can be termed as the *food component* (FOOD). By comparing the component matrix with the rotated component matrix, we find that rotation improved the factor pattern, as the coefficients of the variables for factors 2 and 3 increased substantially.

Another useful way to examine the success of the orthogonal rotation procedure is to plot the variables using the factor loadings as the coordinates. Since there are three factors, SPSS produces a three-dimensional plot of these factors. The coordinates in Figure 6.4 are the factor loadings for the VARIMAX rotated solution. As can be seen from the figure, the first two factors have strong clusters of variables associated with them, while the variables that define *factor 3* do not cluster tightly.

Step 4: Computing factor scores

The final step is to compute the factor scores. The factor scores represent how much of each factor a case has. They are standardized measures with a mean of 0 and a standard deviation of 1.0, computed from the factor score coefficient matrix. There are several methods for estimating factor score coefficients¹. Since principal component extraction is used in this analysis, all the methods will result in the same factor score. Thus, factor scores can quantify individual cases

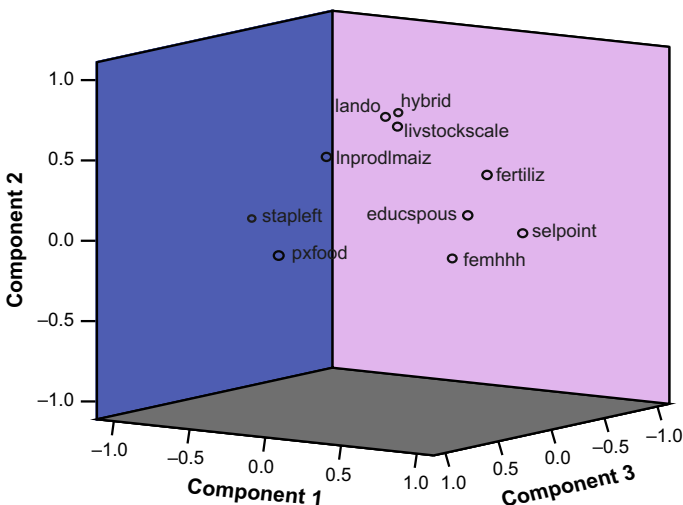


Figure 6.4 Component plot in rotated space.

using a Z-score scale which ranges from approximately -3.0 to $+3.0$. The factor score for household j for factor k can thus be derived as follows:

$$\hat{F}_{jk} = \sum_{i=1}^p W_{ji} Z_{ik} \quad (6.6)$$

where the W s are the factor score coefficient and all the variables and factors are standardized. The component score coefficient matrix is given in Table 6.8.

For any household j , the first factor score vulnerability and access (VA) can be computed as follows:

$$\hat{F}_{jVA} = 0.237(\text{fertiliz}) + 0.342(\text{selpoint}) + \dots + 0.104(\text{pxfood}) \quad (6.7)$$

where the subscript VA denotes *vulnerability and access*. Similarly, the factor scores can be computed for other households and factors.

In summary, we undertook the following steps in factor analysis. In the first step, we determined whether factor analysis was a suitable approach. This is undertaken using the KMO measure. We find that the KMO value was 0.732, which ensured that factor analysis approach is appropriate. Once established that the variables were related to each other, in the second step, we wanted to examine the factors that explained the observed correlation among the variables. We used a principal component approach to extract the factors. We found that the first three components explained almost 57 per cent of the total variation and thus we retained these components. We also wanted to determine how the variables and factors were related. This was done by expressing each variable as a linear function of the factors. The purpose of this exercise was to extract

Table 6.8 Component score coefficient matrix

Variables	Component		
	1	2	3
FERTILIZ	0.237	0.159	-0.087
SELPOINT	0.342	-0.054	-0.081
STAPLEFT	-0.388	0.164	-0.028
EDUCSPOUS	0.340	-0.052	0.301
LIVSTOCKSCALE	-0.057	0.387	-0.208
LNPRODLMAIZ	-0.048	0.319	0.247
HYBRID	-0.025	0.369	0.006
LANDO	-0.085	0.347	-0.017
FEMHHH	0.002	0.055	-0.558
PXFOOD	0.104	-0.004	0.577

Extraction method: principal component analysis. Rotation method: VARIMAX with Kaiser normalization.

a small number of factors that described the original variables. We found that the following variables had higher factor loadings with the first component: FERTILIZ, SELPOINT, STAPLEFT. LNPRODLMAIZ, HYBRID and LANDO had higher factor loadings with the second component. Finally, per capita expenditure on food (PXFOOD) had very high factor loadings with the third component. In the third step, we undertook a VARIMAX method of rotation to minimize the number of variables that have high loadings on a factor. The purpose was to interpret the factors more easily. The first factor was highly correlated with the following set of variables: use of fertilizer, human capital, staple left and distance of the household to the private traders' selling point. However, since the absolute magnitude of private traders' selling point and staple left over are greater, we call this factor *vulnerability and access* (VA). Similarly, we call the second factor *assets and technology adoption* (ASSET-TECH). The third factor is called the *food component* (FOOD). Finally, we derive the factor scores for each of these components.

Conclusion and policy implications

Food marketing policies need to be understood as part of a broader development strategy that can affect food security and poverty alleviation. As pointed out by Jayne and Jones (1997), food market liberalization in sub-Saharan Africa has generated more successes than originally recognized. Grain retailing and milling sectors are examples where consumers have gained from the lower milling margins of small-scale hammer mills. Additionally, there is a greater availability of food grains in many deficit areas due to the strengthened inter-rural private grain trade. However, success of these reforms can only be sustained if the private sector's expectation of payoffs and risks to future investment is incorporated in these reforms. This is because, historically, in most countries, small-scale cereal trading always coexisted with official marketing activities, while inputs were distributed only by the state. Although private traders have penetrated the fertilizer and seed markets in many countries, input marketing activities are still dominated by state-owned enterprises or multinational firms (Kherallah et al., 2002). In many instances, owing to various external shocks such as droughts and wars, countries reversed their reform policies and reimposed controls on the private sector. For example, Ethiopia and Zambia reintroduced fertilizer subsidies and allowed the state enterprises to distribute fertilizer.

Additionally, countries did not have a clear understanding of the appropriate timing and sequence of policies since reforms took place. Countries that simultaneously eliminated fertilizer subsidies and devalued witnessed a significant decline in the use of fertilizer (for example, in Malawi and Nigeria). Additionally, a devaluation of the currency without an appropriate liberalization strategy of the main export crop led to a shift of resources to other sectors of the economy. When reforms were implemented, the vested interests

of the civil servants often led to reversal of reforms, which made it extremely difficult for the private sector to participate effectively in the reform process. Although in all the reforming countries market entry by private traders occurred in the food and cash crop markets, the wholesale and more capital-intensive marketing activities (such as motorized transport or external trade) were limited to groups that had strong social networks and state connections. Thus, all of the above factors did not lead to successful participation by the private sector in the reform process, since their expectation of the payoffs were low ex-ante.

To address the above constraints and policy reversals, government actions to reduce price instability can include improving the transport infrastructure, promotion of regional trade, market information systems that expand information on prices across borders, trade flows and improving communication infrastructure.

In this chapter, we undertook a factor analysis exercise to determine the underlying factors that explain the correlation among a large number of variables, which influences food security. From our analysis, we found that vulnerability to food insecurity and market access, technology adoption and assets owned by the household and per capita consumption expenditure on food are all critical components/factors in determining food insecurity. The analysis identified the dimensions through which households can become food insecure. Additionally, it is possible to undertake hypothesis tests in subsequent analysis using the factor scores. For example, one can test the null hypothesis that men and women have the same average values for each of the three factors using a *t*-test (as in Chapter 2). Besides, regression analysis can be undertaken to determine if these factor scores are significant determinants of food insecurity (as in Chapter 10).

Technical appendices

Factor analysis decision process

Factor analysis is an analytical technique that has been extensively used by various social scientists. Factor analysis using principal components is a method of data reduction in which many variables are chosen initially and they are explained by a few ‘factors’ or ‘components’. When conducting a factor analysis study, a number of issues should be considered. Hair et al. (1998) concentrate on five main issues: the choice of how many variables to include; the choice of a factor model to be used; the decision about the number of factors to retain; the methods of rotation; and the interpretation of the factor solution.

The number of factors to be chosen will be a subset of highly correlated variables from the original set of variables, while there is very little correlation between the factors. Each factor then comprises a group of variables that

represent a single construct, responsible for the interrelationships between the variables. These factors should be easy to interpret and lack complex loadings. In the second step, the researcher must decide which factor model to use. There are two different approaches: common factor analysis and principal component. The principal component model assumes no unique or error variance in the data. In contrast, the common factor model assumes that the variance in a variable can be explained by common and unique components, with the unique variance being further divided between specific and random error variance (Hair et al., 1998).

In the next step, the number of factors to be retained prior to rotation affects the outcome of a factor analysis (Tabachnick and Fidell, 2001). The Kaiser-Meyer-Olkin criterion of retaining factors with eigenvalues greater than one is often considered as the most appropriate for principal component analysis. The scree test can determine the number of factors to retain.

In the next step, the rotation of factors is undertaken to improve the meaningfulness, reliability and reproducibility of factors (Hair et al., 1998). There are two methods of rotation: orthogonal and oblique. If the axes are rotated and are perpendicular to each other, the rotation is called orthogonal. However, if the axes are not maintained at right angles, the rotation is called oblique. The factor axes are rotated so that variables with the largest correlations are associated with a smaller number of factors. While orthogonal rotation is simple and conceptually clear, oblique rotation can sometimes portray the complexity of the variables, as factors in the real world are rarely uncorrelated.

Finally, interpreting the factors is important to provide meanings or labels to the factors. Large sample sizes are highly recommended for factor analysis studies. Recommendations vary from five observations per variable to a ratio of ten observations per variable (Tabachnick and Fidell, 2001).

Exercises

1. Explain, in your own words, the various steps involved in a factor analysis. How are the factor coefficients extracted? How does one interpret the factors?
2. Based on the factor scores VA, ASSETTECH and FOOD, undertake an independent sample *t*-test as in Chapter 2, to determine if there are significant differences between male- and female-headed households in the above scores.
3. Now undertake a multivariate regression analysis, with FOODSEC as the dependent variable and the factor scores VA, ASSETTECH and FOOD as the independent variables. What is the adjusted R^2 ? Which variables are significant in your regression analysis? Interpret the results in light of access to markets, technology adoption and asset ownership as critical determinants of food security.
4. After studying the paper by Beynon et al. (1992), critically discuss the impact of the private sector on food market liberalization. What are the main policy implications that are suggested for private sector development?

5. Explain the methodology in Stifel et al.'s (2003) paper of how isolation affects rural poverty in Madagascar. What are the variables used in the study to measure transaction costs? What are the main findings of road quality improvement on rice production? Discuss critically.

Notes

1. SPSS contains three methods, namely regression, Andersen-Rubin and Bartlett. The Anderson-Rubin method produces uncorrelated scores with a standard deviation of 1. The regression method factor scores can be correlated even when factors are orthogonal. Bartlett factor scores minimize the sum of squares of the unique factors over the variables.

Section II

Nutrition Policy Analysis

Introduction

In this section, we use four related statistical techniques to introduce advanced methods of estimation and inference. They are applied to develop policy and program options for addressing issues related to child malnutrition and its determinants.

Why study nutrition security?

At present, more than half of the world's population suffers from one or another form of malnutrition, deficiency diseases and/or diseases caused by overnourishment. Despite considerable effort and some amount of progress¹, the goals that were defined at the World Food Summit in 1996 and the United Nations Millennium Declaration (2000) to reduce malnutrition in the world are far from being achieved. While progress is being made in reducing nutrition insecurity in many parts of the developing world (for example, prevalence of stunting for children below 5 years of age declined by almost 20 percentage points between 1980 and 2000, while the prevalence of underweight declined by 13 percentage points during the same time period; see, for example, de Onis et al., 2004), African countries are an unfortunate exception to these trends.

Over the past decade alone, economic growth accompanied with an increase in the population growth rate has resulted in an increase in the number of undernourished from 171 million in 1990–92 to 204 million in 1999–2001 in sub-Saharan African countries. Several countries saw large increases in the number of undernourished during the same time period. Conflict in Congo contributed to an increase of more than 25 million. In Tanzania, dislocations associated with economic restructuring resulted in an increase in 5.7 million additional people malnourished. Burundi, Madagascar, Somalia and Zambia each experienced an increase of more than 1 million undernourished (Benson, 2004). The countries where the number of undernourished declined were Ghana, Nigeria and Malawi. Natural calamities and civil strife created food emergency situations in many countries. Civil conflict created food emergencies

in Angola, Burundi, Congo, Cote d'Ivoire, Guinea, Liberia, Sierra Leone, Sudan and Uganda. Drought and, in some countries, floods affected Eritrea, Ethiopia, Sudan and much of Southern Africa. Food security crises are exacerbated by economic downturns, spread of HIV/AIDS or political disputes that further reduce the ability of households and governments to cope effectively with these emergencies (Benson, 2004).

What is nutrition security and why study it?

Nutrition security is a multidimensional phenomenon that requires interventions in securing access to adequate food, an improved sanitary environment, adequate health services and knowledgeable care resources to ensure that individuals and households can make or find food available, have access to it and properly utilize it. **Figure II.1** presents a broad framework for understanding nutrition security and is an extension of the UNICEF conceptual framework, which was developed during 1990.

As evident from **Figure II.1**, the four dimensions of access (namely physical, economic, social and physiological) are interdependent. In other words, if only one dimension of access is narrowly considered, the overall impact on nutrition

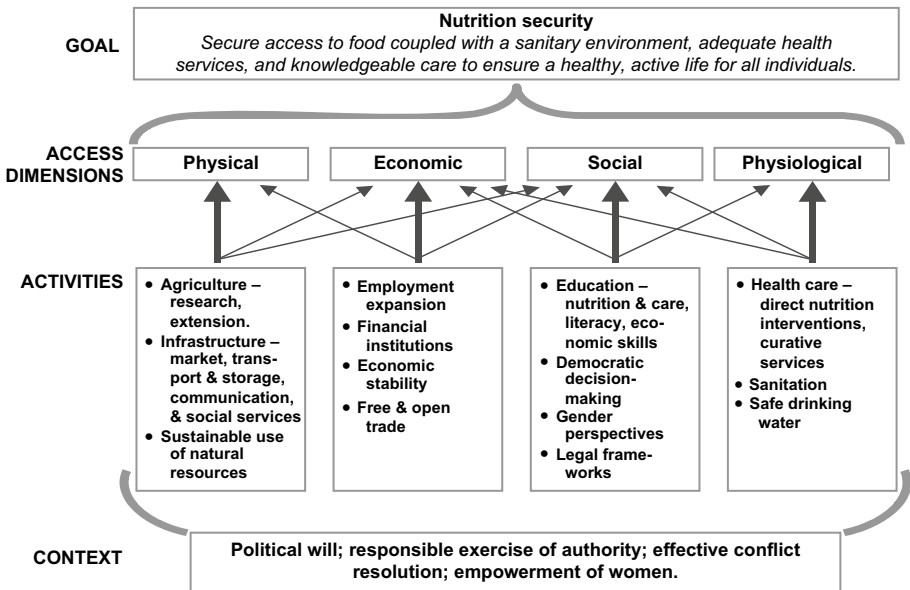


Figure II.1 Extended conceptual framework of nutrition security. (Sources: From HTF, 2003 and Benson, 2004)

security can be endangered due to lack of complementary investments in the other dimensions. For example, the physical ability of markets to deliver food to consumers and inputs to farmers cannot be successfully undertaken if markets are not efficient and there are no effective economic incentive structures for agents. Similarly, the physiological dimensions of access, such as preparing a nutritionally sound diet, may not be undertaken if the caregiver lacks sufficient nutritional knowledge (such as lack of understanding the components of a proper diet, proper feeding and care practices of infants, etc.).

It is also important to note that the foundations for sustained nutrition security cannot be achieved if only a few conditions are met. For example, political will cannot ensure nutrition security when conflict (such as wars) makes the entire population vulnerable. Similarly, good governance cannot help the malnourished segments of the population without the political will to do so. Finally, given that mothers and other women are the principal food preparers and care-givers for children, social and economic empowerment of women is necessary so that they can undertake these activities effectively.

Studying malnutrition is critically important since, during the past two decades, more and more countries are faced with two types of problems which have significant effect on both public health and development: malnutrition in children under 5 accompanied with micronutrient deficiencies among adults mainly in developing countries and the diet-related non-communicable diseases (NCDs), such as obesity, cardiovascular diseases and certain forms of cancer that have started to reappear in industrialized nations (Cohen et al., 2008).

There are substantial social and economic costs associated with malnutrition and micronutrient deficiencies, such as increased mortality and morbidity, reduced physical and intellectual development and reduced capacity for learning and work. WHO has shown that half of the deaths of children under the age of 5 are linked with malnutrition and various infections. Similarly, micronutrient deficiencies, such as iron deficiency, are one of the main causes of maternal mortality, while iodine deficiency is the main cause of mental retardation. By increasing mortality and morbidity, malnutrition also increases the cost of health. The 'life-cycle' approach to nutrition can explain why malnutrition during the fetal stage and infancy increases the likelihood of developing NCDs as an adult. This is particularly important for industrialized countries, but is also relevant for many developing countries. The likelihood of NCDs is increased due to changes in lifestyle and eating habits that are linked to economic development and urbanization (Black et al., 2008).

In industrialized countries (such as the USA), the budget allocated by the state for nutrition education programs is extremely low in comparison to the sums spent by the agri-food industry (Le Bihan et al., 2002). In the USA, 4 billion dollars are spent each year on advertisements for fast food, soft drinks, snacks and breakfast cereals compared to only 333 million dollars spent on nutrition education, with the consequence that almost one-third (31%) of Americans in the lowest income group suffer from obesity (see, for example, Joint Canada/United States Survey of Health at <http://www>.

statcan.ca/Daily/English/040602/d040602a.htm). This demonstrates that the agri-food industry needs to pay sufficient attention to the long-term implications for health of the population.

What interventions are desirable to improve nutrition security?

While the individual is ultimately responsible for assuring his or her nutritional status, a number of constraints prevent them from taking the necessary actions to pursue a good and healthy life. For example, resource constraints leave individuals with negligible income and physical assets to purchase or produce the food they need to prepare in a nutritious manner. Similarly, the local environment can impose barriers to good nutrition because of poor health conditions or variable food availability. Benson (2004) proposes a number of interventions that can affect nutrition security in a positive way and they are as follows:

1. *Economic growth*: rapid economic growth is essential for sustaining nutrition security. This is because economic growth creates additional resources that can enhance access to the components of nutrition security, such as increase in food consumption and dietary diversity, better access to clean water and sanitation, a broader range of health care and improved educational opportunities.

Agricultural productivity must be given high priority to achieve improved nutritional levels. High levels of agricultural productivity stimulate the food sector in particular and other sectors in the economy through expanding employment opportunities and raising household income. In rural areas, increased incomes of the farm sector stimulate the demand for goods and services of the local non-farm sector, consequently boosting the income of that sector. Also, increased income could lead to investments in a wide range of assets (such as land, capital). These assets augment the overall productivity of the rural economy, while also providing a safeguard to the vulnerable segments of the population during periods of adverse shocks to the economy (Smith and Haddad, 2000).

For example, a new program called the 'HarvestPlus Program', led by the Consultative Group for International Agriculture Research (CGIAR) seeks to improve the nutrient density of many staple food crops by increasing the levels of bioavailable iron, zinc and vitamin A that are contained in them (Graham et al., 2001). Farmers would be able to offer a low-cost and sustainable way to improve the nutritional situation of many people around the world if such a program can bring in high yielding varieties of staple crops.

2. *Health interventions*: nutrition activities are typically part of a broader range of primary health care activities. The objective of primary health care services is to ensure that individuals enjoy a healthy and active life (WHO Declaration of Alma-Ata, 1978). It involves not only the provision of basic services (such as maternal and child health care, immunization against major infectious diseases, prevention and control of locally endemic diseases and provision of essential drugs), but also related sectors and aspects of national and community development, such as promotion of the food industry, education, housing, public

works, communications. Health care activities demand the coordinated efforts of all these sectors (Benson, 2004).

The health sector has a critical responsibility for coordinating and leading direct nutritional intervention programs². It is important not to underestimate the impact of direct nutritional interventions in addressing nutrition security, since these programs are important investments in human welfare and in productivity.

3. *Role of national governments and cross-sector coordinations*: many dimensions of nutrition security that individuals require cannot be supplied through the market (Gillespie and Haddad, 2001). National governments thus should take the responsibility for assuring that all citizens enjoy nutrition security. Providing sufficient quantities of food is a pre-requisite for a balanced diet – other important determinants being the means to acquire food, nutritional education and provision of clean water and adequate sanitation.

In addition, it is critical for the agriculture and nutrition communities to collaborate with each other and form partnerships with other agencies such as in education and public works that can effectively address the constraints of nutrition security.

4. *Gender dimensions*: improvements in child nutrition are intrinsically linked to women's access to the resources that can be used to improve child-care practices and in improving the quantity and quality of food to the children. Competing demands for time and resources often interfere with the nutritional well-being of the woman herself. The nutritional well-being of the child is also at a discount if additional sacrifices need to be made by the care-giver. Thus, improving the level of equity between men and women is good for nutrition security (Oniang'o and Mukudi, 2002). In the absence of such equity, women would have poorer nutritional status, have less access to health care and education and thus would be unable to provide knowledgeable care for their children and dependents.
5. *Education and nutrition communication*: several studies have demonstrated that improved maternal education and nutritional knowledge can translate into better care practices which, in turn, improve child nutritional status. Consequently, primary education curricula in African countries should pay particular attention to nutrition communications. While formal education is one of the ways to communicate information, adult training programs and regular primary health care initiatives are other important ways of disseminating information on good diets and proper nutritional care.

The nutrition education message should consist of balanced diet, the value of exclusive breastfeeding, the importance of prenatal care and child growth monitoring, maintaining a healthy environment including better sanitation facilities and the control of infant and childhood illnesses.

As pointed out by Benson (2004), most of the determinants of nutritional status operate on a much broader geographical scale than at the level of the individual and this has implications for policy making, resource allocation and program implementation in reducing nutrition insecurity. First, since heterogeneity exists within the areas of analysis (e.g. agro-ecological variations and differences in the degree to which smaller areas are integrated to the markets), the availability and access to food will greatly vary from one region to another. The strategies to enhance nutrition insecurity must be context specific in their implementation. Second, efforts aimed at improving food and nutrition security which involve strong central government planning and control are not likely to succeed. The role of the central government should consist of giving general directions to local and

community efforts and facilitating these efforts by providing the needed expertise and financial and institutional support.

Overall, since nutrition insecurity is a critical constraint to economic growth in many African and South Asian countries and an immediate cause of widespread mortality and morbidity, national governments must collaborate and form partnerships with donors and other agencies to facilitate such access (Benson, 2004).

The above issues are highlighted throughout the chapters of this section. A brief description of individual chapters of this section is given below.

Chapter 7

Explaining the nutritional status of children in various societies of the world has been of interest to nutritionists, epidemiologists and physical anthropologists. While the causes of child malnutrition are multiple and complex, understanding these causes and devising strategies that generate better child health outcomes is the theme of this chapter. A few studies on the effect of maternal nutrition knowledge and schooling in India, good care practices and child nutrition in Ghana and the impact of maternal schooling and maternal nutrition knowledge on child nutrition in Indonesia are used to exemplify the concepts and methods. How specific variables affect child nutrition is analyzed using the two-way analysis of variance (ANOVA) approach. The empirical analysis is demonstrated by defining the main effect of an independent variable, partitioning sum of squares and interpreting the interaction effect and post-hoc tests.

Chapter 8

Analysis of the correlates of indicators and causal factors of nutrition is the subject of Chapter 8. Examining how various nutritional indicators are associated with each other and their determinants can be, among other things, useful for monitoring and evaluating food and nutrition interventions and their effect on a nutritionally vulnerable population. The review of the studies used in the chapter include: the role of household food availability and health security on nutritional status of children in rural communities in Pakistan; the impact of income growth on child nutrition in Vietnam; the impact of safe water and sanitation on infant mortality; and the relationship between the prevalence of stunting and underweight on per capita income. Correlation analysis is explained using scatter-plots and Pearson correlation coefficient is defined. Examples of policy conclusions based on the analysis are given.

Chapter 9

This chapter is concerned with the study of statistical relationships between the nutritional outcomes and their determinants. Simple linear regression method is

introduced in this chapter to develop an understanding of the role of causal factors and their relative impact on child nutritional status. The reduced form equations of the determinants of nutrition are derived from a household utility maximization framework and the empirical analysis shows how the different individual, household and community factors affect child nutrition. The concepts of independent and dependent variables are introduced along with normality tests and transformation of variables. Interpretation of the regression results along with policy implications is also discussed.

Chapter 10

This chapter extends the simple linear regression introduced in Chapter 9 to multiple variables. The main purpose of this chapter is to demonstrate how to predict the nutritional outcomes when two or more independent variables are at work. The chapter discusses various topics including the derivation of the least squares estimates, estimation of coefficients of the multiple regression models, examination of power of the model prediction, hypothesis testing of individual coefficient, checking for the violation of regression assumptions and interpretation of regression results.

Notes

1. There has been some progress in reducing iodine deficiency and vitamin A deficiency and the treatment of severe infant malnutrition.
2. These programs include encouraging exclusive breastfeeding for the first 6 months of life, appropriate use of fortified complementary foods as the child grows, prevention of anemia among women and children through iron supplementation and food fortification, prevention of low birth-weight through micronutrient supplementation, eliminating iodine deficiency disorders through iodine supplementation, undertaking interventions to prevent diseases and reduce parasite loads, such as malaria, diarrhea, guinea worm, etc., which reduce the body's ability to absorb and retain nutrients (Engle et al., 1999).

7 Impact of maternal education and care on preschoolers' nutrition – application of two-way ANOVA

The doctor of the future will give no medication, but will interest his patients in the care of the human frame, diet and in the cause and prevention of disease.

Thomas A. Edison.

Introduction

Child malnutrition persists in many parts of the developing world despite various efforts to improve the nutritional status of mothers and children. The causes of malnutrition are multiple and include inadequate food, health, lack of sanitation facilities, high fertility rates, ignorance about child-care practices and lack of access to health services. WHO (2005) estimates show that poor water, sanitation and hygiene account for 16 per cent of deaths of children under 5 globally. Thus, understanding the causes and context of malnutrition is important in devising strategies that generate better child health and nutritional outcomes.

The importance of mothers' education for child health and survival through various pathways was first demonstrated by Caldwell (1979) in his seminal paper on Nigeria. This study suggested that education of women played an important role in determining child survival even after controlling for other socioeconomic characteristics. The various pathways suggested by the study of how mother's education can enhance child survival were implementation of health knowledge, an increased capability to interact in the modern world and greater control over health choices for her children.

During the 1980s, the understanding of the association between maternal education and child health at the micro-level expanded greatly with the World Fertility Survey (WFS) program and from a United Nations study that used both survey and census data. Hobcraft et al. (1984) covered 28 WFS surveys and Mensch et al. (1985) covered 15 countries. Both studies demonstrated that the association between mother's education and child survival were weaker in sub-Saharan Africa than in Asia and Latin America, where socioeconomic differences were generally larger. The above studies also suggested that there was no threshold level of maternal education that needed to be reached before advantages in child survival began to accrue. Recent research during the 1990s at both national and household levels has also demonstrated that increased maternal

education has a positive impact on the nutritional status of young children, even after controlling for socioeconomic indicators and access to health services (see, for example, Christian et al., 1988; Ruel et al., 1992, 1999). This may be because children of educated mothers have a lower mortality risk, since educated women tend to marry and have their first child at a later age. Educated mothers are also likely to influence the decision making within the family in favor of children's needs. Additionally, schooling makes women aware of the nearest health center, immunization of children against diseases, feeding the child at the appropriate time and in right quantities and taking early actions against infant diarrhea (Joshi, 1994).

From the policy and program intervention perspective, it is useful to know how various determinants of child malnutrition contribute independently and interact with each other in determining the final outcomes. Formal education of the mother may increase the care practices through knowledge. Yet educated mothers are also time constrained due to their participation in labor markets and illiterate care-givers may have time but may have indigenous (or primitive) child survival practices. Understanding the interaction of such related variables has been a policy and programmatic challenge since such interactions are usually cultural and context specific (Cameron et al., 2001).

Understanding the issue is important since maternal education can affect child nutritional status through greater knowledge, greater provision of resources and/or change in a mother's status (Caldwell, 1979). Education provides knowledge which prevents illness and, at the same time, speeds recovery by consistent care of a sick child. Education also serves as a means to higher paying employment with which a household can command more resources through which it can improve the health of its members (Rosenzweig, 1995).

This chapter will examine the impact of maternal education and child-care on children's nutritional status as measured by height for age (HAZ) and weight for height (WHZ) Z-scores, using a two-way ANOVA approach. The advantage of this approach is that one can simultaneously assess the effects of two (or more) independent variables on a single dependent variable and the possible combined effects of the independent variables on the dependent variable can be determined. This is known as the 'interaction effect'. Another way of stating the interaction effect is to say that the effect of one factor (for example, maternal education) depends on the level of the second factor (child-care). In this chapter, we examine one such interaction effect: maternal education and child-care on children's nutritional status. The two-way ANOVA approach will allow us simultaneously to determine the independent and combined impact of maternal education and child-care on children's nutritional status. This chapter is organized as follows: in the next section, we provide a conceptual framework of the linkages between maternal education, child-care practices and nutritional status of children. We also examine the conceptual and measurement issues related to child-care practices. We then review the few studies that examine the role of maternal education and child-care practices on child health outcomes. Next, we present the empirical analysis using a two-way ANOVA approach, followed by our conclusions.

Conceptual framework: Linkages between maternal education, child-care and nutritional status of children

Possible linkages

Figure 7.1 demonstrates one possible pathway through which maternal schooling can affect the nutritional outcomes of children. Women with more education tend to be knowledgeable about health care and, if exposed to new information, can assimilate this improved knowledge into better care practices than women with lesser education. This additional skill level (especially for women) can make them aware of health services (such as health center facilities and availability of doctors) and generate additional nutritional knowledge (such as immunization of children against diseases, taking appropriate actions on incidence of infant diarrhea, feeding the child during sickness and breast-feeding during early childhood). The above good care practices can, in turn, improve the nutritional status of children. Better health care practices are especially relevant for less educated mothers, for mothers with more dependents and for children from households with limited resources, poor housing conditions and lack of access to hygiene and sanitation services. One cannot assume, however, that mothers of malnourished children are necessarily ignorant of child-care practices or that illiterate mothers, whether their children are healthy or malnourished, do not practice enough good care (Christian et al., 1988).

Conceptual and measurement issues on child-care

Child survival, nutrition and health depend on household food security, on a healthy environment and available health services, and care provided to

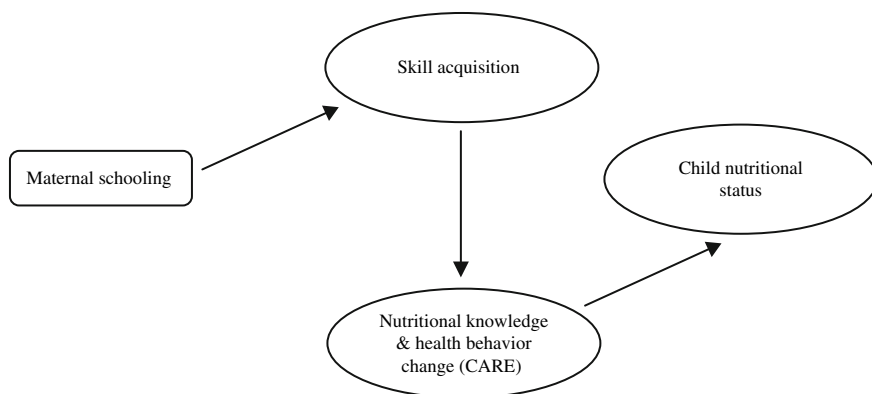


Figure 7.1 Linkages between maternal schooling, child-care and nutritional status. (Source: adapted from Levine et al., 1994)

women and children (UNICEF, 1990). Care has received considerable attention during the 1990s as an important element in improving mothers' and children's nutritional status. The original conceptual model developed by the UNICEF defined care as 'the provision in the household and the community of time, attention and support to meet the physical, mental, and social needs of the growing child and other household members'. An 'extended' conceptual model of care developed by Engle et al. (1999) provides a more detailed conceptual apparatus of both care practices and important household and community-level resources. They characterize behavior patterns into:

1. care for pregnant and lactating women
2. breastfeeding and complementary feeding of young children
3. food preparation and food storage behaviors
4. hygiene behaviors
5. care for children during illness.

The resources for care were classified into six main categories:

1. education, knowledge, and beliefs
2. health and nutritional status of the care-giver
3. mental health, lack of stress, and self-confidence of the care-giver
4. control of resources and intrahousehold allocation
5. workload and time constraints
6. social support from family members and the community.

Figure 7.2 provides an extended UNICEF model of child-care that includes not only an assessment of the care-giver's behavior, but also the behavior of the child and the characteristics of the environmental context. All the three factors play an important role in the nutritional status of the child.

Measurement issues

Two dimensions of caring behavior that have been identified are time spent (quantity of care) and the nature of the activities undertaken (quality of care). The 'time spent on care' method is usually determined by assessing the time spent in specific activities with children (such as bathing, feeding, etc.) along with other activities of the household. Most of the studies do not find any significant association between child-care time and nutritional status. Thus, time devoted to child-care may not be a useful indicator of nutritional status. The 'quality of care' approach tries to determine how specific practices lead to better nutritional outcomes for children. They are usually classified into care-giver and psychosocial care practices. Care-giver practices affect the child's nutrient intake through psychomotor capabilities (such as use of finger foods, spoon handling ability, etc.) and appetite (Engle et al., 1999). Additionally, the care-giver's ability to feed responsively may include encouraging the child to eat, offering additional foods, responding to poor appetite and using a positive

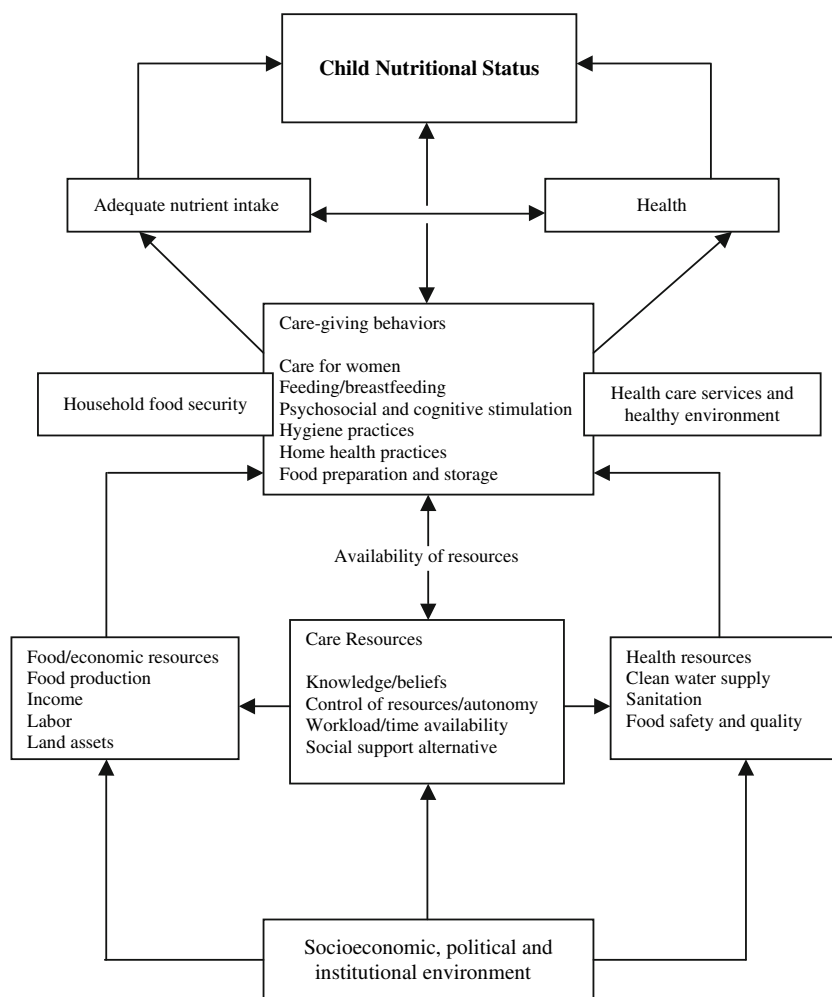


Figure 7.2 Extended model of child care.
(Source: adapted from Engle et al., 1999)

style of interaction with the child. Some studies in developing countries have also found a strong association between specific feeding behaviors (such as location of feeding, organization of feeding event) with mothers' educational status (Guldan et al., 1993). Psychosocial care, on the other hand, refers to the provision of affection and warmth, responsiveness to the child and the encouragement of autonomy and exploration (Engle et al., 1999). Culture plays a central role in psychosocial care.

There are mainly three ways of measuring care practices: observation of specific practices, quantitative assessments of feeding behaviors, and behavioral ratings.

In the observation method, the examiner assesses the care-giver behaviors on a series of items. Bentley et al. (1991) developed a scoring system to measure child and care-giver behaviors for each food rather than for each eating event. They constructed a Guttman scale for child and care-giver behaviors. (The Guttman scale is based on the assumption that there is logical order among dichotomously coded items and the order is unchanged always.) For the child, the three-point scale was based on food refusal, food appetite and food request. For the care-giver, the scale was no response, verbal encouragement, verbal pressure and physical force.

The *quantitative assessment* method counts the number of instances of a behavior during a feeding episode. Sanders et al. (1993) rated the frequency of 14 parent and 17 children behaviors using the mealtime observation schedule in Australia. Behaviors that vary in duration can be coded as whether it is occurring after a fixed interval or not.

The *behavioral rating* method rates the overall quality of the child and care-giver interaction. The behavior rating scale (Bayley scale) for infant development has been used by Engle and Zeitlen (1996) for developing economies. In this method, a domain of behavior is defined by how the care-giver understands the child's need. For example, if a child shouts for the way it is held, the parent can adjust the position. Next, we review specific studies that analyze maternal education and child-care as determinants of child nutrition.

Review of selected studies

While the benefits from female education on child nutritional outcomes are well documented, the pathway through which it contributes to these outcomes has not been adequately analyzed. While many studies (Sahn and Alderman, 1997; Ruel et al., 1999) find strong positive linkages between maternal education and child nutrition, other studies controlling for different factors show little linkages between the two. In Mali, Penders et al. (2000) found no significant effect of maternal education on height for age Z-scores, while Dargent-Molina et al. (1994) reported no beneficial impact on infant outcomes from improvement in maternal education. For the sake of brevity, we will explore only studies that find positive linkages from maternal education on child nutrition working through improved child-care practices.

Christian et al. (1988) was one of the earlier studies that examined the effects of mothers' literacy status and nutrition knowledge on the nutritional status of children in a two-way ANOVA framework. The study was carried out in rural villages of the Panchmahals district of the Gujarat state in India. Education of women was categorized as literate or illiterate, while women's nutrition knowledge was evaluated on a scale of 0 to 9, with the maximum possible score being 9. Nutritional status of the child was categorized into five categories based on weight for age. The study found that both female literacy

and income were important intervening factors in the impact of nutrition knowledge on children's nutritional status. More importantly, the study found that nutritional knowledge exerted a stronger influence on children's nutritional status, which implies that, although all women do need formal education, nutrition education in the short run can significantly reduce the burden of child malnutrition.

In a comprehensive study undertaken in Accra, Ghana (in an urban setting), Ruel et al. (1999) investigated the impact of maternal education on nutritional status of children through the mediating role of child-care practices. The main hypothesis tested was under what conditions are good care practices important for children's nutritional status¹. The survey data were collected between January and March 1997 for a sample of 475 households with children 3 years or younger. The dependent variable was height for age Z-score and the independent variable of interest was care practices (the care index score). Two-way interaction terms between care practices and various other factors were used to test whether some groups of children benefited from good care practices.

The main finding of the study, that good care practices had positive impact on children's nutritional status, has important policy implications. Specific training in child feeding and use of preventive health services for mothers with no formal education could have a large impact on children living under poverty. Also, informal education could mitigate the negative effects of poverty and low maternal schooling on children's nutritional status. Thus, with better care practices, poor children from less educated mothers could improve their nutritional status.

Drawing on a large household survey consisting of 7200 households, using a multistage cluster sampling method in rural central Java, Indonesia, Webb and Block (2003) addressed three issues:

1. what is the impact of maternal schooling compared to maternal nutrition knowledge on child nutrition in the short and long run?
2. are maternal and paternal schooling substitutes for good child nutrition?
3. how do maternal education and nutrition knowledge affect mothers' own nutritional status?

The motivation behind the above set of questions was that, while most mothers understood the importance of maintaining the protein-energy intake to maintain nutritional status, a subset of mothers understood the importance of micronutrient rich foods and thus their children were better protected from the crisis than others.

The study estimated a reduced form nutritional production function, in which nutritional outcome was related to productive resources, maternal schooling and age, paternal schooling and maternal nutrition knowledge. The model thus accommodated the possibility that nutrition knowledge could have differential impacts on nutritional status for different members of the household.

The main results can be summarized as follows:

1. weight for height Z-score was more related to care and feeding practices than household resources. In contrast, maternal schooling had no significant impact on short-term nutritional status. In addition, maternal schooling and nutritional knowledge were neither substitutes nor complements in affecting short-term nutritional status
2. in the long run, nutritional knowledge contributed significantly to height for age Z-score.

Thus, the study concluded that short-term and long-term child nutritional indicators were determined by different sets of factors. Short-term child nutritional status was much more responsive to maternal nutrition knowledge than maternal schooling, while formal schooling of mothers was more important in long-term child nutritional status.

The policy implications from the study are as follows. First, as nutrition knowledge clearly affects short-term child nutritional status more than household resources or maternal education, combining clear nutrition messages with other resources targeted to the poorest households in developing countries can have significant impact. Second, while maternal education is important for long-term child health status, the importance of the father's education should not be ignored as investments in human capital are critical for development.

Empirical analysis

The main question addressed in the present analysis is how education level of the mother and child-care affects child nutritional status. The two-way ANOVA approach can determine if there are overall differences in weight for height Z-scores (ZWH) between different educational levels of the mother, between varying levels of child-care and whether there is an interaction effect of educational level and child-care on improving child nutritional status (Karpinski, 2003). The interaction effect can be thought of as saying that the effect of one factor (e.g. educational level) depends on the level of the second factor (e.g. child-care). For example, it may be the case that higher educated women provide better child-care than lower educated women. Thus, we undertake the following hypothesis tests:

Educational level effect:

H₀: mean weight for height Z-scores do not differ by educational levels of the mother

H₁: mean weight for height Z-scores differ by educational levels of the mother

Care effect:

H₀: mean weight for height Z-scores do not differ by care levels by the mother

H₁: mean weight for height Z-scores differ by care levels by the mother

Interaction effect:

H₀: there is no interaction between educational levels and care levels

H₁: there is an interaction between educational levels and care levels.

Data description

The dependent variable in the analysis is weight for height Z-scores, which is a measure of short-term child nutritional status. We convert this variable into a categorical variable as follows:

$$ZWHNEW = \begin{cases} 1 & \text{if } ZWH \geq -2 \text{ (normal Z scores)} \\ 0 & \text{if } ZWH < -2 \text{ (low Z scores)} \end{cases} \quad (7.1)$$

Thus, a value of 1 indicates absence of wasting, while a value of 0 indicates presence of wasting. The independent variables are as follows:

1. Education of the spouse (EDUCSPOUS): a categorical variable, the value of which ranges from 1 to 7. It measures the education level of the spouse (or mother) in number of years. (In the case of female-headed households in the two-way ANOVA analysis, we separate out females who are heads of the household and thus are not the spouse of a male-headed household.) For example, the variable attains a value of 5 if the spouse completed secondary education. Thus, higher values indicate more number of years in schooling
2. Child-care index (CARE): a composite child-care index was constructed on the lines of Ruel et al. (1999). The index was derived using variables related to child-feeding practices (such as breastfeeding and feeding the child during sickness) and preventive health seeking behavior (whether the child was immunized). The index ranged on a continuous scale from -1 to $+1$, with -1 denoting poor child-care practices and $+1$ denoting good care practices. For age groups where a particular practice (such as breastfeeding for children above 24 months of age and compulsory immunization to children below 9 months) is not likely to improve the growth of children, the component was assigned a value of 0 implying a neutral effect. The index was made age specific for each age group.

The technical appendix provides details about the construction of this index. The composite care index was thus the sum of the individual components, namely the breastfeeding, child feeding during sickness and compulsory immunization components. Terciles (NCARE) of this index were then created to distinguish among children whose mothers had poor caring practices from those with good care practices.

Cross-tabulation of weight for height with mothers' educational levels

First, we look at the prevalence of malnutrition (measured by ZWHNEW and ZHANEW); ZHANEW is constructed similar to equation (7.1) and differentiates between children who are stunted from those who are not by mothers' educational levels using cross-tabulation procedures.

Table 7.1 shows no marked differences in the prevalence of stunting between non-educated and educated women. For example, for mothers with no education, the prevalence of stunting is 51.3 per cent relative to the presence of normal children of 48.1 per cent. On the other hand, for some level of educational attainment of the mother (std 5–8) which in this sample is the highest

educational attainment, the prevalence of stunting is 30 per cent relative to non-prevalence (or normal children) of only 27.9 per cent. The *P* value is 0.457 and, as the significance level is greater than 0.1, the null hypothesis cannot be rejected at the 10 per cent level. Thus, we can conclude that there is no significant difference in prevalence of stunting between educated and non-educated mothers.

Table 7.2 shows that there are significant differences in the prevalence of wasting between non-educated and educated women. For mothers with no education, the prevalence of wasting is almost 79 per cent compared to non-prevalence (47.5 per cent). Thus, it would appear that short-term nutritional status is significantly influenced by mothers' educational level. On the other hand, as educational level increases, there is much less prevalence of wasting. The *P* value from the Pearson chi-square statistic is 0.006 and since it is less than 0.1, the null hypothesis that there is no difference between wasting among uneducated and educated mothers can be rejected. Thus, we conclude that educational level matters for short-term nutritional status. In the next section, we investigate the role of mothers' education and child-care on weight for height *Z*-scores using a two-way ANOVA approach.

Table 7.1 Prevalence of stunting by mothers' educational level

		ZHANEW		Total
		Low	Normal	
EDUCSPOUS	No education	41	50	91
	Adult literacy	1	6	7
	Std 1-4	14	19	33
	Std 5-8	24	29	53
	Total	80	104	184 = <i>n</i>

Table 7.2 Prevalence of wasting by mothers' educational level

		ZWHNEW		Total
		Low	Normal	
EDUCSPOUS	No education	15 78.9%	84 47.5%	99
	Adult literacy	2 10.5%	5 2.8%	7
	Std 1-4	0 0.0%	35 19.8%	35
	Std 5-8	2 10.5%	53 29.9%	55
	Total	19	177	196 = <i>n</i>

Two-way ANOVA results

The two-way ANOVA approach is suitable, since it allows us to determine the interaction effects of educational level of the mother and child-care on weight for height Z-scores and thus provides greater generalizability of results. In a two-way ANOVA, we will obtain three different statistical tests:

1. main effect of educational level of the spouse
2. main effect of care levels by terciles of care
3. interaction effects between educational level of the spouse and care levels.

Definition of main effect

This is the effect of one independent variable on the dependent variable across the levels of the other independent variable. In our example, we want to determine if there is a difference in the mean weight for height Z-scores by the educational levels of the mother averaging over the child-care levels. In other words, ignoring the effect of child-care levels, do weight for height Z-scores differ between educated and non-educated mothers? Second, we want to determine if there is a difference in weight for height Z-scores by child-care terciles ignoring the educational levels of the mother. One way to understand the main effect is to examine the marginal means.

As evident from [Table 7.3](#), we find the mean performance on weight for height Z-scores is greater for mothers with some educational level relative to mothers with no education. Thus, we want to ask the following question: do the marginal means differ?

From [Table 7.4](#), it is evident that the mean weight for height Z-scores is highest for mothers in the medium care tercile (0.974) followed by the upper care tercile. The result possibly indicates that as care behavior improves (such as breastfeeding children below 2 years of age), nutritional status of children improves after controlling for educational level of the mother. Next, we determine if the marginal means among the various child-care terciles differ. This is done by calculating the sum of squares.

Partitioning sum of squares

For a two-way ANOVA, the model has additional components compared to a one-way ANOVA (as introduced in Chapter 5). [Figure 7.3](#) provides a useful way of understanding variance partitioning.

Table 7.3 Effect of mothers' education on ZWHNEW

EDUCSPOUS	Mean
No education	0.844
Adult literacy training	0.75
Std 1–4	1.00
Std 5–8	0.961

The breakdown of the total (corrected for the mean) sums of squares is summarized in Table 7.5.

In our present analysis, the sum of squares between SSB is made up of three parts: the sum of squares of mothers' educational level SS (EDUCSPOUS), the sum of squares of terciles of child-care SS (NCARE) and the sum of squares of the interaction SS (interaction). Thus, the sum of squares of the interaction term is obtained as follows:

$$SS \text{ (interaction)} = SSB - SS \text{ (EDUCSPOUS)} - SS \text{ (NCARE)} \quad (7.2)$$

The SSW or sum squares error is what is left over. Thus, we have:

$$SSW = TSS - [SS(EDUCSPOUS) + SS(NCARE) + SS \text{ (interaction)}] \quad (7.3)$$

In order to determine the mean squares, we have to find the respective sum of squares and divide it by the corresponding degrees of freedom. Thus, the degrees

Table 7.4 Effect of child-care on ZWHNEW

NCARE	Mean
1	0.842
2	0.974
3	0.884

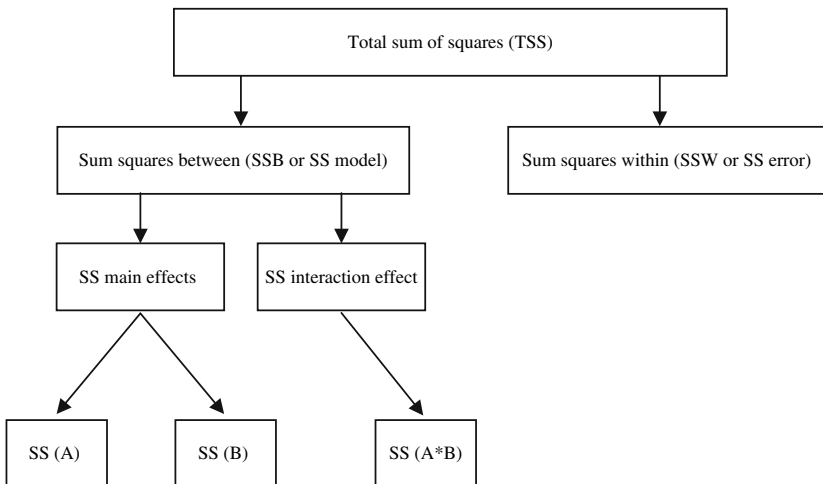


Figure 7.3 Variance partitioning for two-way ANOVA.

Table 7.5 ANOVA table for an $a \times b$ factorial experiment

Source	SS	df	MS
Factor A	SS(A)	$(a - 1)$	$MS(A) = SS(A)/(a - 1)$
Factor B	SS(B)	$(b - 1)$	$MS(B) = SS(B)/(b - 1)$
Interaction AB	SS(AB)	$(a - 1)(b - 1)$	$MS(AB) = SS(AB)/(a - 1)(b - 1)$
Error	SSW	$(N - ab)$	$SSW/(N - ab)$
Total (corrected)	TSS	$(N - 1)$	

Table 7.6 Tests of between subject effects: dependent variable ZWHNEW

Source	Type III sum of squares	df	Mean square	F	P value
SSB	2.187	10	0.218	2.691	0.003
Intercept	64.330	1	64.330	798.914	0.000
EDUCSPOUS	0.987	3	0.329	4.085	0.008
NCARE	0.492	2	0.246	3.056	0.049
EDUCSPOUS*NCARE	0.708	6	0.118	1.468	0.202
SSW	14.971	185	0.081		
TSS	17.158	195			

R squared = 0.132 (adjusted R squared = 0.085).

of freedom for TSS is $(N - 1)$, where N is the total sample size. The degrees of freedom for SS (EDUCSPOUS) and SS (NCARE) are $(k - 1)$, where there are four groups for mothers' education and three child-care terciles. The degrees of freedom for the interaction is equal to the product of degrees of freedom of the SS (EDUCSPOUS) and SS (NCARE) and are 6. The next step is to calculate the three F -statistics for the tests. This is done by taking the mean squares for the two independent variables and the mean square of the interaction and dividing them by the mean squares within. In order to determine if a particular F -statistic is statistically significant, we compare the calculated F value with the critical value of F . If the obtained F value exceeds the critical value, we reject the null hypothesis and conclude that the independent variable has a significant impact.

Interpreting the output from a 2×2 factorial ANOVA involves examining the three F -values associated with the two main effects (EDUCSPOUS and NCARE) and the interaction effect (EDUCSPOUS*NCARE). For the main effect of mothers' education on weight for height Z-score, we obtain an F -value of 4.085 with the corresponding probability being 0.008 (Table 7.6). Since the probability is less than 0.05, we reject the null hypothesis that mean weight for height Z-scores do not differ by educational levels of the mother. Thus, education of the mother has a significant influence on weight for height Z-scores. Taken together

with the estimated marginal mean of Table 7.3, we can conclude that there is a significant difference in the mean weight for height Z-scores between educated and non-educated mothers ignoring the impact of child-care. Examining the main effect of child-care terciles on weight for height Z-score, we find the F -value to be 3.056 with the associated significance level of 0.049. We thus reject the null hypothesis that the mean weight for height Z-scores do not differ by care levels of the mother and thus child-care levels have a significant impact on weight for height Z-scores after ignoring the impact of mothers' education.

Interpreting the interaction effect and post-hoc tests

Since there are more than two means, we want to determine through multiple post-hoc comparisons (such as Tukey or LSD tests; these procedures are discussed in brief in the technical appendix at the end of this chapter) to determine which means (if any) are significantly different. Recall that there are four educational levels of the mother and three child-care levels. Although, from Table 7.6, the overall interaction effect (EDUCSPOUS*NCARE) is not significant, there may be significant differences among the means of mothers' educational levels and child-care. In other words, there may be differences among combinations of education levels and child-care terciles. Post-hoc tests are used when the researcher is exploring differences among group means, otherwise the likelihood of type 1 errors increases. We will carry out an example of carrying out post-hoc tests using educational level of the mother and child-care terciles.

The group means for mothers with no education and standards 1 to 4 (some elementary schooling) are placed on the columns, while child-care terciles (2 and 3) are placed in the rows (Table 7.7). It is apparent that mothers with more education relative to mothers with no education practice greater child-care. The simple post-hoc analysis compares a given pair of means. If they are significantly different ($P < 0.05$), different letters are placed next to these means to indicate that they are significantly different. Let us start with the cell in the upper left-hand corner with a mean of 0.929 and place the letter 'a' next to it. Since the post-hoc tests (both LSD and Tukey) indicate that the next highest mean for the combination of educational level of the mother being in standard 1–4 (some elementary schooling) and second child-care tercile is significantly different, we place the letter 'b' next to it. Then we compare the combination educational level of the mother (Std 1–4) and child-care (2nd tercile) with the next mean

Table 7.7 Multiple comparison test

		EDUCSPOUS No education	Std 1–4
NCARE	2	0.929 a	1.00 b
	3	0.735 c	1.00 d

educational level of the mother (no education) and child (3rd tercile) and find the difference to be significant. We place the letter 'c' next to it. The general principle is that by comparing a given pair of means, if we find the difference to be significant ($P < 0.05$), we place a different letter next to it. On the other hand, if the difference is not significant ($P > 0.05$), then the same letter is placed next to these means to indicate that they are not significantly different. The interpretation of the interaction effect (EDUCSPOUS*NCARE) can be described as follows: for the same level of child-care, higher education among mothers (elementary schooling) improves short-term nutritional status as measured by weight for height Z-scores. On the other hand, for a given level of education (no education or some elementary schooling), mothers in the second child-care tercile perform better than ones in the highest care tercile. The interpretation is that the impact of positive child-care practices improves short-term nutritional status for households in the lower socioeconomic terciles compared to the upper socioeconomic terciles. This result is consistent with Ruel et al. (1999), where care was found to be more critical for children whose mothers had less than secondary schooling and for households in the lower two socioeconomic terciles for Ghana.

Conclusion

The role of care practices in improving child nutritional status has increasingly been recognized during the 1990s with the UNICEF's nutrition conceptual framework. The framework suggested that not only were food security and health care services necessary for child survival, but care for women and children was equally important. Enhanced care-giving can balance the use of resources to promote good health and nutrition in women and children. Engle et al. (1999) improved on this conceptual framework by emphasizing the ways through which child-care practices translate into improved child nutritional status. Six care practices (with subcategories) and three kinds of resources were identified as crucial determinants of child nutritional status. The modified framework emphasized the importance of complementary feeding practices, such as introduction of complementary foods and feeding frequency and care-givers' understanding of children's response to food intake.

The purpose of the present chapter was to examine the roles of maternal education and child-care as well as the interaction of maternal education and child-care on short-term child nutritional status. For this purpose, we developed a composite index of child-care by incorporating breastfeeding, feeding during sickness and immunization of the child as components of this index. The index was made age specific for each age group of the children. Our results indicate that maternal education and child-care have independent and significant influence on child nutritional status. After undertaking post-hoc tests, we find that, for a given level of child-care, education among mothers (elementary schooling) improves short-term nutritional status. On the other hand, for a given level of

education, mothers in a lower child-care tercile perform better than ones in the highest care tercile in improving child nutritional status.

However, specific issues need to be addressed regarding the determinants of care-giving and specific care practices for understanding child nutritional status. It is important to investigate the role of psychosocial care in promoting both physical growth and development in young children. Examining the linkages through which maternal schooling affects child nutrition, for example through improved food selection or greater knowledge, would enhance the child-care programs. Most importantly, at the policy level, programs that include care should make an effort to identify and support good care practices such as identifying the factors that motive care-givers rather than simply advocating them.

Technical appendices

Scoring system used to create the care index (Ruel et al. 1999)

Care index by age group

Table 7.8 Care index by age group

Practices included	Scores allocated by age group (in months)		
	0–8.9	9–23.9	≥ 24
Breastfeeding	No: –1 Yes: 1	No: –1 Yes: 1	No: 0 Yes: 0.5
Sickfeeding: cut-off point was 3	No: –1 Yes: 1	No: –1 Yes: 1	No: –1 Yes: 1
Compulsory vaccination	No: 0 Yes: 0	No: –1 Yes: 1	No: –1 Yes: 1

Two-way ANOVA model

Let us introduce the following notations for understanding the \geq two-way ANOVA model:

a : the number of levels of the first factor (rows)

b : the number of levels of the second factor (columns)

n : the number of observations in each cell

X_{ijk} : the k^{th} observation in the i^{th} row and j^{th} column

\bar{X}_{ij} : mean of the n observations in cell (i, j)

\bar{X}_i : mean of nb observations in row i

\bar{X}_j : mean of na observations in column j

\bar{X} : Grand mean of the nab observations.

Then the total variation can be decomposed into

$$X_{ijk} = \bar{X} + (\bar{X}_{.j} - \bar{X}) + (\bar{X}_i - \bar{X}) + (\bar{X}_{ij} - \bar{X}_i - \bar{X}_j + \bar{X}) + (X_{ijk} - \bar{X}_{ij.}) \quad (7.4)$$

Taking \bar{X} to the left hand of equation (7.4), and squaring both sides of the equation and summing over all observations, we obtain

$$\begin{aligned} \sum_{i=1}^n \sum_{j=1}^a \sum_{k=1}^b (X_{ijk} - \bar{X})^2 &= na \sum_j (\bar{X}_{.j} - \bar{X})^2 + nb \sum_i (\bar{X}_i - \bar{X})^2 \\ &+ n \sum_i \sum_j (\bar{X}_{ij} - \bar{X}_i - \bar{X}_j + \bar{X})^2 + \sum_i \sum_j \sum_k (X_{ijk} - \bar{X}_{ij.})^2 \end{aligned} \quad (7.5)$$

The left-hand side of equation (7.5) is the total sum of squares, while the right-hand side consists of SSB and SSW. The first three terms on the right hand are the sum of squares of factor A, factor B and the interaction term, while the last expression denotes the sum of squares of the error term or the sum of squares within. After dividing the relevant expressions by the degrees of freedom, we obtain the mean square expressions. The corresponding F ratios are obtained by dividing the mean square of factor A, factor B and the interaction term (A*B) by the mean square error.

Post-hoc procedures

It is critical in the ANOVA procedure to reduce the probability of type 1 error to 0.05 or smaller. Post-hoc procedures are used to assess which group means differ from each other after the overall F -test has demonstrated that at least one such difference exists. The group means refer to the means of the dependent variable for each of the k groups (a groups for factor A and b groups for factor B) formed by the categories of the independent variables. The possible number of comparisons is thus $k(k-1)/2$. The q -statistic² (also called the q range statistic) is commonly used for such comparisons. The q -statistic tests the probability that the largest and smallest mean among the k groups formed by categories of the independent variables were sampled from the same population. If the q -statistic computed for the two sample means is not greater than the critical q -value, then one cannot reject the null hypothesis that the groups do not differ at the given significance level ($P < 0.05$). The Tukey honestly significant difference test (HSD)² is undertaken when the sample sizes of the groups are highly unequal. It is a preferred method when the number of groups is large. However, many researchers prefer it for pairwise comparisons. When all pairwise comparisons are tested, this procedure is more powerful than other post-hoc tests. For implementing the Tukey's HSD procedure, one needs to compare the actual t computed for any pairwise comparison to the critical value of the q -statistic. If $t_{computed} > (q_{critical})/\sqrt{2}$, we can reject the null

hypothesis that the groups' means are the same. The least significant difference test (LSD), also called the Fisher's test, is based on the t -statistic and can be considered as a form of t -test. It compares all possible pairs of means after the F -test rejects the null hypothesis that groups do not differ. It can handle both pairwise and non-pairwise comparisons and does not require equal sample sizes. It is the most liberal of all the post-hoc tests and the results need to be interpreted with caution. Since it controls the type 1 error rate at a given level of significance, it is most likely to reject the null hypothesis in favor of finding groups that do differ. Toothaker (1993) recommends against use of LSD on the grounds that it has poor control over the level of significance when better alternatives exist.

Exercises

1. Discuss a methodology in constructing a CARE index after reviewing the existing literature.
2. Discuss how the total sum of squares is partitioned in a two-way ANOVA compared to a one-way ANOVA. What is meant by main effects and interaction effects?
3. Examine critically how Engle et al. (1999) improved on the UNICEF framework on the role of child-care as an additional determinant in improving child nutritional status. What are the specific mechanisms discussed in the paper through which child nutritional status can be improved? Suggest a few dimensions of care that you will recommend to the Ministry of Health in your own country for improving child nutritional status.
4. Undertake a two-way ANOVA analysis with each component of care (CARE1, CARE2 and CARE3) as independent variables separately with education of the spouse (EDUCSPOUS) as the other independent variable. Which component or components turns out significant? Carry out a post-hoc analysis to determine which groups of CARE (CARE1, CARE2 and CARE3) terciles differ by educational status of the mother as analyzed in [Table 7.8](#).
5. After undertaking a two-way ANOVA analysis with per capita expenditure quartiles (NPXTOTAL) and EDUCSPOUS as the independent variables, we obtain the following results:

Source	df	SS	MS	F
NPXTOTAL		0.696		
EDUCSPOUS		0.915		
Interaction		0.850		
Error		16.925		
TSS	235	19.131		

With the above information, calculate the degrees of freedom (df), SS(B), mean square errors and the F -statistic.

6. What are three main ways of measuring child-care practices?

Notes

1. The authors hypothesize that good child-care may be particularly important for children of less educated mothers; for time-constrained women; for households with more dependent children; and for children from households with limited resources, poor housing conditions and lack of access to hygiene and sanitation.
2. Tukey's insight was to determine a sampling distribution related to the t distribution which is the pairwise maximum and is called the studentized q statistic. Mathematically, $q = \sqrt{2}t$.
3. For a useful discussion of the Tukey HSD tests and Fisher's least significant difference test, the reader is encouraged to consult Karpinski (2003) Chapter 6 on planned contrasts and post-hoc tests for one-way ANOVA.

8 Indicators and causal factors of nutrition – application of correlation analysis

Introduction

As mentioned in the earlier chapters, malnutrition remains a chronic and persistent problem in many parts of the developing world. From the most recent estimate of FAO (2006), there are 854 million individuals who are undernourished, constituting about 12.6 per cent of the world's population. Out of the 854 million people who do not get enough food, about 820 million are in developing countries (World Hunger Facts 2008). Additionally, in developing countries, about 160 million preschool children are underweight for their age. Further, one in three children in developing countries suffers from stunting (de Onis et al., 2000).

An understanding of the determinants of malnutrition is important to improve human welfare and target intervention programs and policies. Malnutrition also causes a great deal of human suffering (both physical and emotional)¹. Apart from the human costs, chronic malnutrition has economic costs too. Deficiencies in vitamin A, protein, iron and other micronutrients can cause prolonged impairment, thus reducing productivity of human capital.

Malnutrition is typically caused by a combination of factors, including inadequate food intake, mother's education and care, health status and environmental factors. The immediate determinant of nutritional status is dietary intake (calories, protein, fat, micronutrients, carbohydrates and vitamins). Dietary intake must be sufficient in quantity and quality and nutrients must be consumed in appropriate combinations for the child to absorb them (see, for example, Smith and Haddad, 2000).

Inadequate food intake of a child is the result of households not having enough resources (such as own food production, income or in-kind transfers of food) for gaining access to food. Although sustained income growth can improve the nutritional status of a child through the household's access to various resources, other factors such as women's education and nutritional knowledge play an equally important role. Women with at least secondary education tend to have fewer children and have better knowledge of feeding and caring practices. These knowledge and skills improve the caring practices and thereby positively influence the nutritional status of the child (Engle et al., 1999). A final underlying determinant of nutritional status is health environment and services, which constitute

safe water, sanitation, health care and environmental safety (Smith and Haddad, 2000).

A policy and program intervention challenge frequently faced by policy makers and program managers is which of the various factors have positive or negative association with child nutrition. It is important to understand the factors that are associated strongly with child nutrition, so that appropriate actions could be taken to improve those causal factors thereby improving child nutrition.

The purpose of this chapter is to examine how the various child nutritional indicators (weight for age, height for age and weight for height Z-scores) are associated with each other using a correlation analysis. This kind of analysis can be useful for program monitoring and evaluation for the vulnerable segments of the population. For example, if a significant portion of children of a representative population group is found to be both underweight and stunted and program managers identify lack of child-care practices to be the primary cause, nutrition interventions in the form of health education to the care-giver may be appropriate in a given situation.

In what follows, we first discuss the main studies that use correlation analysis as a tool for examining the causes of child nutritional status. The analysis is similar in logic to the application of multivariate regression. While in multivariate regression we are trying to predict the values of the Z-scores (height for age, weight for age, etc.) based on the different independent variables, in the correlation analysis we are looking at how the independent variables are associated with the outcome variables. Finally, we conclude with a few policy implications of the main results.

Review of selected studies

Explaining high levels of malnutrition in developing countries has been an area of interest to policy researchers and development practitioners. Below, we discuss a few studies that use correlation analysis in addressing nutritional status.

Alderman and Garcia (1994), using a household production function approach, address how household food availability and health security affected the nutritional status of children in rural communities in Pakistan. Nutritional status is considered to be a process governed by two proximate factors, namely, nutrient availability and absence of infection². The controls of the model were a family's nutrient availability, education of the parents, child's age, care and household size. The data were collected over a 3-year survey for a sample consisting of 1200 households (from 52 villages chosen randomly), from the four poorest districts in Pakistan during the period 1986–87.

The study found that more than half of the children were stunted (or chronically malnourished) as defined by WHO reference standards, i.e. they fall below 2 standard deviations from the reference of each district. Additionally, 8.7 per cent of the children in the sample were wasted (low weight for height). However, the

study found low correlation between the two measures of malnutrition (-0.13) and this was not significant. Additionally, the correlation among the different determinants of nutrition was found to be very low.

The main result of the study was that child nutrition was highly responsive to health inputs rather than food availability at the household level. Since morbidity and poor nutritional status are interdependent, the study found diarrhea as the main culprit in reducing a child's height for weight, thereby curtailing long-run growth. In addition, the study found that if all mothers were educated up to the primary level, the level of child wasting would decrease by one-half of the current prevalence levels. Similarly, programs that decreased diarrhea occurrence by 1 day on an average over a 2-week period reduced the incidence of child wasting by 2.1 percentage points.

A clear policy implication of the study is to improve community level investments in order to develop the sanitary environment. Overall, the results of the study indicate that, in Pakistan, food security alone is not sufficient in improving nutritional status, particularly of children. Health and infection are equally or more important factors in determining child nutritional status.

Glewwe et al. (2003) examined the impact of income growth and improvement in health indicators on child nutritional status for Vietnam. Child nutrition is a key issue in Vietnam, since it is one of the poorest countries in the world with per capita GNP of about \$370 during 1999. The study used the 1992–93 and 1997–98 Vietnam Living Standards Survey (<http://www.worldbank.org/html/prdph/lsms/guide/select.html>) with about 4300 households included in the sample. The sample was a large, nationally representative dataset. Height for age (stunting) and weight for age (underweight) Z-scores were considered as indicators of nutritional status of the population and were dependent on household per capita income, parents' schooling, local health environment and child's innate healthiness as the main determinants.

One of the main questions addressed in the study was whether a rapid increase in household incomes and expenditures was the main cause of a decrease in stunting. Undertaking different estimation methods (ordinary least squares (OLS) and instrumental variable), the study demonstrated that the impact of household expenditures on child nutritional status was not always significant. In regard to the other determinants of child stunting, the study found that child age had a strong relationship to stunting, implying the importance of genetic endowments on children's nutritional status. In examining the role of community characteristics (such as health services), the main finding was that the distance to the nearest pharmacies had a negative and significant impact on child health status. Additionally, the study found that providing health centers with good sanitation and ample supplies of oral rehydration salts had a substantial positive impact on child health.

Understanding correlations of water and sanitation conditions with child health variables can be useful for designing intervention programs and policies at the local level. A recent World Bank study (Shi, 2000) addressed how access to safe water and sanitation conditions affects child mortality using 1993 city level

data from the global urban indicators. The primary focus of this paper was to address the impact of the health environment on a health outcome variable: infant mortality. The data came from the global urban indicators for 237 cities in 110 countries on 46 key indicators. Infant mortality was modeled as a function of access to potable water or percentage of households having access to sewerage, a series of dummies that capture the type of organizations responsible for water or sewerage provision and a set of control variables.

The results of the study demonstrated that child mortality was inversely correlated with access to potable water and sewerage connections by undertaking a correlation analysis. Thus, nutritional outcomes improved with progress in the health environment, as measured by water and sanitation conditions. In addition, the lack of health services facilities was also associated with higher child mortality. Cities with higher household income per capita had lower child mortality. Other findings showed that the type of organizations responsible for water service were also important for child mortality. Local government as a water service provider consistently lowered infant child mortality, while private service providers as a service provider were associated with a higher mortality rate.

Svedberg (2004) aimed at challenging the study by Behrman et al. (2004), which argued that infant and child nutrition could be significantly improved by the promotion of exclusive breastfeeding and supplementation of micro-nutrients such as iron, iodine and vitamin A. The main hypothesis tested was that poverty (low income) was the crucial determinant of hunger and malnutrition.

The main focus of the study was to examine the relationship between the prevalence of stunting and underweight on the one hand and real per capita income on the other. The study provided the following rationales of income as a crucial determinant of child nutrition. First, with higher per capita income, households could exert a stronger effective demand for private consumption goods, including food with better nutritional contents. Second, higher gross national income can translate into higher government revenues and expenditures. If these expenditures are used to finance public investment and consumption in health and nutrition related services, it could have a positive impact on child nutritional status.

As the relationship between stunting and per capita income drifted downward during the 1990s, it is likely that non-income factors might have played some role in reducing stunting. The author thus advocates that microlevel interventions and targeting methods must continue. However, in the absence of higher economic growth rates in the poorer countries, the hope of realizing the Millennium Development Goals cannot be achieved.

Given the strong correlation between income growth and child nutritional outcomes at the cross-country level (Smith and Haddad, 2000; Svedberg, 2004) and the strong impact of women's education (operating through better child-care practices and improved maternal nutrition knowledge), it is important to understand which sort of interventions are important for improving child

nutritional outcomes in the short and long term. Understanding the various factors that are associated with child nutritional outcomes will allow policy makers to undertake appropriate actions so that improvement in the causal factors enhances child nutritional outcomes. In the next section, we examine how the child nutritional outcomes are associated with each other using correlation analysis.

Empirical analysis and main findings

The central question addressed in this chapter is to what extent the different indicators of nutritional status are associated with each other. For this purpose, a Pearson's correlation analysis is undertaken. Correlation analysis can be useful for the following reasons:

1. formulating nutrition targets (such as targets within a development plan)
2. planning social development programs/projects for the vulnerable sections of the population (for example, government and non-government organizations use nutrition indicators in implementing, monitoring and evaluating social developmental programs)
3. using it as baseline and benchmark data (nutrition indicators often reflect the current nutrition situation with which future data can be compared at the start of an intervention project).

Cross-sectional surveys are the preferred approach to collect data on health and nutritional variables, as large representative samples and the information on a range of topics can be obtained in a short time period. These surveys are also cost-effective compared to long-term longitudinal studies.

One important limitation of cross-sectional data in the context of health and nutrition surveys is that, unlike longitudinal surveys, they do not support assessment of the direct effect of a particular episode of illness on nutritional status of the child. For example, the assessment of the impact of illness on growth attainment requires knowledge of individual growth trends, which cannot be determined from a single measurement. For this reason, cross-sectional measurements are unlikely to reflect a consistent relationship of nutritional status with reports of illness, whereas a series of measurements obtained at different points in time are very likely to demonstrate a direct causal relationship between episodes of illness, especially diarrhea.

On the other hand, it is reasonable to use cross-sectional data to analyze the correlation of socioeconomic, demographic or environmental factors with nutritional status (McMurray, 1996). Since the association is less direct, population patterns are likely to reflect an association with these factors. However, the method of analysis can affect the results. In particular, the use of a cut-off point to classify cases can blur the association because the causes of child nutritional status in any two groups are not uniform. Thus, given the nature of cross-sectional data and their limitations at the individual level, analysis based on cut-off points should be used in

conjunction with other analytical techniques, which provides a better picture of nutritional patterns across the whole sample (Pelletier et al., 1994).

A better approach to the analysis of cross-sectional data is to treat the anthropometric indicators as continuous variables as done in the present chapter and to focus on patterns of covariation rather than on the odds of being in one discrete category rather than another.

We motivate the empirical analysis by first discussing the methodology of correlation analysis, then examining some descriptive analysis undertaken in various case studies and then undertaking the correlation analysis.

Data description and methodology

The different indicators of nutrition may be classified as follows:

1. outcome variables
2. socioeconomic indicators that affect child nutrition
3. CARE indicators
4. community characteristics.

The latter three indicators are determinants of the child nutritional status and are also associated with the child nutritional status.

The *outcome* variables of child nutritional status are the anthropometric Z-scores of height for age (ZHA), weight for age (ZWA) and weight for height (ZWH).

We consider the following *socioeconomic* indicators that affect child nutritional status significantly. These are:

1. per capita expenditure on food (PXFD): expenditure on food is a critical variable in models of child health and nutrition outcomes and is used as a proxy for income
2. education of the spouse (EDUCSPOUS): this is a categorical variable which has a value ranging from 1 to 7 and measures the education level of the mother in number of years. Higher values of this variable indicate greater levels of education.

The *CARE* indicators included in the analysis are as follows:

1. clinic feeding (CLINFEED): a dichotomous variable denoting whether the child is fed in a clinic or not
2. breastfeeding (BFEEDNEW): also a dichotomous variable denoting whether the child is breastfed or not during his or her infancy.

The *community characteristics* consists of the following set of variables:

1. drinking distance (DRINKDST): a categorical variable assuming values from 1 to 5. Higher values of this variable denote that the distance to a protected drinking source for the household is higher. For example, the variable attains a value of 4 if distance to a protected drinking source exceeds 3 km. We can expect that the greater the distance to a protected water source the more is the likelihood that children will suffer from malnutrition. This is because by reducing the risk of bacterial infections and diarrheal diseases, sanitation and clean water can indirectly contribute in improving a child's nutritional status

2. provision of sanitation (LATERINE): a dichotomous variable assuming two values 0 and 1, with 0 indicating absence of latrine from the household. Sanitation appears more important in nutritional outcomes than presence of protected drinking source, since it is directly related in preventing diarrhea, thereby improving children's nutritional status
3. DIARRHEA: this variable indicates whether the child has diarrhea and is a dichotomous variable assuming two values 0 and 1. 1 indicates that the child had diarrhea during the survey. Infections such as diarrhea can reduce the nutrients in the body and thus increase the likelihood of malnutrition further
4. distance to a health facility (HEALTDST): a categorical variable denoting the distance of the household to a health clinic and assumes 4 values. Higher values indicate that the household is located farther from the nearest health center. For example, a value of 4 indicates that the distance to the nearest health clinic for the household is more than 10 km.

Concepts in correlation analysis

Before proceeding to the analysis, it is important to explain a few concepts associated with the *correlation analysis* (Lowry, 2003).

Suppose we have two random variables X and Y with means \bar{X} and \bar{Y} and standard deviations S_X and S_Y respectively. Then, the correlation coefficient can be computed as follows:

$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{(n-1)S_X S_Y} \quad (8.1)$$

The above equation can be interpreted as follows: suppose that an X value was above average and that the associated Y value was also above average. Then the product $(X_i - \bar{X})(Y_i - \bar{Y})$ would be the product of two positive numbers, which is positive. If the X value and the Y value were both below average, then the product would also be positive. Thus, a positive correlation indicates that large values of X are associated with large values of Y , while small values of X are associated with small values of Y . The correlation coefficient measures the strength of a linear relationship between any two variables and is always between -1 and $+1$. The closer the correlation is to $+1$ or -1 , the closer it is to a perfect relationship. One can also express r in terms of the regression coefficients in Chapter 9 as follows:

$$r = \beta_i \frac{S_X}{S_Y}$$

$$S_X = \sqrt{\sum (X_i - \bar{X})^2} \quad S_Y = \sqrt{\sum (Y_i - \bar{Y})^2} \quad (8.2)$$

The interpretation of r^2 (the square of r) can also be made in terms of variation in the dependent variable Y that is explained by the regression line. Suppose that the total deviation of an actual Y from its mean \bar{Y} can be expressed as the sum of

two non-overlapping components, $(\hat{Y} - \bar{Y})$ and $(Y - \hat{Y})$. The first component represents that part of the total difference explained or accounted by the relationship of Y with X ; the other component represents that part of the total difference remaining after accounting for the relationship of Y with X . Thus, we get:

$$\sum (Y - \bar{Y})^2 = \sum (\hat{Y} - \bar{Y})^2 + \sum (Y - \hat{Y})^2 \quad (8.3)$$

Equation (8.3) can be interpreted as the sum of total variation to be equal to the sum of explained and unexplained variation. The ratio $\sum (Y - \hat{Y})^2 / \sum (Y - \bar{Y})^2$ is the proportion of total variation that remains unexplained by the regression equation. On the other hand, $1 - \sum (Y - \hat{Y})^2 / \sum (Y - \bar{Y})^2$ represents the proportion of the total variation in Y that can be explained by the regression equation. The above ideas can be summarized as follows:

$$\begin{aligned} r^2 &= 1 - \frac{\sum (Y - \hat{Y})^2}{\sum (Y - \bar{Y})^2} = 1 - \frac{\text{Unexplained variation}}{\text{Total variation}} \\ &= \frac{\text{Explained variation}}{\text{Total variation}} \end{aligned} \quad (8.4)$$

Inference about population parameters in correlation

Let us assume a situation in which we have a random sample of n units from a population with paired observations of X and Y for each unit. We want to test the null hypothesis that the population correlation coefficient $\rho = 0$ against the alternative that $\rho \neq 0$. If the computed r values in successive samples from the population were distributed normally, we would have the standard error to perform the usual t -test involving the normal distribution. Thus, we have the following statistic:

$$t = \frac{r - \rho}{S_r} = \frac{r}{\sqrt{(1 - r^2)/(n - 2)}} \sim t_{n-2} \quad (8.5)$$

The standard error of r is given by $\sqrt{(1 - r^2)/(n - 2)}$. Note that the hypothesis testing procedure is in terms of r instead of r^2 .

A few comments may be made concerning the hypothesis testing procedure. First, this technique is only valid for a hypothesized population value of $\rho = 0$. Other procedures such as Fisher's Z transformation³ can be used when the population correlation coefficient is assumed to be different from zero. Second, even though the sample r is significant according to this test, in some instances, the amount of correlation may not be considered important. For example, in a large sample, a low value of r may be found to be different from zero. However, since

little correlation was found between the two variables, it may not be appropriate to infer any association between X and Y for decision-making purposes. Third, the distributions of the t -values computed from equation (8.5) approach the normal distribution as the sample size increases. This is because for large sample sizes, the t -value is approximately equal to z in the standard normal distribution. Thus, the critical values applicable to the normal distribution can be used instead. Finally, in the correlation analysis both X and Y are assumed to be normally distributed random variables. Both variables should be random for hypothesis testing about the value of ρ . In the regression analysis, however, the independent variable X is not a random variable.

Descriptive analysis

We first compute the frequency distribution of the different determinants of nutrition in order to understand general nutritional situation of households in Malawi. Table 8.1 shows the frequency distribution of the various determinants of child nutrition in Malawi.

Table 8.1 displays the frequency distribution of the various indicators that might affect child nutrition. The main areas of concern are education level of the mother (all the mothers in the sample do not have education beyond the primary level), the CARE indicators (such as feeding the child in a clinic and breast-feeding and other complementary feeding) and availability of sanitation facilities. Since better educated mothers usually have better nutrition knowledge, they can make informed decisions regarding good child-care practices, which is one of the pathways through which maternal education might improve child nutrition. Thus, at least in the short and medium term, maternal education seems to

Table 8.1 Frequency distribution of nutritional indicators

Indicator	Cases	Per cent
EDUCSPOUS	No education	52.0
	Adult literacy training	2.8
	Primary education	45.2
CLINFEED	No	80.5
	Yes	19.5
BFEEEDNEW	No	57.2
	Yes	42.8
LATERINE	No	61.1
	Yes	38.9
DIARRHEA	No	83.7
	Yes	16.3
DRINKDST	< 2 km	71.1
	\geq 2 km	28.9
HEALTDST	< 2 km	19.8
	\geq 2 km	80.2

be of great priority. Additionally, for most households (about 80 per cent), the distance to the nearest health clinic is very far (more than 2 km). Such a long distance to a health facility can be an important barrier in the decision to seek modern health care when needed. Thus, a comprehensive nutritional program that addresses health access problems (such as children attending clinic and setting up new health facilities) and improving the level of education of the mother can be very crucial in solving the problem of child malnutrition in Malawi.

Main results

Figures 8.1 and 8.2 provide scatterplots (a geometric representation) of observations on two variables: namely incidence of wasting and distance to a protected water source and underweight with distance to a protected water source. The scatterplot is one of the most useful statistical graphs since it represents data on a two-dimensional plane. The bivariate scatterplot is a natural display of the relationship between any two quantitative variables. As evident from the diagrams, both the incidences of wasting and underweight increase as the distance to the protected water source increases. This is possibly because the risk of bacterial infections and diarrheal diseases increases as the household is located farther from a protected water source which, in turn, affects child nutrition adversely.

Correlation analysis of the outcome variables

We next undertake the correlation analysis among the various anthropometric measures or outcome variables (weight for height, weight for age and height for age Z-scores) in order to understand their degree of association. There are three distinct possibilities in a correlation analysis. First, two sets of variables may show positive correlation (such as dieting and exercise). In other words, as the value of one variable increases, the value of the other variable also increases.

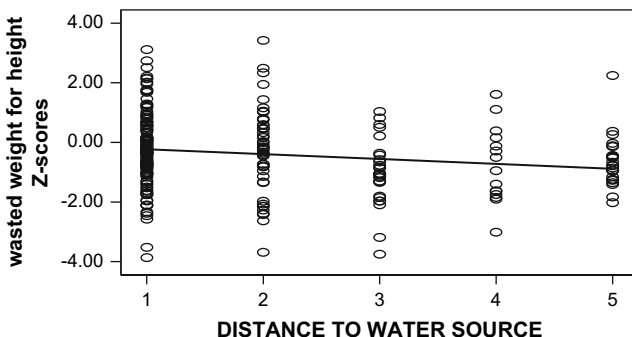


Figure 8.1 Scatterplot of wasting with distance to a drinking water source.

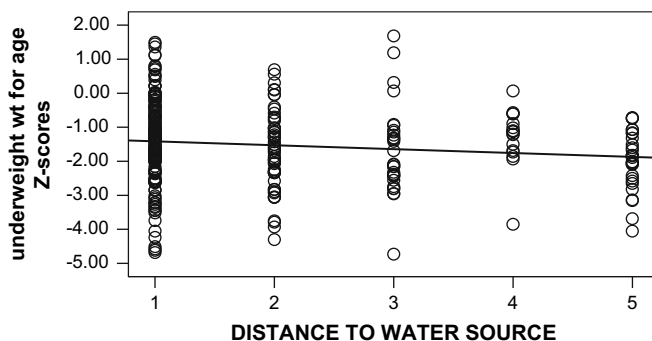


Figure 8.2 Scatterplot of underweight with distance to a drinking water source.

Second, two variables may exhibit negative correlation. In other words, a higher value of one is associated with lower values of the other. Finally, there may be no correlation, i.e. two or more variables may not have any relationship with each other. Correlation can be weak or strong depending on its relative magnitude.

As a rule of thumb, in absolute value terms, the following guideline can be used:

- 0 to 0.2 – weak to negligible correlation
- 0.2 to 0.4 – weak correlation (not very significant)
- 0.4 to 0.7 – moderate correlation
- 0.7 to 0.9 – strong or high correlation
- 0.9 to 1 – very strong correlation.

From Table 8.2, it is evident that stunting (defined as height for age Z-score below -2) and wasting (defined as weight for age Z-score below -2) are very weakly correlated at the 1 per cent level. Since stunting and wasting are usually considered as long-term and short-term indicators of the nutritional status of the child, the low correlation is possibly showing that the determinants of short-term and long-term factors of nutrition are different. On the other hand, the moderate correlation between weight for age (underweight)⁴ and stunting and weight for age and wasting possibly indicate that significant monitoring and evaluation are required, since there is a higher likelihood that a significant proportion of children in Malawi (especially in the rural areas) may suffer from long-term malnutrition problems.

From the descriptive and correlation analysis, it is evident that the main areas that the government of Malawi needs to intervene for a successful nutrition strategy to be effective are:

1. improving the educational level (especially that of females)
2. communicating messages of better care practices (such as timely introduction of breastfeeding and other complementary feeding)

Table 8.2 Pearson correlation coefficient among the various Z-scores

		Stunted height for age Z-scores	Wasted weight for height Z-scores	Underweight wt for age Z-scores
Stunted height for age Z-scores	Pearson correlation	1		
	Sig. (2-tailed)	.		
	N	235		
Wasted weight for height Z-scores	Pearson correlation	-0.160(*)	1	
	Sig. (2-tailed)	0.014	.	
	N	235		
Underweight wt for age Z-scores	Pearson correlation	0.640(**)	0.565(**)	1
	Sig. (2-tailed)	0.000	0.000	.
	N	235	250	276

Notes:

*Significant at the 0.05 level (2-tailed)

**Significant at the 0.01 level (2-tailed).

- improving sanitation facilities in communities where they are lacking, so as to prevent diseases such as diarrhea and other vector borne diseases.

Conclusion and policy implications

Although much progress has been made during the past two decades in tackling the problem of malnutrition (especially in reducing micronutrient deficiencies), a significant proportion of South Asian and African children continue to be malnourished and the numbers are expected to grow in the coming decades. More than 160 million preschool children are underweight and stunted and many are anemic and have vitamin A deficiency. Since malnutrition is not directly observable, it is often overlooked until the problem becomes severe. There are three main reasons for the slow progress in tackling malnutrition. First, it is a complex issue as it encompasses biological and socioeconomic causes. Second, its severity and impact may be ignored even in countries with national nutrition plans. This is because policy makers may fail to understand the urgency and seriousness of the problem. Third, lack of effective organizational skills and design may result in inappropriate programs and strategy such as unaffordable food subsidies.

Thus, understanding the underlying causes of malnutrition may be extremely crucial in developing an effective nutritional strategy. From the existing studies,

it is evident that sustained income growth is necessary for reducing malnutrition. However, income growth by itself is unlikely to reduce malnutrition. Along with income growth, complementary factors such as availability of health care services, maternal education, effective child-care, access to clean water and sanitation, women's relative status and household food security are equally important in tackling the severe problem of malnutrition in developing and developed countries.

From the analysis in the present chapter, it is evident that the main areas of concern in improving the nutritional status of children in Malawi are enhancing the levels of maternal education so that mothers and other care-givers have better health knowledge to undertake better child-care practices. Second, improved sanitation conditions within the household and the community can be an effective way of preventing diseases such as diarrhea which, in turn, can have positive impact on child nutritional status. Also, setting up additional health clinics (both government and private) can be an important tool for modern health care. Plotting the incidence of wasting and underweight with respect to distance to a protected water source, we find that the incidence of wasting and underweight increased as distance to the protected water source increases. From a policy perspective, it seems pertinent to develop a comprehensive nutrition strategy for Malawi that emphasizes not only steady income growth, but additionally highlights improving the levels of mothers' education and setting up additional health facilities in order to tackle the problem of malnutrition.

Exercises

1. Write a correlation syntax for the socioeconomic indicators (PXFD and EDUC-SPOUS), CARE variables (BFEEDNEW and CLINFEED) and community characteristics (DRINKDST, LATERINE, DIARRHEA, and HEALTDST) with ZWA, ZWH and ZHA. In other words, find the Pearson correlation coefficient among the above indicators with the outcome variables. Which indicators are significantly associated with underweight, wasting and stunting? Based on your results, what nutrition interventions will you recommend to the Ministry of Health? How do your results compare with the correlation found with the anthropometric measures?
2. How is correlation analysis helpful in planning for social development programs and formulating nutritional targets?

Notes

1. Malnutrition has been associated with a 10 to 45 per cent increase in the incidence of diarrhea (de Onis et al., 2000). Similarly, vitamin A deficient children are two to four times more susceptible to respiratory disease and twice as susceptible to diarrhea. Costs to the national health system due to poor nutritional status of mothers are substantial. WHO estimates that 1.1 billion days of work time are lost worldwide as a result of various illnesses.

2. The five variables included for nutrient availability and absence of infection were the number of days the child was ill with diarrhea during the past 2 weeks, number of days the child had another illness during the past 2 weeks, whether the child was vaccinated, whether the child was breastfed exclusively and whether the child was born in a hospital.
3. Fisher's Z transformation can be used as follows: $z = \frac{1}{2} \log_e((1+r)/(1-r))$. This statistic is approximately normally distributed with mean $\mu_z = \frac{1}{2} \log_e((1+\rho)/(1-\rho))$ and standard deviation $\sigma_z = \frac{1}{\sqrt{(n-3)}}$.
4. Weight for age is influenced by both the height of the child (height for age) and weight for height. Due to its composite nature, its interpretation is not easy.

9 Effects of individual, household and community indicators on child's nutritional status – application of simple linear regression

Having good health is very different from only being not sick.

Seneca The Younger, 50 AD.

Introduction

Chronic malnutrition in preschool children remains a substantial challenge for developing countries – 178 million children under the age of 5 suffer from stunting (low height for age) as a result of chronic undernutrition (Black et al., 2008). Stunting is associated with higher rates of illness and death, reduced cognitive ability accompanied with lower school performance in children and lower productivity as adults (Cohen et al., 2008). Another 55 million preschool children in developing countries are wasted – lower than expected weight for height – due to acute malnutrition (Black et al., 2008). In addition, each year over 19 million preschool children are born with low birthweights – less than 2.5 kg – accounting for 16 per cent of the developing world's annual births (Cohen et al., 2008). These children face a significantly higher risk of neonatal death than normal birthweight children and, if they survive, have much higher rates of illness and stunting in both childhood and as adults (Black et al., 2008).

Policy makers study the causes of child malnutrition in order to mitigate their effects. Understanding the causes is important, since child malnutrition is one of the severe forms of material deprivations that have intergenerational implications on poverty. Various causes of child malnutrition include poor socioeconomic conditions, inadequate care, maternal malnutrition, large number of dependents, lack of nutritional knowledge, repeated infections and lack of access to health services. It has been estimated that more than 80 per cent of infant deaths are due to mild or moderate malnutrition (Pelletier et al., 1993). Thus, understanding the causal factors and their relative impact on malnutrition is pertinent to devise intervention strategies that can generate better child nutrition and health outcomes.

In addition, it is important to understand the causes of malnutrition, since there is little agreement in the literature on the relative importance of the factors affecting nutritional status. Based on empirical results, some studies stress the importance of parental education and/or nutritional knowledge, while others recommend the need to focus on improving the poverty/income status of households in poor countries (SC UK, 2003; Christiaensen and Alderman, 2004). For example, SC UK (2003) challenges the nutrition component of World Bank funded projects (in Bangladesh, Ethiopia and Uganda), which incorporate growth monitoring as a key strategy to educate mothers as a means of reducing malnutrition in young children. The argument is that these projects are based on the questionable assumption that lack of knowledge, confidence and capacity to solve problems are major causes of malnutrition and that provision of counseling and encouraging women to care for their children will significantly improve nutrition even when families remain trapped in poverty and health and sanitation services are very weak. Thus, while caring practices can contribute to improving child malnutrition, the naïve view that investments in growth monitoring to promote change in care-givers' behavior will necessarily have a significant impact on nutritional status is not well founded. It is therefore critical to understand the individual characteristics, socioeconomic determinants and the community influences on child nutrition in order to develop a more comprehensive policy approach.

In light of the above, this chapter seeks to determine how the various factors (individual, household and community characteristics) affect children's nutritional status as measured by the weight for height Z-score (ZWH). This will be undertaken using a simple linear regression framework. This approach is appropriate since we want to determine how the average score of ZWH changes when an independent variable (causal factor) increases by one standard deviation unit. Thus, we want to determine the unique contribution of the changes in individual, household and community variables on child malnutrition. This chapter is organized as follows. In the next section, we discuss the conceptual framework and indicators of nutritional status. We then review a few studies that examine the role of individual characteristics (such as age of the child), household characteristics (such as maternal education, nutrition knowledge) and community characteristics (such as water and sanitation facilities) on child nutritional status. This is followed by an examination of the role of individual, household and community characteristics on child nutritional status using data from Malawi.

Conceptual framework and indicators of nutritional status

Household utility maximization framework

From an economic perspective, optimum nutritional status can be understood from the perspective of a household that seeks to maximize utility subject to its

time and income constraints. Let the behavioral function of a typical household be as follows¹:

$$U = u(N, H, F, Z, L) \quad (9.1)$$

where N , H , F , Z and L denote nutritional status, health, food, other commodity consumption and leisure time respectively.

The nutritional status of an individual (N) within the household (especially the child) depends on food intake, other commodity consumption (Z), care (C) for children and the health environment vector (Ω). In other words:

$$N = n(F, Z, C, \Omega) \quad (9.2)$$

N refers to nutritional intake as distinct from nutritional outcome such as weight or height. C denotes care received by a typical child, which may consist of exclusive breastfeeding, timely introduction of complementary foods. Ω denotes the health environment, consisting of availability of safe water, sanitation and health services in the household's community.

Health (H) is produced by nutritional intake, food and other commodity consumption, income of the household (I), educational level of the household head (EM), time devoted to health care (TC) and the health environment (Ω). Thus, the health production function is as follows:

$$H = b(N, F, Z, I, EM, TC, \Omega) \quad (9.3)$$

Household production of food F and other commodity (Z) will be dependent on the time needed to prepare it, relevant environmental variables and possibly on the nutritional status of the household head. Additionally, we must have two resource constraints which limit household production and consumption possibilities. The first is the income constraint, which is that household income from all sources must be spent on expenditure on foods and other goods, expenditure on health and care-giving. The second constraint is time, which states that household's time endowment is allocated between labor on the one hand and household production of N , H , F and Z and leisure on the other.

Maximization of equation (9.1) subject to the production constraints of health, nutritional status (as in equations (9.2) and (9.3)), food and other commodities and the household members' time and income constraint determines the nutritional status of a child in any given year as follows:

$$N^* = n^*(\Omega, P, C, I, EM) \quad (9.4)$$

In other words, optimum nutritional status depends on the environmental factors such as access to safe water, sanitation, prices (P) of the food and other non-food items, the household's total income (I), care given by the household to the child, mother's educational level (EM). As explained before, mother's educational level can have an important influence on feeding and caring practices. These knowledge and skills improve the caring practices and thereby positively influence the nutritional status of the child. Having conceptualized in

general terms the important determinants of a child's nutritional status, it is useful to look at some of the critical indicators of nutrition. At the outset, it is important to distinguish between the nutritional outcomes (such as low height for age, low weight for height, body mass index among adults) from the determinants of nutritional status (such as age and sex composition of the household, educational attainment of the household, income, and health environment).

Core indicators of nutritional status

A variety of methods, such as anthropometric, health and demographic approaches, are used to assess the nutritional status of populations (Food and Nutrition Assessment Technical Assistance, 2003). While the anthropometric approach is often used as a proxy to assess the extent and severity of malnutrition, i.e. outcomes from lack of nutrition, the latter two approaches (health and demographic) help in understanding the causal factors and linkages through which malnutrition occurs. We discuss them each in turn.

Anthropometric indicators

Anthropometric indicators are useful both at the individual and population level. At the individual level, they can be valuable for screening children for any intervention required. At the population level, these indicators can be used to assess the nutrition status within a community, country or region and to study the determinants and consequences of malnutrition. Anthropometric survey data often contain measures of weight, height and age of children. It is possible to use these physical measurements to assess the adequacy of diet and growth especially for infants and children. Comparing an individual with a 'healthy' reference group and identifying extreme departures from this distribution could overcome the severity of malnutrition. The three most commonly used anthropometric indicators for children are weight for height, weight for age and height for age.

Weight for height (W/H)

'Weight for height' measures body weight relative to the height of the child. It is normally used as an indicator of current nutritional status and is useful for measuring short-term changes in nutritional status. Low (W/H) relative to a child in the healthy reference group is referred to as 'thinness'. An extreme value of low (W/H) is referred to as 'wasting'. Wasting is often associated with acute starvation as in the case of famine situations or severe disease and may also be the result of a sudden shock on children with chronic malnutrition.

Weight for age (W/A)

'Weight for age' measures body mass relative to the age of the child. Low (W/A) is influenced by the height of the child (height for age) and weight for height. Due to its composite nature, its interpretation is not easy. Low (W/A) relative to a healthy child in the reference population is referred to as 'lightness'. This measure is commonly used for monitoring growth of the child and to understand the severity of malnutrition over time.

Height for age (H/A)

'Height for age' indicates chronic malnutrition or illness and is thus a cumulative indicator of physical growth. Low (H/A) relative to a healthy child of the reference population is referred to as 'shortness'. An extreme case of low (H/A) is referred to as 'stunting'. At the population level, high levels of stunting are associated with increased risk of illness and/or poor socioeconomic conditions over a prolonged period of time.

All the above three measures are usually expressed in the form of Z-scores, which compare the above indicators to a similar child from a healthy reference group. In other words, the Z-score of a child i is the difference between the height of the child (H_i) and the median height of a group of healthy children of the same age and sex from the reference population (H_r), divided by the standard deviation of the height of the same group of children from the reference population σ_r . Thus, the Z-score of height for age (H/A) is defined as:

$$ZHA = \frac{H_i - H_r}{\sigma_r}$$

Similarly,

$$ZWA = \frac{W_i - W_r}{\sigma_r} \quad \text{and} \quad ZWH = \frac{(W/H)_i - (W/H)_r}{\sigma_r} \quad (9.5)$$

Stunted children are commonly defined as more than 2 standard deviations below the median. The two preferred anthropometric indices are stunting and wasting, since they distinguish between long-run and short-run physiological changes. The 'wasting index' (low weight for height) has the advantage that it can be calculated without knowing the child's age. It is particularly useful in the short run in analyzing the current health status of a population and in evaluating the benefits of intervention programs. A disadvantage of this index is that it classifies children with poor growth in height as normal. Stunting (low height for age) on the other hand measures long-run nutritional status of a population, since it uses past nutritional status. WHO (1995) recommends stunting as a reliable measure of overall social deprivation.

Health and demographic indicators

Certain demographic and health indicators can be very useful in understanding various aspects of malnutrition. It is important to emphasize that these indicators should be conceived as determinants or factors that ultimately affect the nutritional status of a population to decline rather than outcomes of lack of nutrition. We discuss three sets of health and demographic indicators: health status indicators, health service indicators and water and sanitation indicators.

Health status indicators

The most commonly used health status measures are discussed below (Skolnik, 2007).

Infant mortality rate

Infant mortality rate can be defined as the number of children less than one year old who die in any given year per 1000 live births. This indicator provides information regarding nutritional conditions such as weaning and reflects other socioeconomic conditions in which the infant grows.

Life expectancy at birth

Life expectancy at birth can be defined as the average number of additional years a person could expect to live if current mortality trends continued for the rest of the person's life. It is a summary indicator of overall health and physical well-being in a country.

Child health conditions (diarrhea and immunization coverage)

Occurrence of diarrhea is one of the main causes for stunted child growth and infant mortality and has a negative impact on child nutritional status. It is not an input of nutrition but rather the outcome of investments in other aspects of health that influence the productivity of inputs into nutrition, or the investment itself. Diarrhea is defined as more than three loose stools passed in a 24-hour period. For children below 5 years, 'diarrheal incidence' may be defined as the ratio of the number of children below 5 years with diarrhea during the last 2 weeks to the total number of children below 5 years.

Similarly, immunization indicators are used to assist operational planning for full immunization coverage and to prevent further diseases. 'Immunization coverage' for children below 1 year is calculated from the number of children fully immunized (defined as the first visit where all the vaccinations are completed) divided by the total number of children below 1 year. The primary course of immunization includes bacille Calmette–Guérin (BCG), three doses of diphtheria-tetanus-pertussis (DTP) and polio, measles vaccine and hepatitis B.

Health service indicators

The commonly used measures to understand availability of health services are as follows (Mcguire, 2006).

Utilization rate

This is defined as the number of visits per person per year to the nearest health facility. This is applicable only in areas and regions where a health facility is available at a reasonable distance.

Health personnel

Along with the data on the number and types of health facilities, data on health personnel are also used as an indicator of physical access to health service. One way of measuring it is to compute the number of health workers as a percentage of total population. However, aggregate measures like this indicator (at the country or regional level) may hide all regional and subregional differences.

Per capita health expenditure

This measure denotes the amount spent on health per person per year. This is also an aggregate measure and does not distinguish between the proportions of population covered by medical schemes from those who are not.

Water and sanitation indicators

Water and sanitation improvements can have a positive and significant impact on nutritional status of a population by reducing a variety of diseases such as diarrhea, guinea worm and skin diseases. Improvement in nutritional status can occur through a variety of mechanisms. Increasing the quantity of water allows better hygiene practices while improving the quality reduces the ingestion of pathogens. With less disease, infants can eat and absorb more food, which improves their nutritional status. Additionally, a healthier adult population can be more productive which, in turn, raises income and the capacity to acquire more food.

Improvements in sanitation can improve the health of the population by lowering the incidence of diarrhea, reducing parasitic infections and ultimately leading to a reduction in morbidity and mortality. Thus, efforts to improve sanitation are worth undertaking as they have community and individual level effects. Improvements in water and sanitation facilities, however, do not automatically translate into improvements in health and nutritional status. Hygiene education is a pre-requisite to have health effects translate into greater nutritional status. Hygiene education consists of hand washing, disposal of feces and protection of drinking water (Billig et al., 1999). The most commonly used water and sanitation indicators are as follows.

Quantity of water used per capita per day

This indicator includes all water collected by or delivered to the household and used for drinking, cooking, personal and household hygiene and sanitation needs by the members of the household. All adults and children in the household are counted. It is assumed that the amount collected is the amount used. It is defined as the ratio of volume of water (in liters) collected for domestic use per day by all households in the sample to the total number of persons in the sample. The above indicator will be measured more precisely if calculated for individual households first and then averaged for the total number of households sampled. This step accounts for the large variations in the number of individuals per household. There are some problems involved in the collection of data for water usage when water is piped directly into the house or compound. Such systems typically are not metered either at the source or at the household and thus total water used in the community cannot be calculated. Additionally, piped water may have leaks or people outside the service area may take water from the household. Under such circumstances, distance to the water source may be an alternative indicator for water use (Billig et al., 1999).

Access to improved water source

Access to an improved water source implies that the home or compound is directly connected to a piped system or a public fountain, well or any other water source that is located within a reasonable distance from the home. It is defined as the ratio of the number of households with access to an improved water source to the total number of households in the sample. The usage can be for drinking, cooking, cleaning and other personal reasons. Unimproved surface water sources, such as rivers, lakes and streams, are not calculated in this procedure.

Percentage of households with access to sanitation

A *sanitation facility* is defined as an excreta disposal facility, typically a toilet or latrine. Access implies that household has a private facility or shares the facility with other people. For urban areas, access to sanitation is defined as being served by connections to public sewers or household systems such as flush latrines, septic tanks, communal toilets and the like. Rural access consists of pour flush latrines, pit privies, etc. It is calculated as the ratio of the number of households with access to a sanitation facility to the total number of households in the sample (Billig et al., 1999).

Review of studies on the determinants of child nutritional status

Below we review a few case studies that examine the determinants of child nutritional status using the framework developed in the above section. The determinants can be classified under child-specific, household characteristics and community characteristics. The child-specific determinants of nutritional status are child's age and gender.

Sahn and Alderman (1997) examined the impact of age specificity (for children below 24 months and those between 25 and 72 months) on child nutritional status. The study used data from Maputo, Mozambique using a randomly selected cluster method consisting of 1816 households. The study defined malnutrition as two standard deviations below the median for height for age Z-scores and found that 32.3 per cent of males and 26.8 per cent of females suffer from chronic malnutrition. The study estimated a reduced form nutrition production function using per capita calorie consumption and birthweight of the child in the aggregate sample (no age differences). Additionally, the production function was estimated with age-specific effects. A number of covariates were also included in the model, such as education dummy variables and information about sanitary facilities.

The main result of the study confirmed that nutrition responds to increases in income and the impact of income is only significant for children 2 years and older. For younger children, mother's education was significant. The above results imply that education and programs that aim at improving child-care practices are appropriate for mothers of younger children.

Guldan et al. (1993) studied how the interaction of maternal education and feeding practices improves child nutritional status. The study was conducted in the Manikganj district in Bangladesh – a rural lowland area situated about 60 miles west of Dhaka. A sample of 185 children aged 4 to 27 months was selected for a 6-month period and the information was gathered through home visits. The main question addressed in the study was whether expansion of education for women promoted child survival through its association with improved infant- and child-feeding practices.

The results of the study consistently demonstrated that educated mothers fed their children in cleaner locations with fewer distractions, where they have more control over the child's meal. Maternal education was also associated with more caretaker initiations of feedings and more attentiveness to the child. Thus, all these behavioral changes would possibly improve child nutritional status. Additionally, the study found that both maternal and paternal education were significant predictors of child-feeding practices and care behavior in rural Bangladesh after controlling for household wealth.

The study provided some policy recommendations for improving child nutritional status. First, the formal education system should be strengthened with an increasing emphasis on health-related components for all family members. Second, since education had a strong impact on feeding practices, it is pertinent to introduce large-scale non-formal education for adults and older children. This will ensure better behavior towards personal and household hygiene, proper weaning practices, feeding children appropriately during and after diarrheal episodes, etc.

Ruel and Menon (2002), using Demographic and Health survey datasets from five countries in Latin America (Bolivia, Colombia, Nicaragua, Guatemala and Peru) between 1994 and 1999, examined the impact of child-feeding practices on child nutritional status. The main objectives of the study were threefold:

1. to assess the feasibility of an age-specific child-feeding index
2. to estimate the strength of association between child-feeding practices and child nutritional status
3. to evaluate whether better feeding practices were more important for some subgroups of children than others.

The main contribution of the study was to identify how care-giving (through better feeding practices) can be a crucial determinant of child nutritional status. The methodology of this study can be used to identify the vulnerable sections of the population that are more likely to benefit from interventions to promote improved child-feeding practices.

Gragnotati (1999), using data from the Guatemalan survey of family health for a survey of 2872 women between the ages of 18 and 35 and a set of community surveys for 60 rural communities for the period May to October 1995, investigates how individual, household and community characteristics affect child nutritional status.

Overall, the results of the study indicated that height for age Z-scores among children varied widely among the communities, with the prevalence of stunting

ranging from 20 to 88 per cent. From the analysis of the community level variables two main findings emerge:

1. more than 90 per cent of the community level variation can be explained by household and community variables
2. altitude accounts for the largest proportion of the overall variation.

Valdivia (2004) explored the impact of public investments in health infrastructure during the 1990s on height for age Z-score. There are several ways through which expansion of public investments in health facilities affect the growth of children. First, by introducing new health care facilities, travel time barriers for mothers are significantly reduced (or the time they have to wait to consult a doctor). Second, building a health facility in a locality that did not have one before, also helps in the organization of the delivery of social services.

The main finding of the study was that mothers' education had a positive and significant impact on child growth consistent with earlier studies. There was also a marginal positive impact of health infrastructure on child height for age. Undertaking the analysis separately for urban and rural areas, the study found that the factors that influence child nutritional outcomes differed significantly. The age effect of the child was more pronounced in the rural areas relative to the urban areas, indicating that some unobserved environmental factors were affecting child growth. The health infrastructure variable was found to have a positive and significant impact on child growth in the urban areas but not in rural areas. There were two plausible reasons for the impact of health infrastructure on the urban areas only:

1. reduction in distance barriers was not enough to benefit rural children
2. cultural factors (such as language barriers) could explain why rural families did not benefit much from augmenting the health infrastructure.

From the analysis of interaction effects, the study found that the only interaction that was significant was education of the mother interacted with health infrastructure, implying that higher benefits occurred to children of less educated mothers. The result can be interpreted as a pro-poor bias in the expansion of health infrastructure. The implication of the above findings suggests that reducing distance and waiting time barriers may be crucial in improving the conditions of the rural poor, but policies that included the indigenous groups must also be taken into account. From the above studies, it is evident that individual characteristics, such as age (younger children are more prone to malnutrition compared to older children; Sahn and Alderman, 1997) and sex of the child, household characteristics, such as income, maternal education and child-care practices and community characteristics, such as health infrastructure, water and sanitation facilities, are all critical determinants of child nutritional outcomes. Since many variables (such as income and maternal education) are associated equally with child nutritional outcomes, it is important to use ordinary least squares regression to explore the bivariate association of one cause at a time. This will allow us to determine the potential explanatory variables that were associated with any of the dependent variable

(child nutritional outcomes) for the multivariate regression analysis developed in Chapter 10.

Empirical analysis and main findings

The critical question examined in the present analysis is how the various factors (individual, household and community characteristics) affect child nutritional status. For this purpose, a bivariate simple regression analysis is undertaken in order to understand the relationship between the dependent variable (child's weight for height Z-score) with the different independent variables. Regression techniques are particularly suitable in the present analysis even when there is correlation among the independent variates (such as in multiple regression framework). For example, even if income and education of the household head are highly correlated, the independent effect of each of these variables on child nutritional status can be properly ascertained in a simple regression analysis framework. In other words, we can determine the independent impact of each of these variables on child nutritional status by looking at the parameter estimates. Another advantage of regression analysis is that it can be used either for continuous or dichotomous variables. A continuous variable, for example, can be converted into a dichotomous variable using specific threshold values of the continuous variate.

Data description

The data collected in Mzuzu, Salima and Ngabu Agricultural Development District (ADD) during 1991–92 represents our sample. It consists of 604 households out of which 197 households had information on 304 children (their height, age, weight) below the age of 5.

The dependent variable in our analysis is weight for height Z-score (ZWH). Since the data were collected on a monthly basis, it is more likely that short-term nutritional status will indicate vulnerability of children over a short period of time. ZWH is defined as the child's weight in relation to the median height of a reference population of that age. In other words:

$$\text{ZWH} = (\text{Observed weight} - \text{median weight}) / \text{Standard deviation}$$

where both the median weight and the standard deviation (how the different values are distributed about the mean) are taken from the normalized growth curves derived from the NCHS /WHO reference values for the given height.

The individual characteristic of the child is measured by age of the child in months (AGEMNTH). The *household* (socioeconomic) characteristics are as follows:

1. education of the household head (EDUCHEAD): a categorical variable which has a value of 1 to 7 and measures the education level of the household head in number of years. Higher values of this variable indicate greater number of years in schooling

2. education of the spouse (EDUCSPOUS): this variable is similarly defined as the education of the household head and denotes the education level of the spouse in number of years. If father's and mother's schooling are complementary factors in improving child's nutritional status, we can expect the coefficients of these variables to be positive. However, if father's schooling substitutes mother's schooling (possibly due to time allocation constraints), we can expect one coefficient to be negative and the other positive
3. total expenditure (LNXTOTAL): the total expenditure of the household and is converted into natural logarithm to ensure normality
4. total food expenditure (LNXFD): the total expenditure devoted by the household on food and related items and is also converted into natural logarithm to ensure normality
5. household size (HHLDQTY): indicates the number of members within a household (including children and other relatives) and is a continuous variable
6. food security (CALREQ): this variable was defined in Chapter 2 and denotes whether the household is able to satisfy at least 80 per cent of the requirement for calorie intake. It is a dichotomous variable assuming two values 0 and 1 respectively, with a value of 1 denoting that the household is food secure.

The CARE variables included in the analysis are as follows:

1. clinic feeding (CLINFEED): a dichotomous variable denoting whether the child is fed in a clinic or not
2. breastfeeding (BFEEDNEW): also, a dichotomous variable denoting whether the child is breastfed or not during his or her infancy
3. number of times child fed during sickness (SICKFEED): a continuous variable denoting how many times a child is fed during sickness. It is not always the case that feeding a child more during periods of sickness improves nutritional status. Optimal feeding (frequency of feeding) accompanied with introducing complementary feeding may be desirable.

Community characteristics included in the analysis are water and sanitation indicators. We did not include the health source (such as hospital) or distance to a health center as independent variables since the coefficients were not significant and adjusted R^2 was negative. They are as follows:

1. water source (WATER): a dichotomous variable assuming 2 values – 0 and 1, indicating unprotected and protected water sources respectively
2. drinking distance (DRINKDST): a categorical variable assuming values from 1 to 4. Higher values denote that the distance to a protected drinking source for the household is higher. For example, the variable attains a value of 4 if the distance to a protected drinking source exceeds 3 km
3. diarrhea: a dichotomous variable denoting whether the child has diarrhea or not.

Incidence of stunting and wasting

We first investigate the prevalence of stunting and wasting for Malawi children. Stunted children are commonly defined as height for age (ZHA) more than 2 standard deviations below the median. Wasting, on the other hand, is defined as

Table 9.1 Percentage of stunted and wasted children

Per cent of stunted children (ZHA ≤ -2)	Per cent of wasted children (ZWH ≤ -2)
44.1	9.4

weight for height more than 2 standard deviations below the median. It usually results from acute food shortages and/or disease (UNICEF). These are the two most preferred measures of child nutritional status, since they distinguish between long-run and short-run physiological changes. The 'wasting indicator' has the advantage that it can be calculated without knowing the child's age. It is particularly useful in the short run in analyzing the current health status of a population and in evaluating the benefits of intervention programs. A disadvantage of the index is that it classifies children with poor growth in height as normal. Stunting (low height for age) on the other hand measures long-run nutritional status of a population, and it takes into account past nutritional status.

It is quite evident that a significant proportion of children (44.1 per cent²) suffer from long-term chronic malnourishment as measured by the height for age Z-score (ZHA) falling below 2 standard deviations below the median (Table 9.1). However, only 9.4 per cent of the children suffer from short-term malnutrition as measured by the weight for height Z- (ZWH) scores. They can also be verified by looking at the mean height for age and weight for age Z-scores. The mean ZHA is -1.76 while the mean of ZWH is -0.38 . Thus, nutrition programs and interventions that can reduce the incidence of chronic malnourishment in the long run are extremely critical for children in Malawi (especially in the rural areas).

Normality tests and transformation of variables

Linear regression often requires that the outcome (dependent) and the independent variables be normally distributed in order for the analysis to be valid. The residuals (the difference between the predicted dependent variable and the observed independent variables) must be normally distributed for the t -tests to be valid. A common cause of non-normally distributed residuals is non-normally distributed dependent and/or predictor variables. Let us start by imposing a normal option to superimpose a normal curve on the dependent variable ZWH (weight for height Z-scores).

From Figure 9.1, it is evident that weight for height Z-score (ZWH) is approximately normal. Now, let us undertake some normality test for total food expenditure (XFD) to determine if this variable is also normally distributed.

Figure 9.2 tests for normality of the total food expenditure. As evident from the figure, total food expenditure by the households is skewed to the right and is not normally distributed. Hence, undertaking a regression analysis of ZWH as the outcome variable and total food expenditure as the independent variable will be inappropriate. Thus, we undertake a natural logarithm transformation of

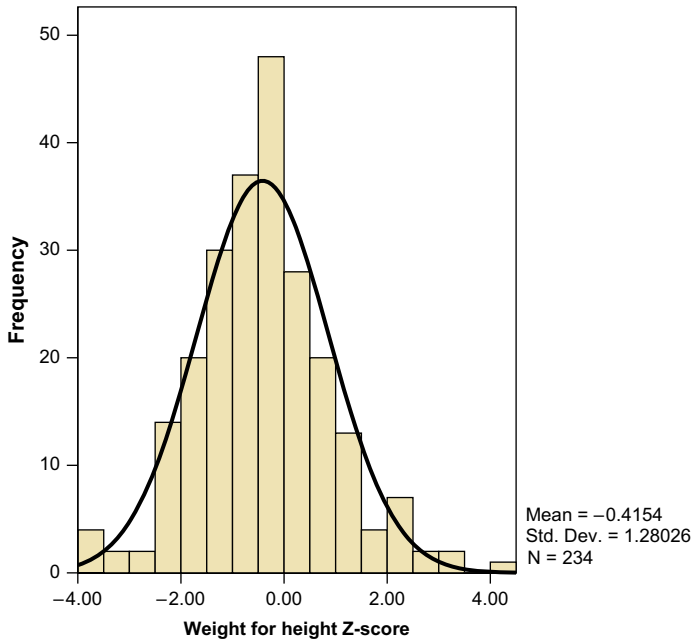


Figure 9.1 Testing normality of ZWH.

XFD and call it LNXFD, in order to determine if this variable is normally distributed or skewed.

As evident from Figure 9.3, LNXFD is much more normally distributed and its skewness is near zero. Thus, taking the natural log of total food expenditure seems to have successfully produced a normally distributed variable and is suitable for regression analysis.

Regression results

First, it may be worthwhile to introduce a few concepts before discussing the results. In the special case of a single independent variable, a regression equation takes the form (Hamburg and Young, 1994):

$$Y = \alpha + \beta X + \varepsilon \quad (9.6)$$

where Y is the dependent variable, β is the regression coefficient corresponding to the independent term, α is the constant or intercept and ε is the residual term. Residual is the difference between the observed values and those predicted by the regression equation. The regression coefficient β is the slope of the regression line, and larger the coefficient, the more the dependent variable changes for each unit change of the independent variable. The coefficient β thus reflects the unique contribution of each independent variable on the dependent variable. The intercept α is the estimated value of Y when X has a value of 0.

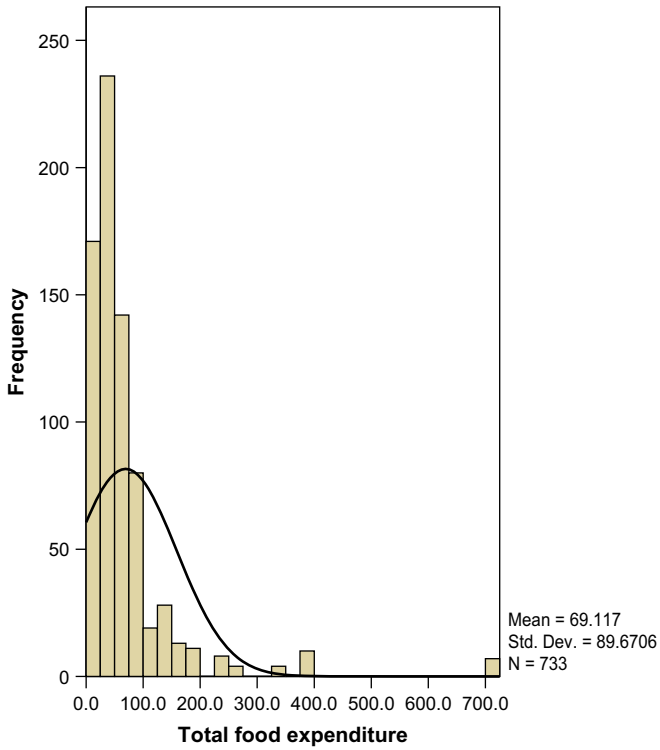


Figure 9.2 Testing normality of expenditure on food.

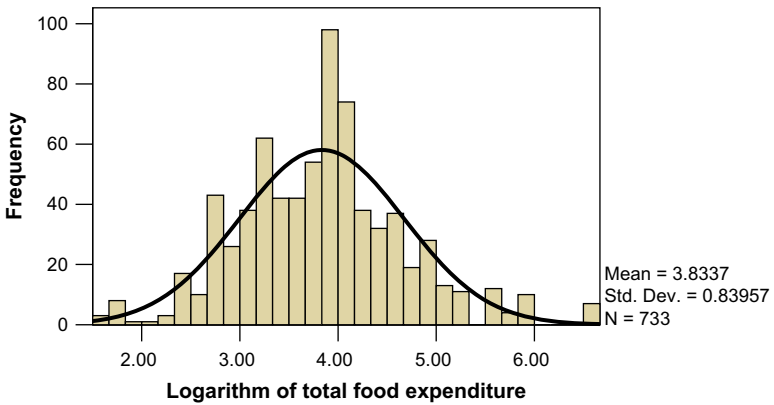


Figure 9.3 Testing normality of logarithm of expenditure on food.

t-tests are used to assess the significance of β in order to test the null hypothesis that $\beta = 0$. A common rule of thumb is to drop the variable or variables not significant at the 0.05 level or higher. R^2 , also called the coefficient of determination, is the per cent of the variance in the dependent variable that is explained uniquely by the independent variables. It can also be interpreted as the proportionate reduction in error in estimating the dependent variable after knowing the independent variables. Mathematically, $R^2 = 1 - (RSS/TSS)$, where RSS is the residual sum of squares and TSS denotes total sum of squares.

F-test is used to test the significance of R^2 , which is the same as testing the significance of the regression model as a whole. If $\text{prob}(F < 0.05)$, the model is considered significantly better than would be expected by chance. One can then reject the null hypothesis of no linear relationship between Y and the independent variables. F is a function of R^2 , the number of independent variables and the number of cases. It is computed with k and $(N - k - 1)$ degrees of freedom, where k is the number of terms in equation (11.6) and N denotes the total number of observations. Mathematically:

$$F = (R^2/k)/(1 - R^2)/(N - k - 1) \quad (9.7)$$

We next look at the regression estimates (along with the significance level) of the individual and household characteristics on weight for height Z-scores. For the sake of brevity, we do not report the estimates of constants.

We undertake the regression analysis with weight for height Z- (ZWH) score as the dependent variable and examine the individual impact of the individual child and household characteristics on ZWH. We select only the child-level observations ($\text{MBRREL} = 3$) in our analysis. The main results are reported in Table 9.2. First, we find that age of the child has a positive and significant impact

Table 9.2 Impact of individual and household characteristics on weight for height Z-scores

Variables	Coefficient	<i>t</i> -statistic	R^2	Prob (<i>F</i>)
AGEMNTH	0.014	2.423	0.025	0.016
EDUCHEAD	-0.085	-1.26	0.007	0.208
EDUCSPOUS	0.100	1.596	0.012	0.112
EDUCHEAD	-0.139	-1.84	0.027	0.053
EDUCSPOUS	0.143	2.14		
LNXTOTAL	0.004	0.04	0.00	0.965
LNXFD	0.116	1.142	0.006	0.255
LNXFD (EDUCHEAD \geq 4)	0.388	2.62	0.054	0.01
HHLQTY	0.047	1.38	0.008	0.168
CALREQ	0.375	1.48	0.009	0.14
CLINFEED	0.324	1.55	0.01	0.123
BFEEDNEW	0.546	3.37	0.04	0.001
SICKFEED	-0.221	-2.959	0.037	0.003

on child nutritional status. This may be because younger children (below 2 years of age) are more likely to be susceptible to diseases than older children. This result is consistent with Alderman and Garcia (1994) that age-specific effects can have differential impact on child nutritional status.

Deprivations during pregnancy, selective mortality (where the less healthy among the poor die early) are possible explanations behind the age-specific effect on child nutritional status. Education variables (education of the household head and the spouse) can have significant influence on child health. Parental education can increase total family resources, affect the mother's cost of time and may also affect the preferences for child health and family size. However, research on the impact of education on child nutritional status is generally ambiguous. Some studies find father's education to be complementary to mother's education, while other studies demonstrate substitution effect. Additionally, the education variable reveals the bargaining strengths of the household head and the spouse and thus the signs of the coefficients for male and female education can be opposite (Mackinnon, 1995). From the regression analysis, we find that education of the household head (usually the male) is negative and insignificant, while the education of the spouse (usually the female) is positive and also insignificant. Thus, we test the null hypothesis whether these two variables are jointly significant. In other words, our null hypothesis is $(\beta_{EDUCHEAD} + \beta_{EDUCSPOUS}) = 0$. This is done using the *F*-test. We reject the null hypothesis and find that, although the coefficients have opposite signs, the education of the spouse is positive and significant. The result possibly reflects that bargaining strengths of the household members (the head and the spouse) are different and that spousal education has stronger influence on child nutritional status.

Another major household resource is income. Since data on income were not available, the analysis relies on expenditure as a measure of permanent income. We use two measures of expenditure to reflect household resources:

1. total expenditure
2. total expenditure on food.

Both coefficients were found to be insignificant. Given the overwhelming evidence that income has an independent impact on improving child health, this result is surprising. Thus, we estimate the impact of total food expenditure on weight for height *Z*-score for the cases where household head had some education level above elementary schooling. We find that one standard deviation change in total food expenditure of these households improves *ZWH* by almost 0.39 points, suggesting that the income effect (through greater spending on food) is coming through education of the household head in increasing the total amount of resources available to the household. The increase in available resources goes in rearing of children and improving their nutritional status.

We find household size and food security (as measured by per capita calorie adult equivalencies) to have no effect on child nutritional status. Thus, food security may not translate necessarily into greater nutritional security. An

Table 9.3 Impact of community characteristics on weight for height Z-scores

Variables	Coefficient	<i>t</i> -statistic	R^2	Prob (<i>F</i>)
WATER	0.21	1.256	0.007	0.21
DRINKDST	-0.142	-2.30	0.02	0.02
DIARRHEA	-0.246	-1.04	0.005	0.296

important point to note from [Table 9.2](#) is that the coefficient of determination (R^2) is very low. This may be due to two main reasons:

1. the nature of the data is cross-sectional (one time period with households from various regions are chosen). In most cross-sectional studies on the determinants of nutritional status, the coefficient of determination is usually low.
2. in the above regression framework, the effect of one independent variable on the dependent variable is investigated. In a multivariate setting (with more independent variables or controls), it is likely that the coefficient of determination will improve.

In regard to the CARE variables, we find that breastfeeding during infancy has a positive and significant impact on child nutritional status consistent with the recent empirical literature on the positive role of care practices on child nutritional status (Ruel and Menon, 2002). However, we find that the feeding during sickness (SICKFEED) has a negative and significant impact on weight for height Z-score. This is possibly either due to measurement error (this variable was originally constructed on a continuous scale without reference to either the age of the child or the kind of food served during sickness) or the lack of nutrition knowledge of the care-giver in the household.

Next, we examine the impact of the community level determinants on child nutritional status.

Water and sanitation improvements can have a positive and significant impact on nutritional status of a population by reducing a variety of diseases such as diarrhea, guinea worm and skin diseases ([Table 9.3](#)). With less disease, infants can eat and absorb more food, which improves their nutritional status. Improvements in water and sanitation facilities, however, do not automatically translate into improvements in health and nutritional status. Hygiene education is a pre-requisite for health effects translating into greater nutritional status. From the regression analysis, we find that only distance to a protected drinking water source has a significant impact on child nutritional status. This is possibly because as drinking distance to a protected water source increases, the household has less access to cleaner water to feed the children. Lower access to protected water sources increases the likelihood of diseases and affects the child nutritional status adversely.

Conclusion

Improved food security does not necessarily translate in improved nutritional status of children (Haddad et al., 1996). Nutritional status of an individual can

be effectively influenced not only by food factors but also through good care practices, improved health care and clean water and sanitation. There is little doubt that household income and other resources play a crucial role in determining both child health and nutrition. Equally important are care factors, such as breastfeeding and complementary feeding practices in improving child nutritional status. Countries that have low rates of antenatal care and low feeding practices can expect substantial returns if nutrition knowledge to women is imparted.

Various authors have also emphasized the role of mothers' education (relative to fathers' education) on child nutrition. However, it is not clear from the existing evidence the mechanisms through which parental education leads to higher knowledge about health and nutrition. It is more likely that the impact of education comes from raising income and these additional resources are invested in improving child nutrition.

Another important determinant of child health and nutrition is health infrastructure and the availability of clean water and sanitation. By preventing infections and diarrhea, a cleaner water and sanitation environment leads to better nutritional outcome.

From our simple bivariate regression framework, it is evident that individual, household (socioeconomic) and community characteristics all significantly matter in influencing child nutritional outcomes. Age-specific effects matter in influencing child nutritional outcome, but so does education of the mother. Increase in food expenditures improves child nutritional outcomes, but only for education level of the household head above a certain threshold level. Thus, income effect is possibly coming through the education level of the household head in generating additional resources. We find care activities significantly to influence child nutritional outcomes, suggesting that it may be as important as income or education. Additionally, we also find community characteristics, such as distance to a protected drinking water source, to have significant impact on child nutritional status.

However, a multivariate regression model is more appropriate in examining how the various determinants affect child nutritional outcome or infant mortality and this will be done in a later chapter.

Exercises

1. Based on the existing literature discussed in this chapter, discuss whether parental education and nutrition knowledge acts as substitute or complementary factors in improving child nutritional status. Justify your answer with appropriate reasoning.
2. Undertake a linear regression analysis with ZHA as the dependent variable and the same independent variables as in the present chapter. Which variables are significant? Interpret your findings in light of the existing evidence on the relationship between individual, household and community characteristics on stunting. (Hint: select the cases with MBRREL = 3 as the unit of analysis.)
3. Select regions 2 and 8 as the unit of analysis separately with ZWH and ZHA as dependent variables and MBRREL = 3 observations only. What are the mean ZWH

and ZHA in these regions? Define new variables ZWHNEW and ZHANEW as follows:

if $(ZHA \leq -2)$ ZHANEW = 0.

if $(ZHA > -2)$ ZHANEW = 1.

and

if $(ZWH \leq -2)$ ZWHNEW = 0.

if $(ZWH > -2)$ ZWHNEW = 1.

What percentage of children are stunted and wasted in each region?

4. What are the causes of child malnutrition? How can the causes of child malnutrition be addressed?
5. How does maternal education correlate with child-care practices in affecting child nutritional status? Discuss critically from the existing studies in this chapter.
6. Carefully examine the role of age-specificity in determining child nutrition after studying the paper by Sahn and Alderman.

Notes

1. We omit superscripts and subscripts to make the analysis simple. The framework is an extended version of Smith and Haddad (2000).
2. Garrett and Ruel (2003) estimate the percent of children stunted to be around 55 per cent using 1992 as the base year.

10 Maternal education and community characteristics as indicators of nutritional status of children – application of multivariate regression

Healthy educated and empowered women have healthy, educated and confident daughters and sons. Gender equality will not only empower women to overcome poverty and live full and productive lives, but will better the lives of children, families and countries as well.

UNICEF 2007 report, *State of the World's Children*.

Introduction

The literature on the welfare of children in developing countries emphasizes the importance of having literate parents and, in particular, of having a literate mother. The nutritional status of children is enhanced by having better educated parents, especially the mother (Booroah, 2002; Pongou et al., 2006). There are both immediate causes of poor health and nutrition, such as lack of access to food, low utilization of health facilities or the poor quality of these facilities and the underlying factors that cause it, such as family income and educational status. The mechanisms through which maternal education affects child health is quite complex (whether through higher wages, better health knowledge, greater child-care or improving the health environment in reducing mortality rates) and thus requires a thorough analysis.

Schultz (1984) argues that mothers' education can influence child health through the following pathways:

1. better educated mothers can be more effective in producing child health for a given amount and mix of health goods (for example, through improved child-care for a given amount of health)
2. schooling can reduce parents' preferences for fewer but healthier children
3. additional schooling raises family incomes either via increased wages or higher productivity which, in turn, can improve child's health status
4. moreover, education raises the opportunity costs of time that tends to decrease the time for child-care.

The purpose of the present chapter is to examine the pathways through which maternal education improves child health and to understand the impact of community characteristics (such as presence of hospitals and better water and sanitation conditions) on weight for age and height for age using a multivariate regression model that controls for other individual characteristics such as child's age. As Schultz (1984) points out, community characteristics can play three major roles in affecting child health:

1. they can reduce the price of health inputs, directly through subsidization of the goods or services, or by increasing access to them indirectly, thereby reducing the travel costs
2. they may provide information of how to produce health more efficiently, such as including information on new inputs, or on efficient practices with traditional inputs such as breastfeeding, bringing the child to a clinic, etc.
3. they can alter the health environment, such as control of malaria and eradication of smallpox.

The issue is important since it addresses policy questions such as: which individual characteristics – including occupation, income and education – play bigger roles? Why do the community factors act differently for different socio-economic groups? The answers to the above questions are important in setting up effective health interventions to improve child health. For example, living in a well-developed community can benefit the disadvantaged household (less educated, lower income) more and function as a substitute to those unfavorable individual characteristics.

This chapter is organized as follows. The next section provides a brief review of the main studies that examine the role of maternal education and community characteristics on child nutritional outcomes. The third section presents the empirical analysis of how individual/household and community characteristics affect child weight for age using a multivariate regression framework, while the final section concludes.

Selected studies on the role of maternal education and community characteristics on child nutritional status

One of the earlier studies by Barrera (1990) addressed why and how mothers' schooling affected child health and whether this impact varied across child age groups. Additionally, the study also examined the pattern of interaction of maternal education with various public health programs in improving child nutrition.

The data came from the Philippines multipurpose survey of 1978 with a supplementary survey during 1981. The sample consisted of 3821 children below the age of 15 from 1383 households. Child health was measured by the height for age Z-scores. The education variable was measured by years of schooling. Water, sanitation and health care variables were also included in the model as proxies for community infrastructure. Household income was measured by the sources of income of the family except mother's cash and non-cash

earnings. Mother's height was used as a proxy for her genetic traits and health endowment. A reduced form equation was estimated where the health of the child was modeled as a function of maternal education, community characteristics and other controls.

Children of more educated mothers had better height for age Z-scores. The impact of maternal schooling, however, varied across the age groups, with preschoolers showing the greatest sensitivity. This is a robust finding as evident from the relatively large coefficients of maternal education for the youngest children. Children of less educated mothers derived greater health benefits from a cleaner environment and water connections, compared to children of more educated mothers. On the other hand, access to health care facilities and toilet connections benefited children of more educated mothers than for mothers with less schooling. These patterns of interactions between maternal education and public health programs suggest that the likely channels through which maternal education might affect child health is by affecting the productivity of health inputs and by lowering the cost of information.

Benefo and Schultz (1996) examined the impact of individual, household and community characteristics that affect fertility in two West African countries – Cote d'Ivoire and Ghana – and analyzed the relationship between child mortality and fertility. The relationship between child mortality and fertility is difficult to conceptualize, since both variables may affect each other, may be modified by other factors and are measured with errors. Thus, both least squares and instrumental variable estimation were used.

The data were obtained from the LSMS surveys conducted by the national statistical agencies in the World Bank during the periods 1985–87 for Cote d'Ivoire and two rounds of surveys for Ghana during the period 1987–88 and 1988–89. The sample consisted of 1943 women in Cote d'Ivoire and 2237 women in Ghana.

The main results of the study can be summarized as follows. First, in examining the determinants of mortality for Ghana, economic resources of households, maternal education and access to markets were all associated with child mortality. Sanitation infrastructure increased child survival but only for children of less educated mothers. There were substitution effects between education of mother and water supplies, implying that more educated mothers were more efficient in reducing health risks. In Cote d'Ivoire, households living at a larger distance from the health clinics experienced higher mortality rates. Since children benefit more from the public health system in Cote d'Ivoire than in Ghana, household assets were not a significant predictor of child mortality. Child survival increased with greater maternal education in both countries. Second, in examining the determinants of fertility, the study found that women's education beyond the primary school level was strongly associated with declines in fertility rates in both countries. However, wealth and socioeconomic status had opposite impact in both countries. In Cote d'Ivoire, assets and maternal health were positively related to fertility, whereas in Ghana these variables were negatively related to fertility.

An indirect policy implication of the study was that a more egalitarian distribution of social services would hasten the decline in child mortality and fertility, if women's education increased more rapidly in the rural areas and rural sanitation and health problems were effectively addressed.

Devi and Geervani (1994) examined the role of child characteristics, parental characteristics and socioeconomic and environmental factors on child health. The study was conducted in four villages in the Medak district of Andhra Pradesh in India, using a 24-hour recall method. One hundred and ninety seven children below 4 years of age were selected from low-income households. Low-income households were selected based on whether the household had at least one preschool child.

From the study, differences in nutritional status of preschool children could be attributed to two main causes. First, children who were vulnerable to more infections during early infancy had higher morbidity and became malnourished. Second, children who did not eat adequate food (possibly because of lack of appetite) were highly vulnerable to diarrheal diseases and consequently became malnourished. Thus, the effects of chronic calorie deficiency and infection were the basic causes of poor nutritional status.

Zhao and Bishai (2004) explored how community factors interacted with various individual characteristics that affected child health. In other words, the study examined which community factors were substitutes or complements to maternal education in improving child nutritional status. The novelty of the study lies in comprehensively specifying community factors such as measures of infrastructure, market activities, water and sanitation conditions and health care services that can affect child health. Additionally, some political and policy features related to child health were also considered as determinants of child health. Finally, the study used analysis from China, where such a study had not been undertaken before.

The dataset used in the analysis came from the China Health and Nutrition Survey (CHNS). The survey covered nine provinces that varied substantially in geography, economic development and health indicators. A cross-sectional analysis using data of children below 10 years of age for the 1993 survey was used in the analysis. A sample of 1848 children was chosen based on anthropometric information (children's height for age), which was then merged with the household and community data.

The main results of the study were as follows:

1. increased access to local infrastructure, basic health services served as substitutes to the household educational levels mainly for the disadvantaged households in reducing child stunting
2. local services that required a certain level of knowledge and skill were complementary to the household level variables in affecting child stunting
3. family planning policy was an extremely important community component in China and the results showed that there was a strong association between stunting and family planning policy.

David et al. (2004) examined the private and public determinants of child health in the context of two Central American countries – Nicaragua and Honduras. Both these countries executed major social programs at the beginning of the 1990s. Honduras executed two major programs, namely the Honduran Social Investment Fund (FHIS) to provide poor communities with basic social infrastructure, such as schools, health centers, water supply and excreta disposal systems, and the PRAF (Family Entitlement Program) that focused more directly on helping poor families, such as providing cash transfers. Nicaragua also initiated similar programs executed by the FISE (Social and Economic Investment Fund) and MIFAMILIA (Ministry of Family). The rationale for these programs was that social investment is currently low in these countries and thus the social returns must be high. However, there was no indication in general of the relative importance of community factors (such as social infrastructure creation) and cash transfer programs on child health, which was the motivation behind this study.

Individual and household level factors (and not the community level factors) were the main determinants of child nutritional status. Maternal endowment, as measured by maternal height, was the key variable in the Honduras sample. Household income came second in relative importance. While educational levels were not significantly related to any of the nutritional status indicators in Nicaragua, in Honduras the primary education of the woman of the household had an impact on height for age and weight for age indicators.

The impact of interaction effects of household income and educational levels were also investigated. In Nicaragua, education of the household head had an independent impact, but only for the higher income bracket. In general, women's education was not significant. In the Honduran case, the educational variable acquired different levels of significance for different quintiles, without any systematic pattern of increasing or decreasing influence across the range of expenditures.

Only in the Honduras sample were few of the community level variables individually significant. The proportion of households with access to tap water and the level of agricultural wages only were significant. In both countries, direct health/nutrition intervention did not have any impact on children's nutritional status. This could be because a food donation to mothers around US \$4 monthly in Nicaragua could be too low to generate a significant change in the feeding patterns.

What is the overall evidence of maternal education and community characteristics on child health outcomes? The answer is mixed. In the case of the Philippines, Barrera found that less educated mothers obtained greater health benefits from water supply and a cleaner environment suggesting complementarity, while Benefo and Schultz (1996) found that better educated mothers obtained greater benefits from child health through better water supply suggesting substitution effects for Ghana. While Barrera found that more educated mothers could take advantage of sanitation facilities thus improving child health in the Philippines, suggesting substitution effect, Benefo and Schultz found that improvement in sanitation facilities improved child survival only for

less educated mothers in Ghana, suggesting complementarities. Yet other recent studies, such as David et al. (2004), demonstrated that community factors were neither complementary nor substitutes with maternal education in affecting child nutritional status.

In light of the above, we investigate the role of maternal education and community characteristics (such as water and sanitation facilities and health infrastructure) on child nutritional status for the case of Malawi. The purpose of the present chapter is to understand if maternal education acts as substitutes or complements to the community infrastructure variables in a multivariate regression framework.

Empirical analysis

It is important to point out at the outset that, while multivariate regression is usually an appropriate framework for investigating the role of individual/household and community characteristics on child nutritional status, a potential endogeneity problem may emerge with a socioeconomic status variable such as income and wealth with nutritional status. In such a situation, it is appropriate to instrument out income using appropriate proxies in the first stage and then the instrumented variable can be used with other variables in a two-stage least squares framework.

The main purpose of the present chapter is to predict the value of the dependent variable (the outcome variable) from the values of two or more independent variables (predictor variables). In our case, we would like to predict the values of weight for age and height for age Z-scores from the values of individual/household and community characteristics. We introduce some technical details and notations before proceeding to the main analysis. The general form of a regression model is as follows (Tabachnick and Fidell, 2001):

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_k X_{ik} + \varepsilon_i \quad (10.1)$$

where $i = 1, 2, \dots, k$ and ε_i follows a normal distribution with mean 0 and variance σ^2 . X_{ij} denotes the j^{th} independent variable for the i^{th} observation. When the above equation is applied to the data, it yields a set of predicted values \hat{Y}_i for which the sum of the $(Y_i - \hat{Y}_i)$ values over all the k cases is a minimum. β_0 is the mean response when all the other independent variables are equal to zero. β_i is the expected change in Y_i per unit increase in X_i . One can obtain the least squares estimates¹ for the regression coefficients in equation (10.1), but this will not be undertaken in the present analysis. The standard errors of the parameter estimates (β_i) can be calculated using the following formula:

$$SE(\beta_i) = \left(\frac{s_y}{s_i} \right) \sqrt{\frac{1}{(1 - R_i^2)}} \sqrt{\frac{(1 - R_y^2)}{n - k - 1}} \quad (10.2)$$

where s_y is the standard deviation of the dependent variable, s_i is the standard deviation of X_i , R_y^2 is the multiple correlation coefficient between the dependent

variable and all the independent variables and R_i^2 is the multiple correlation between X_i and the other independent variables. One can also compare an estimated regression coefficient to a specific value and perform a hypothesis test of a point estimate as follows:

$$\begin{aligned} \circ H_0 : \beta_i &= \beta_{null} \\ \circ H_1 : \beta_i &\neq \beta_{null} \\ \circ t &= \frac{\beta_i - \beta_{null}}{SE(\beta_i)} \end{aligned} \quad (10.3)$$

where β_i is the estimate of β_i , the standard error of β_i is given by equation (10.2) and the degrees of freedom are $(n - k - 1)$. The above test is undertaken to determine whether a given predictor variable can independently account for a significant amount of the variability of the dependent variable.

Applying the regression equation to the independent variables yields a set of estimated \hat{Y}_i values. The simple correlation between Y and \hat{Y} is the multiple correlation coefficient and is given by:

$$R_y^2 = \sum_{i=1}^k R_{yi}\beta_i \quad (10.4)$$

The summation is over all the independent variables and β_i is the standardized regression coefficient for X_i . The semipartial (or part) and partial correlation between each independent variables and the dependent variable is given by the following formulas:

$$sr_i = \beta_i \sqrt{(1 - R_i)} \quad (10.5)$$

$$pr_i = \frac{\beta_i \sqrt{(1 - R_i)}}{\sqrt{1 - R_{y \cdot (i)}}} \quad (10.6)$$

As defined above, R_i is the multiple correlation between X_i and all the other independent variables and $R_{y \cdot (i)}^2$ is the multiple correlation between the dependent variable and all the independent variables except X_i . As explained in Chapter 7, the total sums of squares (TSS), i.e. the total amount of variability in the dependent variable, can be partitioned into the sum squares between (SSB) and sum of squares within (SSW) or the sum of squared errors. The coefficient of multiple determination (R_y^2) can also be computed as follows:

$$R_y^2 = \frac{SSB}{TSS} = \frac{\sum (\hat{Y}_i - \bar{Y})^2}{\sum (Y_i - \bar{Y})^2} = \sum_{i=1}^k R_{yi}\beta_i \quad (10.7)$$

Having obtained R^2 , the question arises with what degree of confidence can we assert the linear relationship between the set of k independent variables and Y

being not zero in the population? In other words, we want to determine if the collection of the independent variables accounts for a significant portion of the variance in the dependent variable. Thus, the following hypothesis needs to be tested:

$$H_0 : \beta_1 = \beta_2 \dots \dots \dots = \beta_k = 0$$

$$H_1 : \text{at least one } \beta \neq 0.$$

To conduct this test, the following statistic needs to be computed:

$$F = \frac{MSB}{MSW} = \frac{\frac{\sum(\hat{Y}_i - \bar{Y})^2}{k}}{\frac{\sum(Y_i - \hat{Y}_i)^2}{(n - k - 1)}} = \frac{R^2(n - k - 1)}{(1 - R^2)k} \quad (10.8)$$

The above distribution follows an F distribution with k as the numerator and $(n - k - 1)$ as the denominator degrees of freedom. One needs to look at the tests of individual coefficients to determine if the overall F is significant.

Data description and methodology

Following Strauss and Thomas et al. (1995), a reduced form demand function for child nutritional status (N^*) can be specified in terms of a vector of individual characteristics of the child, such as age (X_{IC}), household level variables such as income and educational level of the mother (X_H), and community level factors (X_C), such as water and sanitation conditions, health services, etc. Thus, we can write the reduced form demand function for child's nutritional status as follows:

$$N^* = n(X_{IC}, X_H, X_C, \varepsilon) \quad (10.9)$$

ε is a random error term that reflects heterogeneity in individual taste, health endowment and other unobserved factors.

The outcome variables for our analysis are weight for age (ZWA) and height for age (ZHA). These are computed in terms of Z-scores using the NCHS/WHO reference values. The Z-score is defined as the difference between the value for an individual (weight or height) and the median value of the reference population for the same age or height, and divided by the standard deviation of the reference population. A low height for age (often referred to as stunting) results from long-term poor health and nutrition and is often regarded as a stable indicator of child nutritional status, since it is not subject to short-term fluctuations. Stunting in infancy and early childhood often has adverse consequences for later life, such as reduced productivity and increased reproductive and maternal health risks (WHO, 1995).

On the other hand, low weight for age is influenced both by the height of the child (height for age) and weight (weight for height). Its composite nature makes the interpretation complex. One of the drawbacks of this measure is it fails to

distinguish between short children of adequate body weight and tall thin children. This indicator can also reflect the long-term nutritional experience of the population. The X_{IC} vector consists of age of the child in months (AGEMNTH), and the squared term of child age (AGESQ). We include this quadratic term since there was a curvilinear relationship (with bivariate plots) between age of the child and nutritional status as measured by both height for age and weight for age Z-scores. The rationale for such a relationship stems from the fact that younger children are more vulnerable to various diseases such as diarrhea, malaria, etc., and thus are more prone to malnutrition than older children.

The X_H vector consists of the following variables:

1. per capita expenditure on food (PXFDF): this variable is used as a proxy for income since per capita food expenditure varies between 75 and 90 per cent of total per capita expenditure for most of the households. Income is a central variable in models of child health and nutrition outcomes. More resources available to the household can translate into higher expenditures on food and non-food items (such as health). However, as suggested by Chamarbagwala et al. (2004), including income can create two potential problems: first, households can smooth consumption over a certain period of time and thus expenditure is the preferred measure and, second, since income is endogenously determined with child nutrition, including income as a right-hand side variable in a multiple regression framework can result in biased estimates. Thus, we use per capita food expenditure as a proxy for income, since food constitutes an important component of household expenditure. The variable is computed by taking the ratio of total food expenditure to the household size.
2. education of the spouse (EDUCSPOUS): a categorical variable with values ranging from 1 to 7. This variable measures the education level of the mother in number of years. Higher values of this variable indicate greater levels of education.
3. food security (CALREQ): this variable is based on whether the household can satisfy at least 80 per cent of the requirement for calorie intake. This variable is dichotomous assuming two values 0 and 1 respectively, with a value of 1 denoting that the household is food secure. We also use the INSECURE variable as another measure of food insecurity in the determination of stunting, since a large number of dependents accompanied with less number of meals can cause children having less number of meals as well.
4. MBRSEXNEW: this variable is dichotomous in nature assuming two values 0 and 1, with 1 denoting that the member is male.

The CARE variables included in the analysis are as follows:

1. clinic feeding (CLINFEED): a dichotomous variable denoting whether the child is fed in a clinic or not
2. breastfeeding (BFEEDNEW): this is also a dichotomous variable denoting whether the child is breastfed or not during his or her infancy
3. child attending clinic (ATTCLINI): a continuous variable denoting how many times the mother took the child to a clinic during his or her illness. One can expect that the greater the availability of public health services (such as general and specialized health facilities, number of maternity clinics, health clinics and doctors) in a region,

the lower is the risk of the child suffering from malnutrition. For example, the WHO guidelines for the Integrated Management of Childhood Illness (IMCI) recognizes that many children attending a health clinic and not having previous weight record should undergo monitoring of their growth chart for weight for age. This is important as severe malnutrition can be identified and the necessary steps can be taken for prevention².

The *community characteristics* vector (X_C) consists of the following set of variables:

1. drinking distance (DRINKDST): a categorical variable assuming values from 1 to 5. Higher values of this variable denote that the distance to a protected drinking source for the household is higher. For example, the variable attains a value of 4 if distance to a protected drinking source exceeds 3 km. We can expect that the greater the distance to a protected water source, the more is the likelihood that children will suffer from malnutrition.
2. provision of sanitation (LATERINE): a dichotomous variable assuming two values 0 and 1, with 0 indicating absence of latrine from the household. Sanitation appears more important in nutritional outcomes than the presence of protected drinking source, since it is directly related in preventing diarrhea, thereby improving children's nutritional status.
3. DIARRHEA: a dichotomous variable indicating whether the child has diarrhea. This variable assumes two values 0 and 1. 1 indicates that the child had diarrhea during the survey.
4. distance to a health facility (HEALTDST): a categorical variable denoting the distance of the household to a health clinic and assumes four values. Higher values indicate that the household is located farther from the nearest health center. For example, a value of 4 indicates that the distance to the nearest health clinic for the household is more than 10 km.

Descriptive summary of independent variables

We first look at a few descriptive summaries of the independent variables, such as mean and standard deviation, in order to understand the individual, household and community characteristics of the sample. Table 10.1 provides the summary.

The average age of the child in the sample is about 27 months. In regard to the household level (or socioeconomic) variables, we find that the mean per capita expenditure on food (which proxies income) is about 9 kwacha, with the range being 190.5. There is a significant variation in income among the households, with the standard deviation being 9.85. The average year of education for the mother is 2.23 years, which implies that most mothers do not have education beyond grades 1 to 4. The mean value of calorie requirements met (CALREQ) was 0.32, indicating that most households on an average were not food secure. Although the main pathways through which the nutritional status of children can be improved (such as income and maternal educational status) are not large enough, the mean of the CARE indicators (such as bringing the child to clinic during periods of sickness) are

Table 10.1 Means and standard deviations of variables: Malawi sample

Variables	Mean	Standard deviation
BFEEDNEW	1.57	0.49
DIARRHEA	0.16	0.37
CALREQ	0.32	0.47
ATTCLINI	1.32	0.59
AGEMNTH	27.29	16.28
CLINFEEED	2.29	4.57
DRINKDST	1.98	1.39
EDUCSPOUS	2.23	1.30
LATERINE	0.40	0.49
PXFD	9.00	9.85

quite high. It is quite likely that good care practices can mitigate the negative effects of low income and low maternal schooling on child nutritional status.

In regard to the community level variables, the mean distance to a protected water source is about 1.98, which indicates that, on average, households have to travel anywhere between 1 to 2 km to reach a protected water source. Additionally, the mean value of LATERINE for this sample is about 0.4, indicating that on an average most of the households do not have adequate access to sanitation facilities.

Main results

As explained before, model formulation involves selecting a mathematical model that best fits the data. We first fit the model with weight for age as the dependent variable and then undertake the same exercise with height for age as the dependent variable. The following steps are required in a multivariate regression framework.

Step 1: Estimating the coefficients of the model

Tables 10.2 and 10.3 show a reduced form demand function for child nutritional status based on weight for age and height for age as the dependent variables respectively. The coefficients are estimated using least squares method, which results in the smallest sum of squares differences between the observed and the predicted values of the dependent variable. We estimate two models for weight for age. In the first model, we include per capita expenditure on food as one of the regressors to examine the impact of household income on underweight. In the second model, we exclude the impact of income and examine the impact of per capita calorie requirements on underweight. This is done in order to determine if household food security independently affects child nutritional status excluding the impact of income.

Table 10.2 Determinants of weight for age Z-scores

Variables	Model 1		Model 2	
	Coefficients	Std. error	Coefficients	Std. error
Constant	-3.03	0.504	-2.93	0.492
EDUCSPOUS	0.173	0.058	0.156	0.057
ATTCLINI	0.439	0.144	0.439	0.142
DRINKDST	-0.143	0.051	-0.147	0.05
LATERINE	0.134	0.152	0.152	0.148
PXFD	0.009	0.008		
AGEMNTH	-0.084	0.021	-0.088	0.021
AGESQ	0.001	0.0003	0.001	0.0003
CLINFEED	0.717	0.181	0.699	0.179
DIARRHEA	-0.608	0.201	-0.620	0.198
BFEEDNEW	0.664	0.226	0.625	0.224
CALREQ			0.566	0.212
HEALTDST	-0.094	0.071	-0.06	0.072

Table 10.3 Determinants of height for age Z-scores

Variables	Model 1		Model 2	
	Coefficients	Std. error	Coefficients	Std. error
Constant	-2.159	0.677	-2.564	0.685
EDUCSPOUS	0.048	0.072	0.106	0.074
ATTCLINI	0.514	0.180	0.402	0.177
DRINKDST	-0.024	0.064	-0.018	0.062
LATERINE	0.072	0.192	0.114	0.185
PXFD	0.014	0.01		
AGEMNTH	-0.091	0.034	-0.094	0.034
AGESQ	0.001	0.0004	0.0009	0.0004
CLINFEED	0.686	0.227	0.761	0.224
DIARRHEA	-0.829	0.261	-0.932	0.260
BFEEDNEW	0.149	0.305	0.174	0.299
INSECURE			0.252	0.085
HEALTDST	-0.106	0.092	-0.127	0.091

From the above coefficients, the equations to predict the weight for age Z-scores for model 1 for example, can be written as:

$$\begin{aligned}
 ZWA^{pred} = & -3.03 + 0.173EDUCSPOUS + 0.439ATTCLINI \\
 & -0.143DRINKDST + 0.134LATERINE + 0.009PXFD \\
 & -0.084AGEMNTH + 0.001AGESQ + 0.717CLINFEED \\
 & -0.608DIARRHEA + 0.664BFEEDNEW \\
 & -0.09HEALTDST
 \end{aligned} \tag{10.10}$$

The regression coefficient for an independent variable tells us how much the standard deviation units of the dependent variable changes for a one-unit change in the independent variable, when all the other independent variables are held constant. For example, ZWA^{pred} changes by 0.173 units for a unit change in EDUCSPOUS when the other independent variables are held constant.

Table 10.3 provides the estimates of the determinants of height for age Z-scores. As before, we estimate two models for height for age Z-scores. In the first model, the impact of income on stunting is examined while, in the second model, the income effect is separated out and the impact of food insecurity as measured by INSECURE is examined. This variable is included as the regressor, since it fits the data better as a determinant of long-term nutritional status.

Table 10.3 shows that the impact of maternal education on stunting significantly declines compared to the determinants of underweight. On the other hand, health environmental conditions, such as the prevalence of diarrhea, have a larger impact on stunting after controlling for the impact of the other independent variables.

Step 2: Examining how good the model predicts

A reasonable way to determine if the model fits the data is to compare the observed and predicted values of the dependent variable. Tables 10.4 and 10.5 provide some measures based on the correlation between the observed and predicted values for weight for age and height for age regressions.

Multiple R is the correlation coefficient between the observed and predicted values and ranges in value from 0 to 1. The coefficient of multiple determination (R^2) (equation (10.7)) is given in the third columns of Tables 10.4 and 10.5 respectively. It shows the proportion of variability in the dependent variable explained by the regression equation. It is the square of the coefficient of multiple determination and is an important statistic in regression analysis.

Although this coefficient is small for both weight for age and height for age Z-score regressions, it is consistent with other studies³. Adjusted¹ R^2 (\tilde{R}^2) corrects for R^2 being an optimistic estimate of how well the model fits the population. The greater the number of independent variables, sample R^2 is likely to be larger than the population R^2 . Thus, one naturally prefers an estimate of the population R^2 that is more accurate than the positively biased sample R^2 . As can be seen from column (4) of the tables, this estimate is always smaller in magnitude than the sample R^2 . The magnitude of this decline will be greater for

Table 10.4 Summary of the model for determinants of weight for age Z-scores

Models	R	R^2	Adjusted R^2	Std. error of the estimate
1	0.488	0.238	0.203	1.09
2	0.506	0.256	0.222	1.079

¹ $\tilde{R}^2 = 1 - (1 - R^2) \frac{(n-1)}{(n-k-1)}$

Table 10.5 Summary of the model for determinants of height for age Z-scores

Models	R	R ²	Adjusted R ²	Std. error of the estimate
1	0.418	0.174	0.13	1.285
2	0.448	0.201	0.157	1.265

small values of R^2 than for larger values, other things being equal. Additionally, the magnitude of the decline will also be larger as the ratio of the number of independent variables to the number of observations in the sample increases. Finally, the standard error of the estimate is the standard deviation of the residuals (standard deviation of $Y_i - \hat{Y}_i$). For a successful regression model, the standard error of the estimate should be considerably smaller than the standard deviation of the dependent variable. In other words, we want the observations to lie near the regression line.

Step 3: Hypotheses testing

If one needs to draw conclusions about the population from the sample results, the error term ε_i in equation (10.1) must satisfy the following properties:

1. the errors have a normal distribution
2. the errors in the model are all independent
3. the same amount of error is found at each level of X . The implication is that the average difference between the regression line and the observed values is constant across all values of the independent variables. Having equal variance at each level of X is known as ‘homoscedasticity’, while having unequal variance is called ‘heteroskedasticity’.

Tests about the equation

There are several hypotheses tests in a multiple regression output, but all of them try to determine whether the underlying model parameters are actually zero. The first question that may be asked is: ‘is the multiple regression model any good at all?’. In order to address the above question, we want to test the null hypothesis in equation (10.1) as:

$$H_0 : \beta_1 = \beta_2 = \dots = \beta_k = 0 \quad (10.11)$$

The alternative hypothesis is that the slope coefficients are not all equal to zero. The null hypothesis can be tested using the F -statistic as given by equation (10.8). The following analysis of variance (ANOVA) tables (Tables 10.6 and 10.7) divides the observed variability in the dependent variables (namely weight for age and height for age Z-scores) into two parts: the regression sum of squares (SSB) and the residual sum of squares (SSW). The total sum of squares is the sum of these two numbers. We can derive the coefficient of multiple determination (R^2) by dividing the regression sum of squares by the total sum of squares.

Table 10.6 Analysis of variance table for weight for age Z-scores

Models		Sum of Squares	df	Mean Square	F	Sig
I	Regression	89.139	11	8.104	6.797	0.00
	Residual	284.936	239	1.192		
	Total	374.075	250			
II	Regression	95.757	11	8.705	7.475	0.00
	Residual	278.318	239	1.165		
	Total	374.075	250			

Table 10.7 Analysis of variance table for height for age Z-scores

Models		Sum of Squares	df	Mean Square	F	Sig
I	Regression	70.948	11	6.45	3.901	0.00
	Residual	335.649	203	1.653		
	Total	406.597	214			
II	Regression	81.525	11	7.411	4.628	0.00
	Residual	325.072	203	1.601		
	Total	406.597	214			

The observed significance level for the F -statistic tells us if the null hypothesis can be rejected as in equation (10.11).

As is evident from Tables 10.6 and 10.7, the coefficient of multiple determination (R^2) of Tables 10.4 and 10.5 can be obtained as the ratio of the regression sum of squares to the total sum of squares. For example, for model 1 of determinants of weight for age Z-scores, the ratio of regression sum of squares to the total sum of squares is $(89.139/374.075) = 0.238$. The computation of the F -values from equation (10.8) can be demonstrated as follows for model 1 of the weight for age regressions:

$$F = MSB/MSW = 8.1035/1.1922 = 6.797.$$

The critical value of F for 11 and 239 degrees of freedom at the significance level $\alpha = 0.05$ is 1.84. Since the obtained F value exceeds the critical value, we can infer that the slope coefficients are not all zero and conclude that the multiple regression model is better than just using the mean.

Tests about individual coefficients

Even if the null hypothesis is rejected, it does not mean that all of the variables in the equation have regression coefficients that are significantly different from zero. In order to test whether a particular coefficient is zero, we first look at the column labeled t in Tables 10.8 and 10.9, which are derived from Tables 10.2 and 10.3 respectively. This column is computed by dividing each coefficient by its standard error and using equation (10.3). The degrees of freedom are

Table 10.8 Tests of individual coefficients for determinants of weight for age Z-scores

Variables	Model 1		Model 2	
	<i>t</i> -stat	<i>P</i> value	<i>t</i> -stat	<i>P</i> value
Constant	-6.016	0.00	-5.956	0.00
EDUCSPOUS	2.987*	0.003	2.70*	0.007
ATTCLINI	3.047*	0.003	3.102*	0.002
DRINKDST	-2.817*	0.005	-2.938*	0.004
LATERINE	0.882	0.378	1.03	0.304
PXFD	1.185	0.237		
AGEMNTH	-4.041*	0.000	-4.282*	0.00
AGESQ	3.096*	0.002	3.386*	0.001
CLINFEED	3.966*	0.00	3.911*	0.00
DIARRHEA	-3.018*	0.003	-3.126*	0.002
BFEEDNEW	2.935*	0.004	2.791*	0.006
CALREQ			2.668*	0.008
HEALTDST	-1.32	0.188	-0.851	0.396

Note: * denotes at 1 per cent level of significance.

Table 10.9 Tests of individual coefficients for determinants of height for age Z-scores

Variables	Model 1		Model 2	
	<i>t</i> -stat	<i>P</i> value	<i>t</i> -stat	<i>P</i> value
Constant	-3.187	0.002	-3.745	0.000
EDUCSPOUS	0.661	0.509	1.437	0.152
ATTCLINI	2.863*	0.005	2.273**	0.024
DRINKDST	-0.37	0.712	-0.286	0.775
LATERINE	0.375	0.708	0.615	0.539
PXFD	1.479	0.141		
AGEMNTH	-2.642*	0.009	-2.78*	0.006
AGESQ	1.949**	0.053	2.022**	0.044
CLINFEED	3.018*	0.003	3.394*	0.001
DIARRHEA	-3.171*	0.002	-3.584*	0.00
BFEEDNEW	0.489	0.625	0.580	0.563
INSECURE			2.977*	0.003
HEALTDST	-1.15	0.252	-1.395	0.164

Notes: * denotes at 1 per cent level of significance; ** denotes at 5 per cent level of significance.

given by $(n - k - 1)$. The purpose is to determine the independent impact of individual/household and community characteristics on child nutritional status as measured by weight for age and height for age Z-scores.

Comparing Tables 10.8 and 10.9, we find that while maternal education has a positive and significant impact on child nutritional status as measured by weight for age Z-scores, it does not have a significant effect on height for age Z-scores.

The above result is puzzling given that many studies in the literature find a positive and significant impact of maternal education on stunting, which is a long-run measure of child nutritional status. We provide two reasons behind this result:

1. maternal education may be instrumented out using suitable proxies of health knowledge (as in Glewwe, 1999) and then two-stage least squares model may be applied.
2. it is possible that the community variables and the care factors included in the model may have taken away some of the associations between maternal education and stunting.

It is also important to emphasize that after controlling for the dummy variable for Mzuzu and excluding some community level variables (such as distance to a health facility, distance to a protected water source and sanitation facilities) as regressors from the model, both education and income turn out marginally significant (at the 10 per cent level). Our results also indicate that per capita food expenditure (a proxy for household income), although positive was not significant for both weight for age and height for age Z-scores. This may be because of two main reasons:

1. after controlling for mothers' education, income does not significantly affect child nutritional status.
2. income and nutrition may be jointly determined and income may be instrumented out using suitable asset proxies in the first stage, and then the instrumented value may be used in a two-stage least squares framework.

Turning now to the CARE variables (such as attending the child to a clinic, breastfeeding and feeding the child in a clinic), we find that their individual impact is positive and significant on weight for age Z-score and height for age Z-score. However, we did not find breastfeeding to be significant in the height for age Z-score regressions. This is consistent with the existing literature (Ruel et al., 1999), which suggests that proper care of the child can be extremely crucial in improving child's nutritional status in the medium and long run. However, food security (as measured by per capita calorie requirements met or as measured by INSECURE) turns out to be positive and significant suggesting that, after controlling for the household and community level variables, food security at the household level has a positive and significant impact on child's nutritional status.

Examining the impact of age-specific effects on child nutritional status, we find that younger children are more prone to suffer from malnutrition compared to older children. This is evident from the coefficient of the age term (AGEMNTH) being negative and significant, while the coefficient of the squared term to be positive and significant in both the regressions. This is also consistent with the existing literature (see, for example Sahn and Alderman, 1997 and Glewwe, 1999) that younger children are more prone to malnutrition than older children. In regard to the community infrastructure variables, we find that, in general, most of the community level variables are not significant, except for drinking distance of the household to a protected water source in the weight for age regressions. This variable, however, is not significant in the height for age regressions. However, since the impact of diarrhea prevalence on child malnutrition is negative and

significant in both the regressions, it is likely that this variable is capturing the impact of poor water and sanitation conditions.

Part and partial correlation coefficients

Two other statistics that are usually used to assess the contribution of an independent variable to an existing model are part (or semipartial) and partial correlation coefficients, the formula of which are given in equations (10.5) and (10.6) respectively. Both of these measures can range in value from -1 to $+1$. Intuitively, the part correlation coefficient provides unique information about the dependent variable that is not available from the other independent variables in the equation. In other words, it is the correlation coefficient between the dependent variable and the residuals of an equation in which the other independent variables in the model are used to predict the dependent variable. The partial correlation coefficient, on the other hand, is the correlation between the independent variables and the dependent variable when the linear effects of the other independent variables have been removed from both the dependent and the independent variables (Lowry, 2003). We will only report the part and partial correlation coefficients when the income effect is considered (that is model 1), for the weight for age and height for age regressions (Table 10.10).

It is important to note here that even if variables are related to each other, this does not necessarily imply that one causes the other.

Step 4: Checking for violations of regression assumptions

Detecting influential observations

Even before undertaking the regression analysis, it is important to diagnose outliers in the model. The presence of outliers (influential observations) can

Table 10.10 Part and partial correlation coefficients for weight for age and height for age

Variables	Weight for age		Height for age	
	Part correlation	Partial correlation	Part correlation	Partial correlation
EDUCSPOUS	0.169	0.190	0.042	0.046
ATTCLINI	0.172	0.193	0.183	0.197
DRINKDST	-0.159	-0.179	-0.024	-0.026
LATERINE	0.05	0.057	0.024	0.026
PXFD	0.067	0.076	0.094	0.103
AGEMNTH	-0.228	-0.253	-0.168	-0.182
AGESQ	0.175	0.196	0.124	0.136
CLINFEED	0.224	0.248	0.192	0.207
DIARRHEA	-0.17	-0.192	-0.202	-0.217
BFEEDNEW	0.166	0.187	0.031	0.034
HEALTDST	-0.075	-0.085	-0.073	-0.08

influence the slope and/or intercept of the regression model (Tabachnick and Fidell, 2001). Including these observations will thus result in the estimates being biased. The vertical distance of a point from a regression line is called the ‘residual or deviation’, while the horizontal distance of a point from the mean is called ‘leverage’. ‘Influence’ is computed as the product of the residual and the leverage. The influence of a point is the amount by which the slope of the regression line changes when that point is removed from the dataset and thus a new slope is computed. The amount of the change was developed by Cook and is called Cook’s influence or Cook’s distance. Intuitively, Cook’s distance measures the change in the sum of squared differences for every observation, except when the relevant point is removed. In regression diagnostics, values greater than 1 are of concern and should be carefully investigated. When, the regressions are run, the Cook’s influence values will appear in the data set as a new variable labeled `coo_1`, `coo_2`. We delete the observations for which this distance was greater than one and undertake the regression analysis from the reduced sample.

Checking normality of the errors

The histogram of the residuals in addition to normal P-P plot of the standardized residuals can be plotted to check whether the errors are normal or not (Figures 10.1 and 10.2). The latter plot must be approximately linear for the distribution to be normal. The normal probability plot compares the percentiles of the values from the distribution to the percentiles of the standard

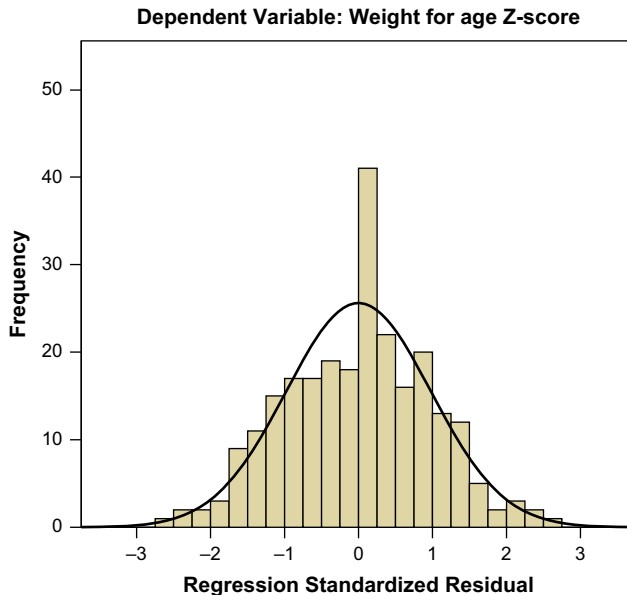


Figure 10.1 Histogram of standardized residuals of weight for age.

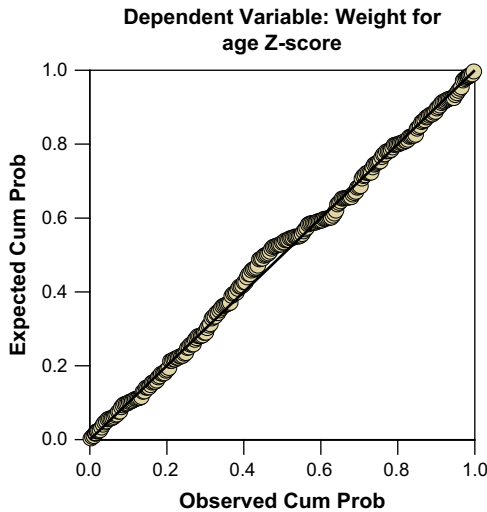


Figure 10.2 Normal P-P plot of regression standardized residuals.

normal distribution (Spanos, 1998). For example, in a normal distribution, approximately 3 per cent of the values are more than 3 standard deviations below the mean, 5 per cent of the values are more than 2 standard deviations below the mean and 33 per cent of the values are more than 1 standard deviation below the mean. The plot will thus have percentiles of the standard normal distribution on the Y-axis and the percentiles of the variable on the X-axis. If the variable has an approximate normal distribution, then the normal probability plot will look like a straight line. We examine the normal probability plot from the weight for age (as an example) for model 1, where per capita expenditure of food is one of the regressors.

As evident from the graphs, the residuals of weight for age are approximately normal. Regression is relatively robust to slight violations from normality as long as the sample size is reasonably large.

Checking for homogeneity of variance of the residuals

The easiest way to check for the homogeneity of variance (homoskedasticity) across different levels of the independent variables is to examine a scatterplot of the residuals against the predicted values. If the spread of the residuals appear to be constant across the different levels of the dependent variables, there is not much likelihood of a problem. It is important to mention that regression is also robust to violations of homoskedasticity. However, mild violations of this assumption are not worrisome (Tabachnick and Fidell, 2001).

From Figures 10.3 and 10.4, it is evident that, while the assumption of homoskedasticity is not violated for the weight for age regressions, it is violated for the case of height for age regressions, since the spread thickens around the center.

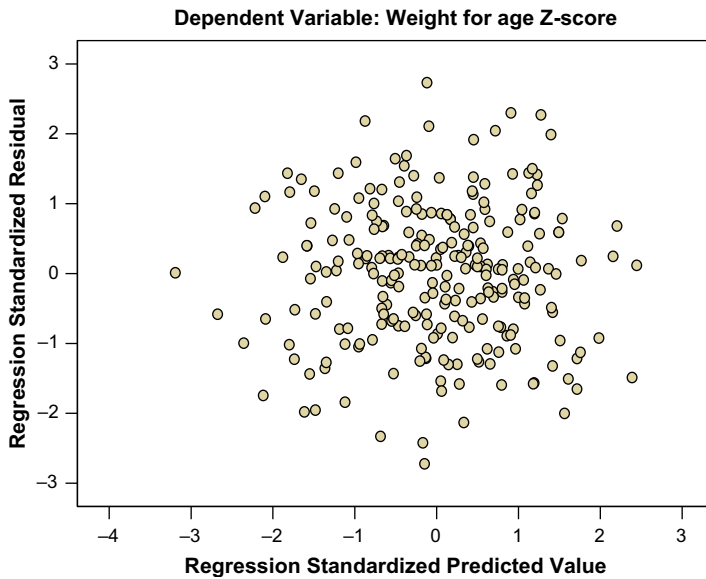


Figure 10.3 Residuals plotted against predicted values for weight for age.

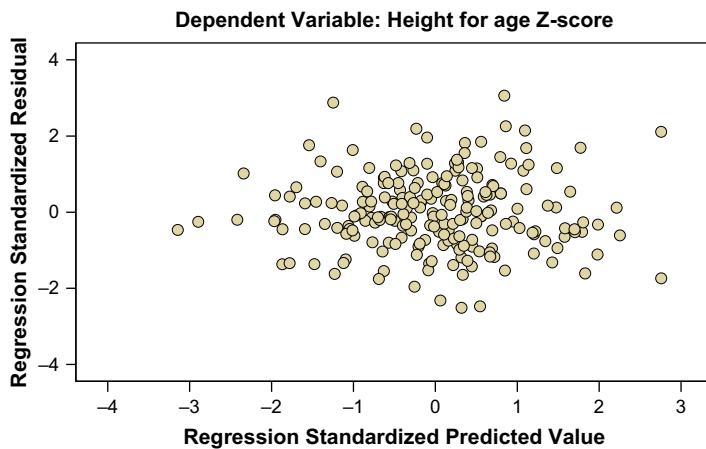


Figure 10.4 Residuals plotted against predicted values for height for age.

Conclusions

The results presented in this chapter have key implications for health and nutrition monitoring in Malawi, i.e. intervention opportunities that might have a positive impact on child nutrition over the long run. Maternal education, as

measured by the number of years in school, has a significant influence on child nutrition. This is in line with the past development research on this subject, which has shown that maternal education compared to fathers' education can have a significant influence on child nutritional outcomes. Although we do not find income to influence significantly child nutritional outcomes after controlling for the impact of maternal education, income might still be important. However, food security significantly influences child nutritional outcomes and, thus, improving food security at the household level seems crucial in the long run. One way to improve household food security is to raise agricultural productivity, especially for the small farmers.

An additional finding to note is that child-care practices had a significant influence on child health and nutritional status. Thus, complementary interventions that improve women's income and wealth earning opportunities and provide better information on care and hygienic practices can be important in improving child nutritional status.

We also found the incidence of diarrhea to have a negative and significant influence on child nutritional status. This might be indirectly capturing poor water and sanitation conditions, which can affect child nutritional status adversely. Increasing education levels of mothers and appropriate hygiene and sanitation practices seems crucial. For example, a higher level of maternal knowledge about hand-washing can have a positive association with child nutrition by preventing diarrhea. The effects of such water and sanitation interventions can be very beneficial for certain subgroups of the population, such as the low-income and the low-educated households. We also found some evidence of increase in distance to a protected water source adversely affecting weight for age but not height for age. Thus, reducing travel time to collect safe water can relax the time constraint of the household. The time saved can be reallocated to leisure, health production and other agricultural activities which, consequently, can improve household productivity and child nutritional status over a longer time horizon.

In conclusion, the results from this chapter can provide general guidelines to program managers, government officials, as well as researchers, as to what interventions are most likely to improve child health and nutrition outcomes. The results presented should help them fine tune those interventions, both programmatically and for the targeted groups.

Exercises

1. Undertake a multivariate regression analysis with weight for height Z-scores (wasting) as the dependent variable and the same set of explanatory variables in this chapter. Which variables significantly influence wasting? What is the value of adjusted R^2 in your model? Plot the normal probability plot and the histogram of the weight for height residuals and examine if these residuals violate the assumption of normality.

2. Create interaction variables of maternal education (EDUCSPOUS) and the child-care variables (ATTCLINI, CLINFEED and BFEEDNEW) as the product of education of the mother and the child-care variables (for example EDUCSPOUS*ATTCLINI). Conduct a multiple regression analysis with EDUCSPOUS, ATTCLINI and EDUCSPOUS*ATTCLINI as the independent variables and ZWH, ZHA and ZWA as the dependent variables respectively (there should be 9 regressions). Repeat the process with EDUCSPOUS*BFEEDNEW and EDUCSPOUS*CLINFEED as the independent variables. Is there a statistically significant interaction between education and the child-care variables? Explain your results.
3. Suppose you are given the following regression equation: $\hat{Y} = 15 + 1.5X_1 + 0.75X_2$. Can you tell the relative importance of X_1 and X_2 from the information given?
4. Study the papers by Strauss and Thomas (1995), Benefo and Schultz (1996) and Zhao and Bishai (2004). In light of the available evidence, explain whether maternal education and community characteristics are substitutes or complements in the determination of child nutritional status. (Your answer should not be more than two pages.)
5. What are the main determinants of fertility and mortality? (Study the paper by Benefo and Schultz (1996) to elucidate your answer.) Through what mechanisms does maternal education affect infant mortality and fertility? Discuss the community characteristics that are complementary and substitutes to maternal education.
6. Discuss the various steps for undertaking a multivariate regression analysis. Why is it important to check for violations of the regression assumptions?
7. How does improved water and sanitation condition translate into better child health outcomes? Critically discuss after studying the literature as presented in this chapter.

Notes

1. In matrix algebra, the parameter estimates can be obtained as $\hat{\beta} = (X'X)^{-1}X'Y$.
2. A WHO supported study in Brazil demonstrated that IMCI nutrition counseling provided by health workers during routine health visits could prevent weight growth faltering for infants between 6 and 12 months. Additionally, it provided a basis for promoting weight growth in infants 1 year and older (Bryce et al., 2006).
3. Coefficient of multiple determination is of a similar magnitude in regressing child nutritional status on its determinants as in Glewwe (1999).

Section III

Special Topics on Poverty, Nutrition and Food Policy Analysis

Introduction

In this section, the book introduces more challenging tools and techniques of food security, poverty and nutrition policy analysis. They include discriminant analysis, logistic regression models, cluster analysis, instrumental variable estimation and linear programming. Developed with the needs for post-graduate level treatment policy analysis, these chapters enable the policy analysts to have an advanced set of quantitative methods in their tool box.

Chapter 11

This chapter introduces discriminant analysis as a tool to identify the most important determinant of food security and nutritional status that can predict best among a large pool of such independent variables. Such variables need to be identified for context and community specific food and nutrition interventions. The chapter reviews selected case studies that attempt to identify good predictors of food insecurity, poverty and malnutrition. Various steps of discriminant analysis, such as specifying the dependent and predictor variables, determining the method of selection criteria for entering the predictor variables in the model and tests of a-priori assumptions of the model, interpretation of discriminant functions and validation of results are described with examples.

Chapter 12

The analysis of measurement and determinants of poverty and its relationship to food security and nutritional outcomes have become a major area of investigation by household welfare analysts. This chapter introduces various approaches to identifying the poor, measurement of poverty, construction of poverty lines and deriving various measures of poverty including headcount index, poverty gap index and squared poverty gap index. Poverty lines are

calculated using food energy intake and cost of basic needs approaches. Analysis of determinants of poverty using binary logistic regression is also demonstrated. Interpretation of the results of logistic regression for deriving policy implications is given.

Chapter 13

This chapter introduces cluster analysis with a goal to find an optimal grouping of observations on food security and nutritional status that are similar in a cluster but are dissimilar to observations in other clusters. It is shown how targeted food and nutrition interventions could be designed for groups of households on the basis of certain socioeconomic characteristics or when certain program interventions are desirable to improve the welfare of specific groups of the population. Initial partitioning of observations, optimum number of clusters, describing characteristics of the clusters and cluster centers are some of the topics covered under this chapter. Several food and nutrition related case studies that use cluster analysis are also reviewed.

Chapter 14

Using case studies from the child nutrition literature, this chapter introduces the instrumental variable model. The analysis is shown in two steps. Estimation of the determinants of child-care practices is carried out in the first stage while, in the second stage, the predicted value of child-care practices along with other control variables are used to determine the impact of child nutrition outcomes.

Chapter 15

Nutrition planners face several programmatic challenges in designing appropriate interventions. Frequently asked field questions include: is it possible to design a diet with locally available food that meets the daily recommended allowances? How do we minimize the cost of achieving such diets?

These questions could be answered through a linear programming approach that helps to examine the compatibility of different mathematical inequalities in using simple mathematics to address the above questions. This chapter introduces elements of linear programming and demonstrates how food and nutrition problems could be solved using Excel spreadsheet. Interpretations of the results of linear programming problems for policy applications are also given.

11 Predicting child nutritional status using related socioeconomic variables – application of discriminant function analysis

*You can tell the condition of a nation by looking at the status of its women.
Jawaharlal Nehru, the first prime minister of India.*

Introduction

Studies explaining child nutrition with related socioeconomic variables have gained momentum in the recent development literature for several reasons (Hobcraft et al., 1984). First, given the high cost of data collection on the nutritional status of children which require special equipments, there is a need for indicators that could predict child nutrition in a cost-effective manner. Second, socioeconomic and demographic surveys that are conducted on a regular basis, such as national expenditure surveys and living standard measurement surveys (LSMS), do not often include nutritional status. Third, there has been increasing interest among nutrition economists to identify a set of robust variables that can explain child nutritional status in a community. Finally, for cross-country comparisons using existing datasets, variables that predict child nutrition consistently could be used in explaining global and regional trends in welfare indicators such as child nutrition.

In this chapter, we introduce discriminant analysis (DA) as a tool to identify the most important variables that can predict child nutrition among a large pool of variables. The method is useful for predicting membership in naturally occurring groups and thus addresses whether a combination of variables (such as women's status, household income and other community variables) can be used to predict group membership (such as child nutritional status). Once group means are found to be statistically significant, classification of variables is undertaken. The method automatically determines some optimal combination of variables so that the first function provides the most overall discrimination between groups, the second provides the second most, and so on. An important

advantage of this method is that the functions will be independent or orthogonal, so that their contributions to the discrimination between groups will not overlap. The subjects will be classified in the groups where they had the highest classification scores. The maximum number of discriminant functions will be equal to the degrees of freedom or the number of variables in the analysis, whichever is smaller (Rencher, 2002).

Women's status in the society has been one of the socioeconomic variables that has gained recognition as a good predictor of child nutritional status (Haddad, 1999). Although much has been emphasized about the various causes of child malnutrition and the ways to eliminate it, little attention has been paid until recently to understand the role of women's status relative to men and its impact on child nutrition in developing countries.

Both anecdotal and empirical evidence suggests that income earned by women is more likely to be spent on food and other basic household needs than income earned by men and, thus, it can have a greater positive impact on children's nutritional status (Kumar, 1979). In general, women in many parts of the world traditionally had major responsibility for feeding and caring for children. Further, women in developing countries generally join the workforce out of economic necessity, so that their incomes must be devoted to survival needs. From the above facts, it is clear that an increase in income earned by women is likely to improve the nutritional status of children. Another reason to focus on women's income is that economically active women are more likely to act on many ideas given in nutrition and health projects than women whose activities are confined to the household sphere (Rogers and Youssef, 1988). The opportunity to earn an income will thus provide an initial incentive for women to change traditional patterns of behavior, which will bring perceptible benefits of improved home management and child-care practices.

In what follows, we first provide a conceptual framework for briefly studying whether women's status is important for predicting child nutritional status. We then review a few studies that attempt to identify good predictors of child nutrition status. A discussion of the issues, data sets, analytical methods and results of these studies serve as a motivation for understanding the use and application of discriminant analysis follows. The final section provides concluding remarks and some implications of the results.

Conceptual framework: linkages between women's status and child nutrition

Linkages between women's status and child nutrition

Figure 11.1 provides a conceptual framework for understanding the various causes of child malnutrition. The immediate causes are inadequate dietary intake and disease. Children can become malnourished due to insufficient food. Diseases, on the other hand, inhibit the absorption of nutrients and affect

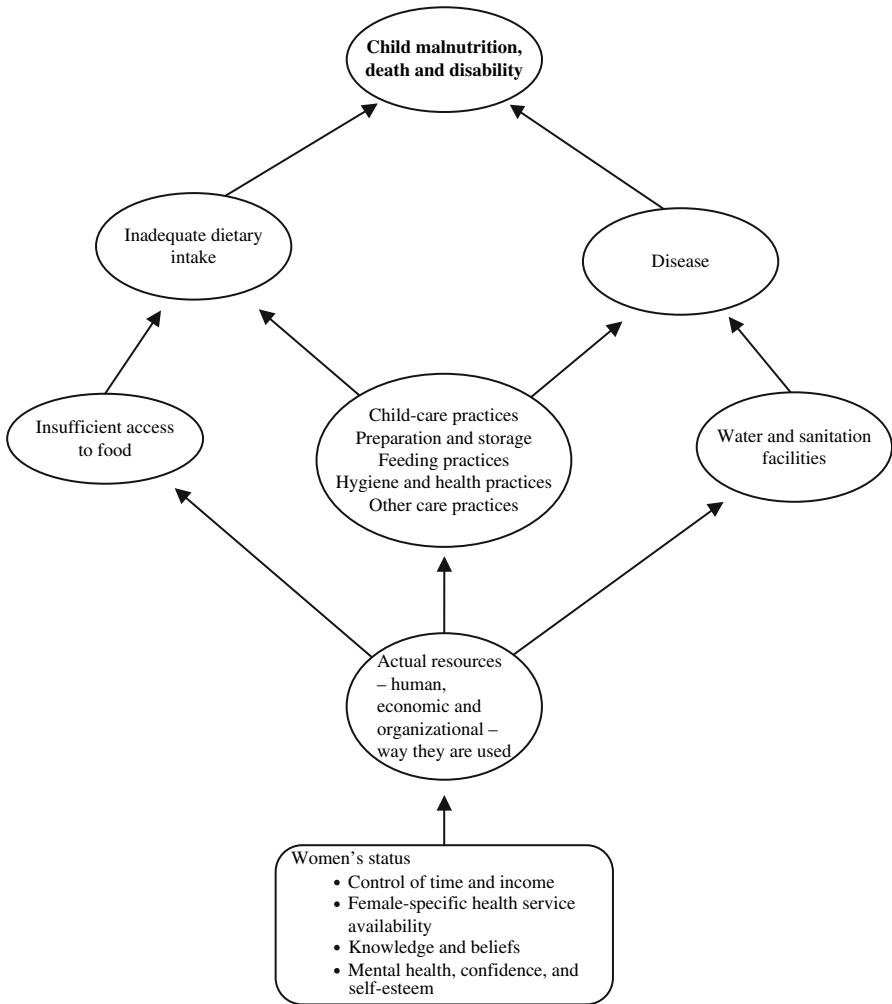


Figure 11.1 Linkages between women’s status and child nutrition.
(Source: UNICEF, 1998; Smith et al., 2003)

children’s growth. At the household level, lack of food security, inadequate child-care practices and poor water and sanitation facilities are the underlying causes of malnutrition. Food security is defined as the access to sufficient food for a healthy life for all household members. Care is the provision in households and communities of time and attention for physical and other needs of the growing child. Feeding behavior (such as breastfeeding) can be critically important in the growth of the child. Also, a proper health environment, such as safe drinking water and sanitary facilities, can help in reducing diseases and thereby improve children’s growth. Finally, the basic (distant) causes of child

malnutrition can be attributed to the resources available in society and women's status (Smith et al., 2003).

Examples of linkages between women's status and children's nutrition

In many societies, women are the primary care-givers for young children. At the same time, in parts of the developing world, women have relatively lower status compared to men. This has consequences for women's control over household time and income, knowledge and beliefs and self-confidence. First, consider women's control over household resources. The greater a woman's control over her income, the more is the likelihood that she will invest greater time in child-care.

Studies (Haddad et al., 1997) have shown that income or assets accruing to women have a positive impact on child nutrition through greater expenditures on food, clothing and health care for the child. However, under certain situations when resources are pooled jointly, a household acts as a unitary decision maker. Under the above circumstances, women's status has no positive impact on the nutritional status of the child. On the other hand, if a woman is time constrained (which is possibly a consequence of low status), she can devote less time to quality care for the child. Less care-giving activities can have adverse consequences for child welfare.

Women with low status have less knowledge and more beliefs (Engle et al., 1999; Kishor, 2000), as they have less mobility and are less likely to go outside the home and engage in social interactions. They are more likely to be exposed to less health and nutrition knowledge, which can have unfavorable impact on the children's nutritional status.

Women's confidence and self-esteem in society can also affect the nutritional status of a child. The more a woman is dependent on her husband, the greater is the likelihood of disrespect. These repeated interactions with the spouse can lead to poor mental health and low self-esteem. Under such situations, it is less likely that the woman will make timely and independent decisions regarding health care treatment of a child (see, for example, Engle et al., 1999).

Indirect linkages, such as lower health status (malnourished or sick) of a woman can have negative consequences on child nutrition. A woman who is malnourished may be less capable of breastfeeding successfully, with the consequence that they may give birth to underweight children. Moreover, women who are more time constrained are less likely to devote time for child-care, which can affect their nutritional status adversely.

Review of selected studies

Direct linkage studies between women's status and children's nutritional status

Direct linkages should be interpreted as those affecting women's status directly, such as her income, work conditions, time constraints and self-confidence, while

indirect linkages can occur through lower health care for the woman, fertility regulation, prenatal and birth care practices and is usually caused by women's lower status relative to men.

Kennedy and Haddad (1994) examined the impact of income level by gender of the household on child nutritional status for Kenya and Ghana. Six hundred and seventeen households were chosen for Kenya over a 3-year period in South Nyanza district (a rural area characterized by low population density, highly productive agricultural land and a maize/sugarcane production mix).

For Ghana, the living standards survey (LSS) data were from a nationally representative survey of 3136 households. Households were disaggregated according to the self-reported household head's gender and months spent away from the residence by the self-reported male head. Thus, *de facto* female-headed households were classified as those where the self-declared male head was absent for at least 50 per cent of the time, whereas *de jure* female-headed households were those in which a woman was generally considered as the legal and customary head of the household¹. Female-headed households were 17 and 30 per cent of all the households in the sample from Kenya and Ghana respectively.

The main conclusion from the study was that the complex interactions of income, gender of the household head and gender of the preschooler had an important influence on child nutritional outcomes. An interesting finding was that some poorer female-headed households were able to ensure better nutritional status for their children than wealthier male and other female-headed households. An important implication of the study is that targeting interventions by gender of the household head may not be the most effective way to reach the poorest household, while interventions that promote the returns to appropriate nurturing behaviors (such as providing provision for public health services) can be extremely effective in short-term gains to child health and nutrition.

Barros et al. (1997) analyzed the characteristics and behavior of female-headed households in urban Brazil and identified the consequences of growth of these households for child welfare. The rationale for choosing Brazil was that female-headed households had a much higher probability of being poor compared to male-headed households. The main question addressed in the study is as follows: do female-headed households have a lower number of earners with less income-earning power or more mouths to feed? The main criteria for defining a household head were twofold. First, the person who had the highest income in the household was considered as the head. Second, the household head was the one who devoted the maximum effort (measured by the number of hours worked) on behalf of the household. The data used in the study were from the 1984 Brazilian household sample survey. Since there were high and variable rates of inflation during the 1980s in Brazil, the task of conducting intertemporal and interregional comparisons of income becomes vastly complicated. The study was conducted in three representative metropolitan areas of Brazil, with poverty defined according to relative income in each area.

One of the main conclusions from the study was that female-headed households were a heterogeneous and diverse group with substantial variations by

region. Female-headed households were not, on average, a vulnerable segment of the population and the extent of poverty among the female-headed households varied greatly among regions. In the northeast region, female-headed households were generally poorer, especially in the area of Recife. Female-headed households (FHH) with children did display a greater income gap compared to other households. Second, female-headed households had lower income, as the head of the household earned less. Thus, the analysis showed that the best interventions for eliminating poverty for the targeted group would be to focus explicitly on ending wage discrimination and ending occupational segregation for women. Third, the results suggested that special intervention was required for children in female-headed households, since such children usually stayed out of school. Even after controlling for household income, the results demonstrated that children in female-headed households had poorer school attendance records than other children. This was especially true for older children. The above finding possibly indicates that female-headed households need to balance the trade-off between earning more income and the time constraint that they face in child-care practices.

In a comprehensive study conducted between 1990 and 1998 for three major regions (South Asia, sub-Saharan Africa (SSA) and Latin America and the Caribbean (LAC) and included 36 countries), Smith et al. (2003) examined the role of women's status on child's nutritional status. The sample included 117 242 children less than 3 years of age and 105 567 women who were usually mothers. The sample children lived in two-parent households, while the sample women included those individuals who were married and had at least one child less than 3 years old. The study used both least squares and logistic regression methods. There were 25 dependent variables examined, with six of them being measures of child nutritional status. Various socioeconomic measures and household characteristics were controlled for as independent variables.

The major inference from this highly influential benchmark study demonstrated that women's status was critically important in improving children's nutritional status. However, the strength of the impact varied across regions. Women's relative decision-making power had a strong influence on child nutritional status in South Asia, moderate and positive impact in SSA and affected only the short-term nutritional status in the LAC region. Gender equality appeared to have a weaker impact on child nutritional status, with the positive impact occurring only in South Asia. Finally, the study found that economic status and women's status have strong linkages in affecting child nutritional status among the poorer households.

Indirect linkages between women's status and child's nutritional status

Lower status of women translates into greater likelihood of them being malnourished and sick which, in turn, reduces their energy level and responsiveness to needs of the child declines. A woman who is malnourished may be

incapable of breastfeeding successfully. Moreover, if she is often pregnant, the nutrient reserves of the body decline which, in turn, could lead to poor growth of the child. A woman with lower status usually does not have decision-making capability in fertility matters. Micronutrient deficiency of the woman can be passed on to the child during the pregnancy period and affect the nutritional status of the child adversely (such as low birthweight).

Ukwuani and Suchindran (2003) examined the relationship between women's work conditions and child nutritional status (stunting and wasting) for a sample of Nigerian children aged 0–59 months, using the 1990 Nigerian Demographic and Health Survey data set. Women's work conditions can serve as an important component of women's status, as it can influence the nutritional status of the child through the pathways of income and child-care. The novelty of the study was in going beyond simple categorization of women's work, as it examined whether women's earned cash from work and taking their children to work had a significant impact on child nutritional status².

The main hypotheses examined in the study were as follows:

1. women's work had a negative impact on child nutrition during infancy. This negative effect could be reduced when women combined work with child-care
2. women's work had a positive impact during childhood when women could earn cash from work.

The dependent variable was child nutritional status, as measured by stunting and wasting. The primary independent variable was women's work. Other controls were socioeconomic factors, household characteristics, child-care and water and sanitation conditions.

The authors recommend provision of child-care services for working mothers, as there is evidence of the negative impact of mother's work on child nutritional status during infancy. Additionally, since mother's work had a negative impact on stunting during childhood, better employment opportunities and empowering women remains a crucial agenda in Nigeria. Since the incidence of diarrhea caused wasting and lack of immunization had a strong effect on stunting and wasting, policy makers would be better off undertaking vigorous health interventions for maternal and child health care. Overall, the study concluded that empowering women through better work conditions could alleviate the problem of malnutrition to a significant extent.

In another study, Li (2003) examined the impact of fertility reduction (one-child policy) on the well-being of Chinese children. The major issues addressed in this study were:

1. what was the impact of one-child policy on the health status of Chinese children? In other words, the author examined if there was a trade-off between quantity and quality of children.
2. did the decrease in family size help in improving girls' well-being?

The data were collected from the China Health and Nutrition survey conducted during 1989, 1991 and 1993. About 190 communities from eight provinces were

chosen with differing levels of economic development, public resources and health indicators. A total of 3800 households were chosen consisting of 16 000 individuals.

A reduced form specification was estimated using least squares, where the nutrient intake (measured alternatively by average calorie intake, protein intake and fat intake) and health status (measured by the height for age Z-scores) were regressed on individual characteristics of the child such as age, sex and birth order; household characteristics such as mother's education, household income; and community characteristics such as one-child policy, water and sanitary conditions and unobserved individual, household and village specific fixed effects.

The paper evaluated indirectly the impact of women's status (fertility reduction) on child nutrition with a focus on gender differences. The findings indicate the following facts. First, parents trade-off quality and quantity of children in China. By reducing family size, the one-child policy (a reduction in fertility rate) significantly improved children's well-being. Second, sex selection in China did not eliminate the discriminating treatment towards girls compared to boys.

Overall, what can we conclude from the existing studies of the relationship between women's status and child nutrition? As pointed out by Buvinic and Gupta (1997) and Fuwa (2000), the answer is at best ambiguous. On the one hand, if FHHs are indeed poorer than non-FHHs in terms of both consumption and leisure, then children's welfare in FHHs tend to be lower through lower consumption (including food consumption, which could have long-term effects), lower educational expenditures, etc. On the other hand, children within the FHH households could be better off than their non-FHH counterpart due to systematic differences in the patterns of household resource allocation as a result of differential preferences between women and men. Thus, there are mixed results from the existing empirical studies on the relationship between female headship and the welfare of children. The present chapter uses discriminant analysis as an analytical tool to determine how child nutritional status can be predicted from a set of group variables, with one of the grouping variable being women's status. In this analysis, if the means for a variable are significantly different in various groups, then this variable discriminates between the two groups, allowing the use of that particular variable to predict group membership.

Empirical analysis and main findings

We undertake discriminant analysis (DA) to understand which series of variables best predicts the nutritional status of the child³. A DA approach is suitable since the dependent variable nutritional status (weight for height Z-scores) can be categorized into discrete groups and one can predict group membership from a set of predictor variables (both discrete and continuous). In a DA approach, we want to determine a function that maximizes the distance between the groups. In other words, we want to come up with a function that has strong *discriminatory power* among the groups.

It is essentially identical to multiple regression but, in reality, the two techniques are quite different. In linear regression, we estimate the parameters to minimize the residual sum of squares, whereas in the DA procedure, we estimate the parameters which minimize the within group sum of squares. A DA model looks as follows:

$$Z = a + W_1X_1 + W_2X_2 + \dots + W_kX_k \quad (11.1)$$

where Z is the discriminant score, i.e. a number that can be used to predict group membership, a is a discriminant constant, W_k denotes the discriminant weight or coefficient, which is a measure to the extent that X_k discriminates among the groups of Z . X_k is a predictor variable, which can be either discrete or continuous. The various steps involved in the discriminant analysis are as follows:

- specify the dependent and the predictor variables
- determine the method of selection and criteria for entering the predictor variables in the model
- test the model's assumptions a-priori⁴
- estimate the parameters of the model
- determine the significance of the predictors
- validate the results.

Data description and analysis

The Z-score weight for height (ZWH) is considered as the group variable and is divided into three categories as follows: $ZWHNEW = 0$ if $ZWH \geq 0$. This category represents good nutritional status. $ZWHNEW = 1$ if $-2 < ZWH < 0$. The above category represents moderate to low wasting. $ZWHNEW = 2$ if $ZWH < -2$. This category will be called severe wasting. The reference group for comparison is $ZWHNEW = 0$ (good nutritional status). (We categorized $ZWHNEW$ initially into five different categories by differentiating between good nutritional status, low wasting, moderate wasting, high wasting, and severe wasting with different threshold values of ZWH . However, the discriminating function was unable clearly to differentiate the cases between the different groups. Additionally, some of the covariance matrices of the groups were singular, possibly indicating some linear dependency among the variables. Thus, the above classification was not undertaken in subsequent analysis.) The predictor variables are classified into individual characteristics (X_{IC}), household or socioeconomic variables (X_H), and community level factors (X_C), similar to the multivariate regression model. Thus, the discriminant model looks as follows:

$$ZWHNEW = a + W_1X_{IC} + W_2X_H + W_3X_C \quad (11.2)$$

The *individual* characteristics or the individual predictor variable (X_{IC}) is the age of the child in months (AGEMNTH). The *household or socioeconomic* vector (X_H) consists of the following set of variables:

1. per capita expenditure on food (PXFD): income is a central variable in models of child health and nutrition outcomes. As more resources become available to households,

they can incur higher expenditures on food and non-food items (such as health). We use per capita food expenditure as a proxy for income, since food constitutes an important component of household expenditure in Malawi. This variable is computed by taking the ratio of total food expenditure to the household size

2. women's status (S): this is the key predictor variable in our model and is measured by the difference in educational status between the household head and the spouse. It is a continuous measure with values ranging from -3 to $+3$. Since education equips individuals with skills that allow them to understand better and operate in a modern environment in order to undertake quality child-care, it is important to understand how women are educated relative to men. Additionally, this variable may also reflect intrahousehold bargaining power, which translates into differences in relative power. This measure is defined to have a threshold level such that a woman has as much or more education than her husband. Child-care variables are also critical in improving nutritional status of children. The following variable is used as a proxy for child-care:
3. BFEEDNEW: a dichotomous variable indicating whether the child is breastfed or not.

The *community characteristics* variables (X_C), such as water and sanitation indicators, usually affect the health production function and, consequently, influence the nutritional status of the child positively. The different community characteristics considered in the present analysis are as follows:

1. drinking distance (DRINKDST): a categorical variable assuming values from 1 to 5. Higher values of this variable denote that the distance to a protected drinking source for the household is higher. We can expect that the greater the distance to a protected water source, the more is the likelihood that children will suffer from malnutrition
2. provision of sanitation (LATERINE): a dichotomous variable assuming two values 0 and 1, with 0 indicating absence of latrine from the household
3. DIARRHEA: this variable indicates whether the child has diarrhea and is a dichotomous variable assuming two values 0 and 1. 1 indicates that the child had diarrhea during the survey.

In addition to the above measures, we also consider the provision of health and infrastructural facilities, which indirectly contribute to improved child nutritional status. They are:

4. HOSPITAL: a dichotomous variable assuming two values 0 and 1, with 1 indicating presence of modern medical care. Since all the households in the sample have some form of medical care (either modern facilities or traditional doctors in the community), there is no variation among households with this measure. Thus, we expect that this variable may not be able to discriminate clearly among the groups
5. SADMDIST: a categorical variable assuming values from 1 to 5. Higher values indicate that the distance to the nearest ADMARC market for private traders to sell their products is higher.

Descriptive statistics

We first look at a few descriptive statistics relating the various characteristics of the households (households which have information pertaining to both food security and nutritional status of children, market access variables and

the community characteristics variables) with the gender of the household head.

Table 11.1 shows that female-headed households are relatively much less educated compared to the male-headed counterparts and this difference is significant using the chi-square tests. Additionally, 70 per cent of the female-headed households have no latrine in the house compared to about 60.5 per cent of the male-headed counterparts, while 62.5 per cent of the female-headed households have unprotected drinking water sources. Thus, female-headed households are relatively at a greater disadvantage than their male counterparts. Having looked at some of the characteristics of the household with the gender dimension, let us investigate whether children from female-headed households have better nutritional status.

Table 11.2 shows some consistent patterns. Children from the female-headed households are less prone to being underweight and wasted than male-headed

Table 11.1 Gender of the head and household characteristics

Characteristics of the household	Categories	Male headed	Female headed
Educational levels	No education	19.75	50.0
	Adult literacy training	0.64	2.5
	Std 1–4	28.02	17.5
	Std 5–8	45.22	30.0
	Secondary education	6.37	0.00
Latrine in house	No	60.51	70.0
	Yes	39.49	30.0
Drinking water source	Unprotected	48.41	62.5
	Protected	51.59	37.5

Note: The numbers in the table denote percentage.

Table 11.2 Gender of the head and nutritional status of children aged 0–5

Nutritional status measures	Categories	Male headed	Female headed
ZWHNEW	Good	32.42	38.89
	Low to moderate wasting	58.24	52.78
	Severe wasting	9.34	8.33
ZHANEW	Good	26.04	23.53
	Low to moderate stunting	29.59	29.41
	Severe stunting	44.37	47.06
ZWANEW	Good	8.91	15.79
	Low to moderate underweight	55.94	63.16
	Severe underweight	35.15	21.05

Note: The numbers in the table denote percentage.

households. In contrast, children from male-headed households are less prone to be stunted relative to the female counterparts (although this difference is not significant after undertaking chi-square tests). This may be because wasting and stunting measure different dimensions of child nutritional status and the underlying determinants can differ. One plausible reason why female-headed households may have a greater percentage of stunted children is that both income and educational level of these households are lower compared to the male-headed households. The above differences translate into lower nutritional status of children in the long run, as female-headed households have less resources. At the same time, these households are not aware (possibly less exposed to the media sources) of how to improve children's nutritional status (for example through better care practices), since they are less educated on an average than male-headed households.

Testing the assumptions underlying DA model

Box's M test

This procedure tests the assumption of homogeneity of the variance–covariance matrices. For g number of groups, the null hypothesis is of the form:

$$H_0 : \sum_1 = \dots\dots\dots = \sum_g \quad (11.3)$$

Box (1949) derived a test-statistic based on the likelihood ratio test and it is known as Box's M . The details are given in the technical appendix of this chapter.

For moderate to small sample sizes, an F approximation is used to compute its significance.

Table 11.3 shows that the test is significant, approximate $F = 1.71$, $P = 0.00$. Thus, we conclude that the three ZWHNEW groups differ in their covariance matrices, which violates an assumption of DA. However, DA analysis is robust even when the homogeneity of variance assumption is not met since we have eliminated the outliers from the data set. Also, since the number of observations is reasonably large, small deviations from homogeneity will be found significant.

Table 11.3 Box's M test results

Box's M		139.94
F	Approx.	1.714
	df1	72
	df2	7355.08
	Sig.	0.00

Tests null hypothesis of equal population covariance matrices.

Tests of equality of group means

The rules for variable selection in the stepwise method are as follows:

- eligible variables with higher inclusion levels are entered before eligible variables with lower inclusion levels
- the order of entry of the eligible variables with the same even inclusion level is determined by their order on the ANALYSIS specification
- the order of entry of the eligible variables with the same odd level of inclusion is determined by their value on the entry criterion and the variable with the 'best' value for the criterion statistic is entered first
- prior to including any eligible variables, all the entered variables which have level one inclusion numbers are examined for removal. A variable can be removed if its F value to remove is less than the F -value for variable removal. Otherwise, if the probability criterion is used, the significance of the variable F to remove exceeds the specified probability level.

If more than one variable is eligible for removal, the particular variable is removed which leaves the 'best' value for the criterion statistic for the remaining variables. This process continues unless no other variables are eligible for removal.

On the other hand, a variable with an odd inclusion number is considered ineligible for inclusion if the following conditions are satisfied:

- its F to enter is less than the F -value for a variable to enter value or
- the significance level associated with its F to enter exceeds the probability to enter.

One of the most commonly used metrics is to test the null hypothesis that the group mean vectors are equal. In other words, we want to test the null hypothesis:

$$H_0 : \mu_1 = \mu_2 = \dots = \mu_g \quad (11.4)$$

where μ_i is the p -length population mean for group i . The non-rejection of the null suggests that the distribution of the variables does not differ significantly across the groups. In other words, the values of the variables are not useful in explaining or predicting groups.

Table 11.4 tests for the equality of group means of the predictors. The smaller the Wilks' lambda (λ), the more important is the effect of the independent variable to the discriminant function. The null hypothesis can be rejected when the value of the test statistic is greater than the critical value of F for the desired level of significance. In the present case, λ is significant by the F -test for women's status as measured by the educational difference between the household head and the spouse. Thus, women's status is a significant predictor of the discriminant function. Additionally, λ is also significant for the CARE variable as measured by the breastfeeding of the child. Thus, both women's status and child-care are significant predictors of the child nutritional status. Moreover, the presence of protected drinking water source and the availability of infra-structural facilities in the household and the community appear to be significant

Table 11.4 Tests of equality of group means

	Wilks' lambda	F	df1	df2	Sig.
PXFD	0.992	0.828	2	199	0.438
EDUCDIFF	0.938	6.531	2	199	0.002
BFEEDNEW	0.975	2.513	2	199	0.084
AGEMNTH	0.969	3.157	2	199	0.045
DIARRHEA	0.996	0.397	2	199	0.673
DRINKDST	0.933	7.173	2	199	0.001
HOSPITAL	0.995	0.515	2	199	0.598
SADMDIST	0.960	4.197	2	199	0.016
LATERINE	0.996	0.356	2	199	0.701

predictors for the various groups. Interestingly, however, we do not find sanitation facilities to be a significant predictor of the discriminant function.

Summary of main findings

One discriminant function will be computed from the lesser of $(g - 1)$ (number of dependent groups minus 1) or k (the number of independent variables). Since the dependent ZWHNEW has three groups, the number of discriminant functions computed is two. Now to ascertain which of these discriminant functions is significant, we undertake the eigenvalue (Δ) and the corresponding Wilks' lambda tests. In matrix algebra, an eigenvalue is a constant, which when subtracted from the diagonal elements of a matrix results in a new matrix whose determinant is zero.

The Wilks' lambda test is given as follows: suppose that there are random samples of sizes N_1, \dots, N_g for each of the g -groups, and let $\bar{X}_1, \dots, \bar{X}_g$ be the sample mean vectors for each group, then Wilks' lambda is defined as:

$$\Delta = \frac{W}{T} = \frac{\sum_{i=1}^g \sum_{n=1}^{n_i} (X_{in} - \bar{X}_i)(X_{in} - \bar{X}_i)'}{\sum_{i=1}^g \sum_{n=1}^{n_i} (X_{in} - \bar{X})(X_{in} - \bar{X})'} \quad (11.5)$$

where the numerator denotes the within-groups sum of squares matrix, while the denominator is the total deviation sum of squares matrix. To test the significance of the discriminating functions after the first case, the test statistic is given as:

$$\chi^2 = -(n - (q + g)/2 - 1) \ln \Delta_k \quad (11.6)$$

where n is the total sample size and q is the number of variables selected at each step. The test-statistic is distributed as χ^2 with $(q - m + 1)(g - m)$ degrees of freedom at the m^{th} step. The exact computational procedure will be discussed in the technical appendix.

In the present case, since the group variable (ZWHNEW) consists of three groups, two eigenvalues can be extracted. The eigenvalue is the ratio of between

the group sum of squares to the within group sum of squares. The larger the eigenvalue, greater is the discriminatory power of the model.

For the first and second functions, the eigenvalues are respectively 0.135 and 0.092 (Table 11.5). The variances explained by the two functions are 59.5 and 40.5 per cent respectively. Now, in order to know which eigenvalues are significant, two statistical indicators can be derived, namely canonical correlation (η) and Wilks' lambda (λ). The canonical correlation (η) can be computed as:

$$\eta = \sqrt{\frac{\lambda}{(1 + \lambda)}} = \sqrt{\frac{SSB}{TSS}},$$

where SSB denotes the sum of squares between the groups, while TSS denotes the total sum of squares. For our example,

$$\eta = \sqrt{\frac{0.135}{1.135}} = 0.344.$$

Wilks' lambda is used to test the null hypothesis that the populations have identical means on the discriminant function. It is given by $\lambda = WSS/TSS = 1 - \eta^2$, and is distributed as χ^2_{k-1} , where k is the number of parameters estimated. WSS denotes the within group sum of squares among the various groups. For the first function, $\chi^2_{16} = 41.829$, with the associated $P < 0.0001$. Thus, the null hypothesis that in the population the $SSB = 0$, $\eta = 0$, is rejected. For the second function, $\chi^2_7 = 17.15$, with the associated $P = 0.016$. Thus, for both the functions, the impact of the predictor variables on the various groups of child nutritional status as measured by weight for height Z-score will be assessed.

Relative impact of the predictor variables on ZWHNEW

Since the predictor variables per capita food expenditure are in monetary units, while age of the child is in months and feeding practice, availability of health facilities, infrastructural facilities, incidence of diarrhea, distance to protected water

Table 11.5 Eigenvalues and Wilks' lambda

Function	Eigenvalue	% of variance	Cumulative %	Canonical correlation
1	0.135	59.5	59.5	0.344
2	0.092	40.5	100.0	0.290

First two canonical discriminant functions were used in the analysis.

Test of function(s)	Wilks' lambda	Chi-square	df	Sig.
1 through 2	0.807	41.829	16	0.000
2	0.916	17.150	7	0.016

source are dichotomous or discrete variables and are measured in different units, the relative difference among the discriminant coefficients cannot be compared. We need a standardized discriminant function, which is of the following form:

$$ZWHNEW_{STD} = W_4X_{IC} + W_5X_H + W_6X_C \quad (11.7)$$

The coefficients can then be interpreted as the beta weights in a multiple regression model. The $ZWHNEW_{STD}$ has been transformed using a weighted unstandardized discriminant function coefficient and will be discussed in greater detail in the technical appendix. Notice that there is no constant term in equation (11.7). This is because the mean of a standardized variable equals zero, while the variance is unity.

From the Wilks' lambda test, we use the associated predictors that were significant in the test for equality of group mean in our analysis (Table 11.6). The variables which were not significant in the test for equality of group means will not be included in the standardized discriminant function analysis.

The two standardized discriminant functions in this case are given as follows:

$$\begin{aligned} ZWHNEW_{STD1} &= 0.664 EDUCDIFF + 0.315 BFEEDNEW \\ &\quad + 0.275 AGEMNTH - 0.582 DRINKDST \\ &\quad - 0.071 SADMDIST \\ ZWHNEW_{STD2} &= 0.337 EDUCDIFF - 0.042 BFEEDNEW \\ &\quad + 0.335 AGEMNTH + 0.463 DRINKDST \\ &\quad + 0.508 SADMDIST \end{aligned} \quad (11.8)$$

From equation (11.8), it is evident that, for the first standardized discriminant function, the maximum impact of the child's nutritional status comes through educational difference between the household head and the spouse. A unit increase in educational difference between the household head and the spouse raises the standardized weight for height Z-score by 0.664 units. The above result signifies that the greater the educational differences, the lower is the possibility that women will be aware of child-care practices. At the same time, it is also possible that women may have less bargaining power in the intrahousehold decision process. Both these effects reinforce the negative impact on child's nutritional status.

Table 11.6 Standardized canonical discriminant function coefficients

Predictors	Function	
	1	2
EDUCDIFF	0.664	0.337
BFEEDNEW	0.315	-0.042
AGEMNTH	0.275	0.335
DRINKDST	-0.582	0.463
SADMDIST	-0.071	0.508

For the second standardized discriminant function, we find the maximum effect occurring from the community level variables such as distance to a protected water source and availability of infrastructural facilities. The independent impact of DRINKDST and SADMDIST are respectively 0.463 and 0.528. This indicates that, as the distance to a protected water source increases for the household, the health environment deteriorates, which has adverse consequences on the child nutritional status. We can thus name the first discriminant function as women's status and the second discriminant function as community infrastructure.

Correlation between the predictor variables and discriminant function

Table 11.7 shows the structure matrix, which is the correlation between each predictor with the discriminant function. The structure coefficients indicate the simple correlation between each variable and the first discriminant function. The higher the absolute value of the coefficient, the greater is the discriminatory impact of the independent variable on the dependent variable. In the determination of the two discriminant functions, the first function has the highest correlation with educational differences, breastfeeding practices and age of the child, while the second function has the highest correlation with distance to protected water source and selling point distance of the private traders to ADMARC, which reinforces our earlier finding from the standardized discriminant function analysis that women's status and community infrastructure are significantly correlated with the discriminant functions.

Table 11.7 Structure matrix

Predictors	Function	
	1	2
PXFD	0.032	0.299*
EDUCDIFF	0.601*	0.431
BFEEDNEW	0.412*	0.162
AGEMNTH	0.448*	0.226
DIARRHEA	-0.025	0.206*
DRINKDST	-0.487	0.662*
HOSPITAL	0.196*	-0.018
SADMDIST	-0.191	0.638*
LATERINE ^a	0.045	0.056

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions. Variables ordered by absolute size of correlation within function. *Largest absolute correlation between each variable and any discriminant function. ^aThis variable not used in the analysis.

Classification statistics

It is also informative to examine the mean values of each of the functions for each group. These means are called group centroids. Group centroids provide an indication whether the discriminant function will contribute significantly to the separation of groups. The main objective of this analysis is to maximize the amount of variance between each group and grand mean for all the groups, while simultaneously minimizing the amount of variance that exists within each group.

Table 11.8 shows that the first discriminant function discriminates well between the healthy child group from those who are severely wasted. For this function, the mean value of group 0 (the healthy group) is 0.428, while the mean value of group 2 (the severely wasted group) is -0.837 . Thus, most of the discriminatory power of this function comes from differentiating between the children with good nutritional status with that of the severely wasted group. On the other hand, the second discriminant function does not differentiate significantly between the healthy children and the children who are severely wasted. However, it does a good job in differentiating the groups of children who are low to moderately wasted ($ZWHNEW = 1$) with that of children in the severely wasted category ($ZWHNEW = 2$). Thus, most of the discriminatory power of this function comes between differentiating the children who are severely wasted to the children who are low to moderately wasted.

Classification function based on equal and unequal prior probabilities

In order to assess the performance and in interpreting the results of a discriminant analysis model, an internal classificatory analysis can be used to assess the probabilities of correct classification (hit rates). The most common hit rate is based on the actual sample-based conditional hit rate, which represents the hit rate for a given sample-based classification rule. (For a more comprehensive treatment of the different kinds of hit rates, see, for example, Huberty et al., 1987.) SPSS uses the leave one out (L-O-O) method, which involves a two-step process. First, each observation is deleted in turn from a sample of size n and the classification functions are determined on the remaining $(n - 1)$ observations.

Table 11.8 Functions at group centroids

Weight for height category	Function	
	1	2
0.00	0.428	-0.230
1.00	-0.121	0.239
2.00	-0.837	-0.668

Note: Unstandardized canonical discriminant functions evaluated at group means.

Then, in the second stage, the classification functions are used to classify the deleted observations into one of the g groups.

Table 11.9 classifies the cases when all the three groups are assumed to be equally likely in the population, while Table 11.10 classifies cases when the groups are assumed to have different prior probabilities based on their actual frequency. In the first case, we find that only 49.5 per cent of the original cases are correctly specified. For children who have good nutritional status ($ZWHNEW > 0$) and for children who are severely wasted, the correct classification rates (hit ratio) are 60.3 and 66.7 per cent respectively. However, it fails to classify children in the low and the moderately wasted group and predicts wrong group membership (about 40.5 per cent).

For the case where groups are assumed to have different prior probabilities, we find that 60.4 per cent of the original cases are correctly predicted to belong to their respective groups. This method of assigning unequal prior probabilities based on the actual frequency now increases the correct classification rate for the children belonging to the moderate and low wasting group

Table 11.9 Classification results based on equal prior probabilities (a)

		Weight for height category	Predicted group membership			Total
			0.00	1.00	2.00	
Original	Count	0.00	41	7	20	68
		1.00	42	47	27	116
		2.00	4	2	12	18
	%	0.00	60.3	10.3	29.4	100.0
		1.00	36.2	40.5	23.3	100.0
		2.00	22.2	11.1	66.7	100.0

a. 49.5% of original grouped cases correctly classified.

Table 11.10 Classification results based on unequal prior probabilities

		Weight for height category	Predicted group membership			Total
			0.00	1.00	2.00	
Original	Count	0.00	23	45	0	68
		1.00	19	96	1	116
		2.00	2	13	3	18
	%	0.00	33.8	66.2	0.0	100.0
		1.00	16.3	82.8	0.9	100.0
		2.00	11.1	72.2	16.7	100.0

(almost 83 per cent). However, correct classification of the healthy children and children who are severely wasted suffers from correct classification. Since around 57 per cent of the children in the sample are low to moderately wasted, that information has overwhelmed the information in the discriminant scores, leading to classification in the largest group. When sample proportions are markedly unequal, their use as prior probabilities always increases the rate of correct classification.

From the discriminant function analysis, we find that improving women's status in Malawi (such as providing them with greater educational opportunities) can improve child nutritional status, possibly through the linkages of greater decision making within the household. Since improvement in educational opportunities can improve both nutritional knowledge and better care practices, it can indirectly improve children nutritional status even in the short run. Additionally, we found that better health infrastructure (such as lower distance to a protected water source) can improve child health by reducing the exposure to infections from water-borne pathogens and releasing the labor of the caregiver for various productive activities.

Conclusions

Smith et al. (2003) have convincingly demonstrated that women's status can have a positive and long-term impact on children's nutritional status across major developing regions. This is possibly because women with greater status have more control over resources in their households, are less time constrained, have better mental health and self-confidence and live in areas with greater availability of health services, which cater to their needs. Improvement in women's status relative to men can have a significant impact on children's nutritional status through a wide range of caring practices, such as complementary feeding of children in a timely fashion, treatment of illness of children and timely initiation of breastfeeding practices.

Education can equip individuals with the necessary skills that allow them better to understand, interpret and operate in a modern environment. Differentials between male and female education rates can cause women to be substantially disadvantaged not only in terms of future employment prospects but also with fewer resources (especially for female-headed households)⁵. Additionally, an uneducated female is more likely to lack nutritional knowledge and good child-care practices.

We find that educational difference, a measure of women's status, turns out to be an important discriminating factor in affecting children's nutritional status. Since there is a substantial gap in the number of years of education between the household head and the spouse, it is likely that, in Malawi, a significant portion of females within male-headed households as well as female-headed households are illiterate. Thus, they lack both nutritional knowledge and good child-care practices that are conducive to child growth. We find breastfeeding to be an

important discriminating factor for child nutritional status, which might be indirectly capturing the lack of nutritional knowledge arising out of lack of education of females. Additionally, community level variables are significant discriminatory factors in improving children's nutritional status. The above variables possibly capture the improvement of the health environment for the community as a whole, which affects the health production function and subsequently influences children's nutritional status.

An important implication that emerges from the present analysis is that improving women's educational status (both formal and informal) remains a critical agenda for Malawi, since a significant percentage of women are either illiterate or do not have basic primary educational levels. Improving educational status of women may have long-run implications on maternal nutritional knowledge, which can translate into better care practices. Additionally, access to gainful employment can help women in bargaining situations, while rightful ownership of land and ownership of productive assets can improve the likelihood of women receiving a larger share of resources.

Technical appendix: discriminant analysis

Discriminant analysis decision process

This section follows from Rencher (2002) as we have permission to reproduce from Wiley Publishers. The application of discriminant analysis (DA) can be understood from the following six-stage model building perspective: objectives, research design, assumptions, estimation, interpretation of discriminant functions and validation of discriminant results. The basic idea in a discriminant analysis is how to determine the variables that discriminate between two or more naturally occurring groups. For example, a financial researcher may be interested in determining what characteristics best discriminate between good and bad credit customers, a medical practitioner may be interested in knowing which variables best predict whether a cancer patient will recover completely, partially or not at all. Discriminant analysis is useful in the following types of situations:

1. incomplete knowledge of future situations
2. unavailable or expensive information.

DA is the appropriate statistical technique for testing the hypothesis that the group means of a set of independent variables for two or more groups are equal. For this purpose, the analysis multiplies each independent variable by its corresponding weight and adds these products together. The result is a single composite discriminant Z-score for each entity. By averaging the discriminant scores for all the entities within a particular group, one arrives at the group mean. The group mean is referred to as a *centroid*. The centroids determine the typical location of an entity from a particular group and a comparison of the group centroids determines how far apart the groups are along the dimension being tested. The statistical significance of the discriminant function is

a generalized measure of the distance between the group centroids. Now let us explain the various steps of a discriminant analysis.

Stage 1 Objectives

Discriminant analysis in general has the following research objectives:

1. to determine if statistically significant differences exist between average scores on a set of variables for two (or more) a priori defined groups
2. to determine which independent variables account for most of the differences in the average score profiles of two or more groups
3. to establish the number and composition of the dimensions of discrimination between groups formed from the set of independent variables.

This method is most appropriate when there is a single categorical dependent variable and several categorical or continuous independent variables. For understanding group differences, this technique provides insight into the role of individual variables as well as defining the combinations of variables that represent dimensions of discrimination between groups.

Stage 2 Research design

In order successfully to apply this technique, the researcher must specify which variables are independent and which variable is dependent. The number of dependent variable groups can be two or more, but these groups must be mutually exclusive and exhaustive. The independent variables can be selected in two main ways. The first approach involves identifying variables that are justified based on a theoretical model. In the second approach, the identifying variables may consist of selecting them on an intuitive basis but that logically might be related to predicting the groups for the dependent variable. Discriminant analysis is also quite sensitive to the ratio of sample size to the number of predictor variables. Many studies suggest a ratio of 20 observations for each predictor variable. While this ratio is difficult to maintain in practice, the results become unstable as the sample size decreases relative to the number of independent variables. In addition to the overall sample size, the sample size of each group must be taken into account. In practice, the smallest group size must exceed the number of independent variables. Before discussing the assumptions of the discriminant analysis, it may be useful to understand some technical aspects to it. The following section closely follows Rencher (2002) and is reproduced based on permission from Wiley Interscience.

Discriminant analysis for several groups: a technical digression

For several groups, we want to find the linear combination of the independent variables that best separate the g groups. Then a subset of the original variables is constructed that best separates the groups. The variables are then ranked in

terms of their relative contribution to group separation and the new dimensions represented by the discriminant function are interpreted. Without loss of generality, let there be g groups with n_i observations in the i^{th} group. Let $Z_{ij} = w'X_{ij}$, $i = 1, 2, \dots, g$; $j = 1, 2, \dots, n_i$ and the means $\bar{Z}_i = w'\bar{X}_i$, where $\bar{X}_i = \sum_{j=1}^{n_i} X_{ij}/n_i$. The vector w maximally separates the g groups $\bar{Z}_1, \bar{Z}_2, \dots, \bar{Z}_g$. To express separation among $\bar{Z}_1, \bar{Z}_2, \dots, \bar{Z}_g$, let the squared distance function between any two groups be expressed as:

$$\frac{(\bar{Z}_1 - \bar{Z}_2)^2}{S_Z^2} = \frac{W'(\bar{X}_1 - \bar{X}_2)(\bar{X}_1 - \bar{X}_2)'W}{W'S_P W} \tag{11.9}$$

where S_P denotes the pooled common population variance–covariance matrix. Let us assume that g independent random samples of size n are obtained from k -variate normal populations with equal covariance matrices and let matrix H be the between sum of squares (SSB) on the diagonal for each of the k variables. Off-diagonal elements are sums of products for each pair of variables. On the other hand, let matrix E be the within sum of squares (WSS) for each variable on the diagonal, with analogous sums of products off-diagonal. (For additional details on how these matrices are constructed, refer to Rencher, pp. 160–161.) Extending (11.9) to g groups, we have:

$$\lambda = \frac{W'HW}{W'EW} \tag{11.10}$$

where H is substituted for $(\bar{X}_1 - \bar{X}_2)(\bar{X}_1 - \bar{X}_2)'$ and E is substituted for S_p .

Equation (11.10) can be rewritten in the form:

$$W'(HW - \lambda EW) = 0 \tag{11.11}$$

Pre-multiplying (11.11) E^{-1} we have:

$$(E^{-1}H - \lambda I)W = 0 \tag{11.12}$$

The derivation of equation (11.12) is given in Rencher, pp. 278–279.

The solutions of (11.11) are the eigenvalues $\lambda_1, \lambda_2, \dots, \lambda_s$ associated with the eigenvectors W_1, W_2, \dots, W_s . From the s eigenvectors W_1, W_2, \dots, W_s of $E^{-1}H$ corresponding to $\lambda_1, \lambda_2, \dots, \lambda_s$ one obtains s discriminant functions $Z_1 = W'_1X, Z_2 = W'_2X, \dots, Z'_s = W'_sX$. These discriminant functions are uncorrelated but are not orthogonal. The relative importance of each discriminant function Z_i can be assessed by considering its eigenvalue as a proportion of the total (i.e. by $\lambda_i / \sum_{j=1}^s \lambda_j$). By the above criterion, often two or three discriminant functions can describe group differences.

Stage 3 Checking assumptions

In discriminant analysis, the key assumptions to be met are multivariate normality of the independent variables and equal covariance structure for the groups as defined by the dependent variable. If the sample sizes are small and the covariance

matrices are unequal, then the significance of the estimation process is adversely affected. This effect can be minimized by increasing the sample size and by using group-specific covariance matrices for classification purposes. Formally, this is given as follows: for g multivariate populations, the null hypothesis of equality of covariance matrices is given by equation (11.3) above. For independent samples, n_1, n_2, \dots, n_g one can calculate:

$$M = \frac{|S_1|^{v_1/2} |S_2|^{v_2/2} \dots |S_g|^{v_g/2}}{|S_p|^{\sum_i v_i / 2}} \quad (11.13)$$

where, $v_i = n_i - 1$, S_i is the covariance matrix of the i^{th} sample, S_p is the pooled sample covariance matrix, and $\sum v_i = \sum n_i - g$. The statistic M is a modification of the likelihood ratio and varies between 0 and 1. Values near 1 favor H_0 as in equation (11.3), while values near 0 lead to rejection of H_0 . Box (1950) provided both χ^2 and F approximations for the distribution of M and these approximate tests are called *Box's M-test*. (The details of deriving the approximate F -statistic is beyond the scope of the current chapter. The interested reader can consult Rencher, pp. 257–258.)

The χ^2 approximation is given by:

$$\ln M = \frac{1}{2} \sum_{i=1}^g v_i \ln |S_i| - \frac{1}{2} \left(\sum_{i=1}^g v_i \right) \ln |S_p| \quad (11.14)$$

Stage 4 Estimating the discriminant function and assessing overall fit

In order to derive the discriminant function, the researcher must decide on the method of estimation and then determine the number of functions that can be retained. The overall fit of the model can be assessed by either looking at the discriminant Z -scores or by comparing the group means on the Z -scores to measure discrimination between groups.

Two *computational* methods are available in SPSS in deriving a discriminant function, namely the simultaneous and stepwise methods. In the simultaneous estimation, the discriminant function is computed with all the independent variables considered simultaneously. This method is appropriate when the researcher wants to include all the independent variables in the analysis and is not interested in looking at intermediate variables based on the most discriminating factors.

Stepwise estimation, on the other hand, involves entering the independent variables into the discriminant function one at a time on the basis of their discriminating power. This approach begins by choosing the single best discriminating variable. The best discriminating variable is then paired with each independent variable one at a time and the variables that are best able to improve the discriminatory power of the function in combination with the best discriminating variable are retained. This process is repeated when all the independent variables contribute significantly to the discriminating power. This

method is useful when the researcher sequentially selects the best discriminating variable at each step and the variables that are not useful in discriminating between the groups are eliminated.

Standardized discriminant functions: the relative contribution of the X s to the separation of several groups is informative only if the variables are measured on the same scale with comparable variances. For the case of two groups, the discriminant function in terms of the standardized variables can be expressed as:

$$\begin{aligned}
 Z_{1i} &= a_1^* \frac{X_{1i1} - \overline{X_{11}}}{s_1} + a_2^* \frac{X_{1i2} - \overline{X_{12}}}{s_2} + \dots + a_k^* \frac{X_{1ik} - \overline{X_{1k}}}{s_k} \\
 Z_{2i} &= a_1^* \frac{X_{2i1} - \overline{X_{21}}}{s_1} + a_2^* \frac{X_{2i2} - \overline{X_{22}}}{s_2} + \dots + a_k^* \frac{X_{2ik} - \overline{X_{2k}}}{s_k} \quad (11.15)
 \end{aligned}$$

where $\overline{X}'_1 = (\overline{X_{11}}, \overline{X_{12}}, \dots, \overline{X_{1k}})$ and $\overline{X}'_2 = (\overline{X_{21}}, \overline{X_{22}}, \dots, \overline{X_{2k}})$ are the mean vectors for the two groups and s_r is the within sample standard deviation of the r^{th} variable, obtained as the square root of the r^{th} diagonal element of S_p . In vector form the coefficient a can be expressed as:

$$a^* = (diag S_p)^{1/2} a \quad (11.16)$$

Evaluating group differences: from equations (11.10) to (11.12), $\lambda = \frac{W'HW}{W'EW}$ is maximized by λ_1 , the largest eigenvalue of $E^{-1}H$ and the remaining eigenvalues $\lambda_2, \dots, \lambda_s$ correspond to other discriminant dimensions. These eigenvalues are the same as that of the Wilks' test for significant differences among the mean vectors. The test is given as follows:

$$\Delta_1 = \prod_{i=1}^s \frac{1}{(1 + \lambda_i)} \quad (11.17)$$

Since, Δ_1 is small if one or more λ_i s are large, Wilks' Δ tests for significance of the eigenvalues and thus for the discriminant functions. The s eigenvalues denote s dimensions of the separation of the mean vectors $\overline{X}_1, \overline{X}_2, \dots, \overline{X}_k$. The χ^2 approximation for Δ_1 is given by:

$$\begin{aligned}
 V_1 &= - \left[(n - 1 - \frac{1}{2}(q + g)) \right] \ln \prod_{i=1}^s \frac{1}{(1 + \lambda_i)} \\
 &= \left[(n - 1 - \frac{1}{2}(q + g)) \right] \sum_{i=1}^s \ln (1 + \lambda_i) \quad (11.18)
 \end{aligned}$$

which is approximately χ^2 with $q(g - 1)$ degrees of freedom. q denotes the number of variables selected at each step. If the above test leads to rejection of the null hypothesis, then one can conclude that at least one of the λ s is significantly different from zero. Thus, there is at least one dimension of separation of the mean vectors. In order to test the significance of $\lambda_2, \dots, \lambda_s$,

the procedure is to delete λ_1 from Wilks' Δ and the associated χ^2 approximation for Δ_2 is given by:

$$\begin{aligned} V_2 &= - \left[(n-1) - \frac{1}{2}(q+g) \right] \ln \prod_{i=1}^s \frac{1}{(1+\lambda_i)} \\ &= \left[(n-1) - \frac{1}{2}(q+g) \right] \sum_{i=2}^s \ln(1+\lambda_i) \end{aligned} \quad (11.19)$$

which is approximately χ^2 with $(q-1)(g-2)$ degrees of freedom. If the test leads to rejection of the null hypothesis, one can conclude that λ_2 is significant along with the associated discriminant function $Z_2 = W'_2 X$. The test statistic at the m^{th} step is given by:

$$\begin{aligned} V_m &= - \left[(n-1) - \frac{1}{2}(q+g) \right] \ln \prod_{i=m}^s \frac{1}{(1+\lambda_i)} \\ &= \left[(n-1) - \frac{1}{2}(q+g) \right] \sum_{i=m}^s \ln(1+\lambda_i) \end{aligned} \quad (11.20)$$

which is approximately distributed as χ^2 with $(q-m+1)(g-m)$ degrees of freedom.

Stage 5 Interpretation of discriminant functions

If the discriminant function is statistically significant, one needs to interpret the findings. In other words, it is important to examine the relative importance of each independent variable in discriminating between the groups. Three methods are usually proposed in the literature:

1. standardized discriminant weights
2. structure correlations
3. partial F -values.

Discriminant weights: the sign and magnitude of the discriminant coefficient (coefficients in Table 11.6) is called the discriminant weight. Each weight shows the relative contribution of its associated variable to that function. Variables with relatively larger weights contribute more to the discriminatory power of the function than do variables with smaller weights. The sign only denotes whether a variable makes a positive or negative contribution. The interpretation of the discriminant weights is analogous to the interpretation of the beta weights in a regression analysis and is subject to the same criticisms. It is important to interpret these weights with caution while interpreting the results of a discriminant analysis.

Structure correlations: this measure (often called discriminant loadings) is the simple linear correlation between each independent variable and the discriminant function. These correlations reproduce the t - or F -statistic for each variable and thus show how each variable separates the groups by ignoring the presence of the other variables. However, these correlations do not provide information

about how the variables contribute jointly to the separation of the groups and can become misleading in interpreting the discriminant functions.

Partial F-values: for any variable X_r , one can calculate a partial F -test showing the significance of this variable after adjusting for the other variables. For the several groups case, the partial Δ for X_r adjusted for the other $(k - 1)$ variables is given by:

$$\Delta(X_r|X_1, \dots, X_{r-1}, X_{r+1}, \dots, X_k) = \frac{\Delta_k}{\Delta_{k-1}} \quad (11.21)$$

where Δ_k is Wilks' Δ for all the k variables and Δ_{k-1} involves all the variables except X_r . The corresponding partial F is given as follows:

$$F = \frac{1 - \Delta}{\Delta} \frac{(n - g - k + 1)}{(g - 1)} \quad (11.22)$$

The partial F is distributed as $F_{g-1, n-g-k+1}$. The partial F -values are not associated with a single dimension of group separation as the standardized discriminant function coefficients. However, the partial F -values will often rank the variables in the same order as the standardized coefficients for the first discriminant function if $\lambda_i / \sum_{j=1}^s \lambda_j$ is very large such that the first function accounts for most of the separation among the groups.

Stage 6 Validation of results

The final stage of the discriminant analysis involves validating the discriminant results so that the results have both internal and external validity (see [Tables 11.9 and 11.10](#)). Cross-validation is an essential step in achieving validity. The most widely used procedure in validating the discriminant function is to divide the groups randomly into analysis and holdout samples. This procedure involves developing a discriminant function with the sample in the analysis and then applying it to the holdout sample. The rationale for dividing the sample into groups is that an upward bias will occur if the prediction accuracy of the discriminant function used in developing the classification matrix is the same as those used in computing the function. In other words, the classification accuracy will be higher than is valid for the discriminant function if it was used to classify a separate sample. SPSS uses the 'leave-one-out' principle in which the discriminant function is fitted to repeatedly drawn samples of the original sample. The most prevalent method is to estimate $(n - 1)$ samples, eliminating one observation at a time from a sample of n observations. This approach can only be used when the smallest group size is at least three times the number of predictor variables.

Exercises

1. Carry out a discriminant analysis by categorizing height for age (ZHANEW) and weight for age (ZWANEW) into three or four different categories similar to the

exercise undertaken in the present chapter. What are the discriminatory factors in each of the cases? Interpret the classification statistics based on equal prior probabilities and unequal prior probabilities for each group.

2. Define women's status as the product of per capita total expenditure (PXTOTAL) and the female-headed household dummy (FEMHHH). Call this variable PEXPGEND. Undertake a discriminant analysis with PEXPGEND as the variable measuring women's status along with the other predictors. Is this variable a significant predictor of child nutritional status as measured by ZWHNEW? How many discriminant functions can be derived? Interpret the classification statistics based on equal prior probabilities and unequal prior probabilities for each of the groups.
3. Now, define women's status as the product of land owned (OWNED) and the female-headed household dummy variable (FEMHHH). This is an interaction variable which shows the amount of land owned by female-headed households relative to male-headed households. Call this variable LANDGEND. Is this variable a significant predictor of child nutritional status as measured by ZWHNEW? How many discriminant functions can be derived? Interpret the classification statistics based on equal prior probabilities and unequal prior probabilities for each of the groups.

Additionally, undertake a similar analysis with ZHANEW and ZWANEW by forming similar groups like ZWHNEW, with LANDGEND as one of the predictors along with the other predictors of the present chapter. Do you find this variable to be a significant predictor of child nutritional status as measured by ZHANEW and ZWANEW? How many discriminant functions can be derived for each case? Interpret the classification statistics for both ZHANEW and ZWANEW based on equal prior probabilities and unequal prior probabilities for each of the groups.

4. Define women's status in your own words. How does improvement in women's status translate into better child nutritional outcomes? What are the different policy interventions needed to improve women's status?
5. Describe the various steps in undertaking a discriminant analysis? How does Wilks' lambda test help us in determining which discriminant functions are significant?

Notes

1. De facto FHHs are households where the male member is absent for a significant part of the time. On the other hand, de jure FHHs are those where the self-reported female head does not have any legal or common male partner. These households are usually headed by widows, unmarried women or those who are divorced or separated.
2. The impact of women's work on child health is generally ambiguous. This is because women's work can have a positive impact on child health by providing greater income and child-care. At the same time, more work can have a negative impact on child health through time constraints (such as time available for breastfeeding).
3. A very useful web resource for multiple discriminant analysis can be found at David Garson's webpage at <http://www2.chass.ncsu.edu/garson/pa765/mda.htm>
4. The main assumptions in the discriminant analysis are (a) predictor variables are multivariate normal; (b) predictor variables are non-collinear; (c) absence of outliers; (d) sample is large enough (at least 30 cases) for each predictor variable; and (e) variance covariance matrices of the predictor variables across the various groups are homogeneous.
5. UNICEF (1998) has identified 4 years of primary education as the threshold point, since women with less than 4 years of education are more likely to be illiterate than those who complete at least primary education. This is because literacy is a skill that can only be realized after the minimum number of years of education.

12 Measurement and determinants of poverty – application of logistic regression models

Through education, learning, and skill formation, people can become much more productive over time and this contributes greatly to the process of economic expansion.

Amartya Sen, Nobel Laureate in Economics, 1999.

Introduction

Poverty reduction is considered to be one of the most important goals of development and of development policy. According to the World Bank (2000), poverty is defined as ‘pronounced deprivation in well-being’, where well-being can be measured by individual or households’ possession of income, health, education, assets and certain rights in a society, such as freedom of speech. For simplicity, poverty is usually referred to as ‘whether individuals or households have enough resources or abilities to meet their needs’ (Asian Development Bank, 2001). Although the above two definitions are clearly related, in the latter definition, comparison of individuals’ income, consumption, education or other attributes with some threshold level is considered and, if individuals fall below this threshold level with a certain attribute, they are considered poor. Additionally, poverty can also be conceived of as lack of opportunities, powerlessness and vulnerability. Thus, poverty is a multidimensional phenomenon requiring multidimensional interventions in order to improve the well-being of individuals (Hulme and Shepherd, 2003).

In this chapter, we introduce concepts and methods for measuring and understanding poverty and its causes. The next section addresses the various dimensions of poverty, the causes of poverty and justifies the rationale for measuring poverty. In the following section, we explain the steps in measuring poverty and the various indicators that are widely used to measure poverty. We then discuss how poverty lines are constructed after a suitable indicator is chosen. The derivation of the poverty line based on the cost of basic needs approach is also described. This is followed by discussion on the various measures of poverty such as the headcount ratio, poverty gap and squared

poverty gap and the derivation of these measures is illustrated using Malawi data. This section also looks at the various socioeconomic characteristics of the poor. The literature on the determinants of poverty using a logistic regression framework is briefly reviewed. We then use a logistic regression model to examine the determinants of poverty using the Malawi data set and finally conclude with some implications for future poverty research.

Dimensions and rationale for measuring poverty

Defining and measuring poverty

Poverty can be understood from two broad approaches: the income and basic needs approach and the capability approach. The income and basic needs approach (often coined as the means indicators) is mainly characterized by quantitative indicators, while the human capability approach (often coined the ends indicators) is characterized by both quantitative and qualitative indicators. The capability approach usually incorporates more qualitative indicators which supplement the income and basic needs approach. The income indicators are used in the monetary approach and the basic needs approach to measure poverty, while in the capability approach, welfare is understood as an expansion of human capabilities. The latter approach assesses well-being and policy objectives in terms of freedom of individuals to live lives that are valued in realizing their true potential. This approach can be further divided into the capability approach and the participatory approach. We discuss these four approaches in turn.

Monetary approach

This is the most commonly used method in identifying and measuring poverty. In this approach, poverty is identified as a shortfall of income or consumption from some poverty line (Ravallion, 1998). Valuation of the different components of income or consumption is done at market prices that require imputing the monetary values for the items. For goods that cannot be valued at market prices (such as subsistence production and public goods), imputing monetary values is crucial for measuring poverty. The appeal of this approach to economists lies in being compatible with utility maximizing behavior of households with expenditure reflecting the marginal value that individuals place on commodities. Welfare is then measured as the total consumption enjoyed either by individuals or households and poverty is defined as the shortfall below some minimum level of resources – the poverty line.

Basic needs approach

The basic needs approach is a natural extension of the monetary approach to evaluate global poverty. ‘Basic needs’ are defined to include not only food, water, shelter and clothing, but also access to assets such as education, health,

participation in political process, security and dignity of individual (Streeten et al., 1981).

The Human Poverty Index (HPI) created by the United Nations Development Programme (UNDP) aimed to reduce the problem of income measures by using indicators that show the depth of deprivation across countries (UNDP, 1997). HPI is a composite index which uses three indicators in measuring poverty – a short life, lack of basic education and lack of access to public and private resources. The first component relates to survival and vulnerability to death at an early age. In developing countries, the index represents the percentage of people expected to die before the age of 40, while in developed economies the index represents the percentage of people expected to die before the age of 60. The second component relates to knowledge acquisition and is measured by the percentage of adults in the country who are illiterate. The final component of the index relates to overall standard of living and is a combination of three variables: the percentage of people with access to health services and safe water and the percentage of malnourished children below the age of 5.

Capability approach

The ‘capability approach’, developed by Sen (1985, 1999), is a natural extension of the HPI approach. In this approach, monetary income as a measure of well-being is rejected and indicators of the freedom to live a valued life are emphasized. In this framework, poverty is defined as deprivation in the space of capabilities or failure to achieve certain minimal or basic capabilities. ‘Basic capabilities’, according to Sen, ‘is the ability to satisfy certain important functioning up to certain minimally adequate levels’.

In this approach, well-being is seen as the freedom of individuals to live lives that are valued in terms of realization of the human potential and is thus an ends based approach. Monetary resources are considered only as means to enhance well-being, rather than the actual outcome of interest. These resources may not be considered as reliable indicators of capabilities since achievements (or functionings) can differ based on individual characteristics or contexts in which individuals live in. For example, able-bodied and handicapped individuals need different amounts of resources to obtain the same outcome. Contexts in which individuals live can also differ, such as areas where basic public services are provided versus areas where such services are absent. The conceptual framework of the capability approach is illustrated in [Figure 12.1](#). Both monetary income and public goods along with individual’s own personal characteristics (such as gender, age, and physical capacities) determine the capability set of the individual.

Participatory poverty approach (PPA)

Conventional measures of poverty (such as the income approach) rely mainly on statistical information contained in household surveys, combined with an arbitrary cut-off point (the poverty line) in separating the poor from the non-poor.

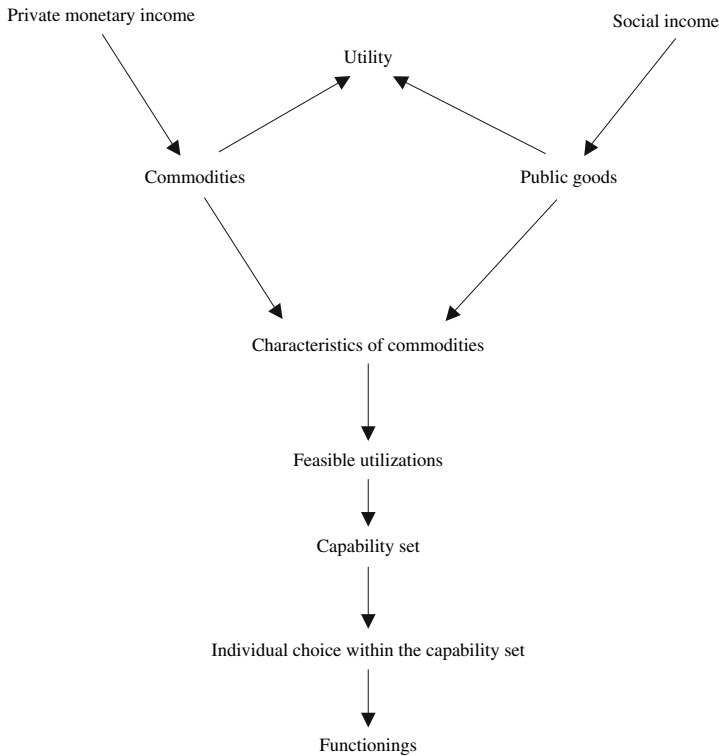


Figure 12.1 Capability approach.
(Source: adapted from Laderchi et al., 2003)

A recent empirical approach adopted by the World Bank asks people what to them constitutes poverty.

Participatory surveys are designed to learn how individuals learn from various social groups to assess their own poverty, how various survival strategies work, what kind of poverty reduction strategies people prefer and are prepared to support. These surveys draw their methodology from analytical instruments used by the World Bank such as beneficiary assessments and participatory rural appraisals (World Bank, 2000).

Rationale for measuring poverty

There are two main reasons for studying poverty:

1. targeting interventions
2. designing programs and policies to reduce poverty (Ravallion, 1998).

Targeting interventions

Having data on household poverty status allows a researcher to evaluate the impact of programs on the poor and determine whether these programs achieve

the goals with respect to targeting a certain group of households. Targeting can be an important step in effectively reaching the disadvantaged groups and backward areas. The most important use is to reduce aggregate poverty through regional targeting. An example of targeting is employment targeting. Employment targeting can help the vast majority of households in a certain country to escape poverty by their earnings through employment.

Designing programs and policies

The main purpose of this process is to inform policy makers on poverty measurement and diagnostics so as to reduce poverty over a sufficiently long-run period. For example, the World Bank introduced the concept of Poverty Reduction Strategies Paper (PRSP) for the Highly Indebted Poor Countries (HIPC) in 1999, setting out a strategy for fighting poverty. The main principle of the PRSP was that fighting poverty should be country-driven, result-oriented and comprehensive. It must also be based on the participation of civil societies along with partnerships from donors. The emphasis of the PRSP process is to have a long-term development plan to reduce poverty. The main step is to understand the characteristics and causes of poverty once it is determined how many poor are there. Once the poor are identified, the next step in the PRSP process is to choose public actions and programs that have the greatest impact on poverty.

Indicators in measuring poverty

For quantitative analysis of poverty, household income and consumption expenditure provide direct measures of household welfare. In order to assess poverty based on household expenditure, the use of an expenditure function can be a convenient tool (Deaton, 1997). An expenditure function shows the minimum cost of achieving a given level of utility u , which is derived from a vector of goods q and prices p . It is obtained by minimizing an objective function (in this case expenditure), subject to given level of utility, assuming prices to be fixed. Typically, in household surveys, the actual level of expenditure is used for information on consumption.

Income measure

While household income is a direct welfare measure, its definition remains a problem. The most accepted measure of income formulated by Haig and Simons and documented by Rosen (2002) is:

$$\text{Income} = \text{consumption} + \text{change in net worth}$$

The main problem with the above definition, however, is choosing an appropriate time period. Should it be defined over a 1-year, 5-year period or over a lifetime? An additional problem concerns measurement. While it may be easy to measure wages and salaries, interest, dividends and income from self-employment, it is difficult to measure the value of housing services or capital

gains (such as increase in the value of house, increase in the value of stocks, etc.). For these reasons income is largely understated.

For countries with significant large agricultural populations, income is seriously understated. The main reasons for income to be understated are as follows:

1. individuals may be reluctant to disclose the full extent of their income because of the tax-collector or other external problems
2. people forget, especially in a single interview, about the items they may have sold or money they have received up to a year before (Ravallion, 1998).

Consumption expenditure

Consumption includes both goods and services that are purchased and those provided from one's own production. Consumption can be a better indicator of lifetime welfare than income, since income fluctuates from year to year (it typically rises and then falls in the course of an individual's lifetime, whereas consumption remains fairly stable). However, consumption can also be systematically understated, since households may under-declare what they spend on luxuries and other illicit items (Deaton, 1997).

Durable goods can be another challenge in the computation of total consumption expenditure by households. This is because goods such as refrigerators, televisions and cars can be bought at a point in time and can be used over a period of several years. Consumption should thus include the amount of durable good that is used up during the year, which can be measured by the change in the value of asset during the year plus the cost of locking up the money in the asset. For example, if a bicycle was worth \$75 a year ago and is worth \$60 now, then \$15 worth was used. Suppose the individual used the money and earned 5 per cent in interest during the year from a savings account. Then the true cost of the bicycle was \$18.75.

The value of durable goods as part of consumption expenditure is used to achieve comparability across households. If this value were not included, one might have the impression that a household that spends \$100 on food and \$15 on renting a bicycle is better off than a household that spends \$100 on food and owns a bicycle (that it could rent out for \$15), when in fact both households were equally well off.

In measuring the value of housing services, one needs to ask how much they would have paid in rent for the house if they had not owned it. The standard procedure to impute the value of rent is to estimate rent as a function of housing characteristics such as the size of the house, the year in which it was built, the type of roof, number of bedrooms, etc. For households owning their house, the imputed rental along with the costs of maintenance and other repairs will represent the annual consumption of housing services (Deaton and Zaidi, 2002). For households that pay interest on a mortgage, the imputed rental, costs of maintenance and other repairs will represent consumption, but the mortgage interest payments should not be included in the computation (since this would represent double counting).

Household composition can be an important problem in measuring poverty. In order to avoid this problem, a direct approach is to convert household consumption to individual consumption by dividing total expenditure by the number of people in the household (Deaton and Zaidi, 2002). Then expenditure per capita is the measure of welfare assigned to each member of the household. This approach, however, is not satisfactory, since individuals have different needs. For example, a young child does not have the same food need as an adult. Also, there are economies of scale in consumption (especially for non-food items). It costs less to house a couple than to house two single individuals.

In order to address this problem, a system of weights called equivalence scales may be used. For a household of a given size and demographic composition, an equivalence scale measures the number of adult males which that household is deemed to be equivalent to. Thus, each member of the household is counted as some fraction of an adult male. Hence, household size is the sum of these fractions and is measured in the numbers of adult equivalents and not in numbers of persons. One common way of measuring this is the OECD scale of adult equivalents (AE), which can be written as:

$$AE = 1 + 0.7 * (N_{adults} - 1) + 0.5 * N_{children} \quad (12.1)$$

Thus, a one-adult household would have an adult equivalent of one, a two-adult household would have an adult equivalent of 1.7. 0.7 thus represents economies of scale. 0.5 weight is given to children, since presumably they have lower needs (such as less food, space and housing).

Construction of poverty lines using food energy intake (FEI) and cost of basic needs (CBN) approaches

Poverty lines in theory

This section closely follows and utilizes Ravallion (1998) and Ravallion and Bidani (1994). A poverty line can be defined as the minimum cost to the household for attaining the poverty level of utility at prevailing prices and for given household characteristics. Formally, let a household's utility function be represented by $u(q, x)$, where q denotes a bundle of goods in quantities and x represents the household's characteristics. The function $u(\cdot)$ assigns a single number to each possible q , given x . Let the household's expenditure function be denoted by $e(p, x, u)$, which is the minimum cost to the household with characteristics x to attain a given level of utility u when facing a price vector p . When evaluated at the actual utility level, $e(p, x, u)$ is the total expenditure on consumption, $y = pq$, for a utility maximizing household. Let u_z be the reference utility level required for escaping poverty. Then the poverty line is given by:

$$z = e(p, x, u_z) \quad (12.2)$$

The above definition shows how to arrive at poverty in terms of money to poverty in terms of utility. However, the poverty level of utility (u_z) is still not

defined. To measure poverty, one needs to combine the poverty line with the distribution of consumption expenditures. The two ways of combining the poverty line with the distribution of consumption expenditure are as follows:

1. *Welfare ratio approach*: in this approach, the money income or total expenditure (pq) can be deflated by the poverty line z so that the ratio (y/z) is the welfare ratio. Alternatively, one can compute the true cost of living index as $e(p, x, u_z)/e(p^r, x^r, u_z)$, where p^r and x^r denotes the base prices and base characteristics at a given point in time and location and $e(p^r, x^r, u_z)$ is the base poverty line. Then, the cost of living index is the ratio of each household's poverty line to the base poverty line. All money incomes can then be normalized to comparable monetary units and a single poverty line can be applied with respect to the base.
2. *Equivalent expenditure method*: in this approach, welfare is computed using the expenditure function given by:

$$y^e = e[(p^r, x^r, v(\cdot))p, x, y] \quad (12.3)$$

where $v(\cdot)$ is the indirect utility function¹ obtained as a function of prices and expenditure. Since both p^r and x^r are fixed, y^e is a monotonically increasing function of utility. The welfare ratio can then be calculated as the ratio of y^e and the base poverty line to obtain the equivalent welfare ratio.

Absolute and relative poverty

Absolute poverty is defined in terms of the standard of living in a location at a point in time, while the relative poverty increases with average expenditure. An absolute poverty line is used for the anti-poverty measures so that valid comparisons can be made between one country and another or one region to another. However, the absolute poverty line being invariant to welfare measure does not mean that it is invariant to average expenditure as well. If welfare depends on the expenditure relative to the mean of a reference group, then the real value of the poverty line will also vary with the mean. Formally, this is demonstrated as follows:

$$u = f\left(y, \frac{y}{\bar{y}}\right) \quad (12.4)$$

where $\frac{y}{\bar{y}}$ denotes an individual's or household's relative expenditure and \bar{y} is the mean expenditure of the reference group. If poverty line is absolute in the utility space, then:

$$u_z = f\left(z, \frac{z}{\bar{y}}\right) \quad (12.5)$$

Then assuming invertibility, the implicit function relating poverty line to the mean expenditure is given by:

$$z = f^{-1}(\bar{y}, u_z) \quad (12.6)$$

In other words, for the poverty line to be absolute in the space of welfare, the commodity based poverty line (z) has to increase as \bar{y} increases.

Referencing and identification problems

From the above analysis, we can see that poverty lines cannot be derived without first determining how ‘utility’ needs to be ascertained. The *referencing problem* asks the question: what is the appropriate value of u_z so that an individual can escape poverty? While it can be said that the choice is essentially arbitrary, Ravallion (1998) points out that, in the practice of poverty measurement, the choice of reference is far from arbitrary, but is crucial for poverty measure. The choice of this variable can allow for qualitative comparisons of poverty in different regions and can make priorities for policy makers for geographic targeting.

The second problem (*identification*) relates to the correct value of z , i.e. the commodity value of the poverty line. The problem arises as households vary in size and demographic composition, which influence welfare.

Deriving a poverty line

Given the above problems, how does one determine a poverty line? A solution to the above question is through constructing an objective poverty line². The key idea is that poverty lines should be set at a level that enables households to achieve certain capabilities, such as healthy and active lives and full participation in a society. There are two main approaches in constructing an objective poverty line: (a) the food energy intake (FEI) method and (b) the cost of basic needs (CBN) method. We demonstrate how to compute the poverty lines using the above approaches for Malawi and Mozambique respectively.

Food energy intake method

In this method, the poverty line is set by finding the consumption expenditure or income level at which food energy intake is just sufficient to meet pre-determined food energy requirements. Determining the food energy requirements can be difficult since requirements vary across individuals and over time for an individual. The basic idea is illustrated in [Figure 12.2](#), which shows a calorie income function.

In [Figure 12.2](#), the vertical axis is food energy intake (FEI), which is plotted against total income or expenditure on the horizontal axis. The function shows that as income (or expenditure) increases, food energy intake also rises, but more slowly. Thus, if k denotes food energy intake, with $k = f(y)$, then, for a given minimum adequate level of calorie intake k_{min} (such as 2100 kcal per day), the poverty line is given by the following equation:

$$z = f^{-1}(k_{min}) \quad (12.7)$$

This approach is parsimonious since it does not require any information about the prices of goods consumed. Let us now apply this method using the Malawi dataset. Let k denote the calories per adult equivalent for the household and let x

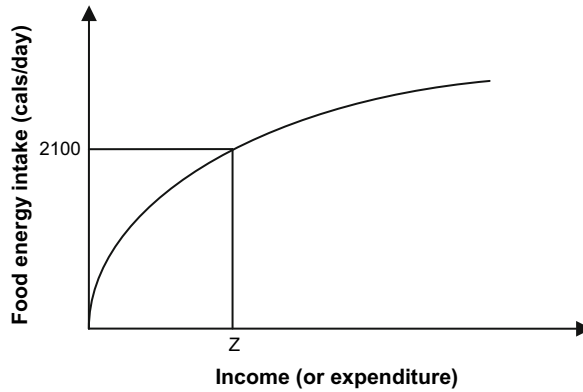


Figure 12.2 Calorie income function.
(Source: from Ravallion, 1998)

be the total household expenditure. Then the cost of calories function can be represented by:

$$\ln x = a + b k \quad (12.8)$$

Let the minimum calorie requirements be set at 2250 kcal per day. Then the poverty line is given by:

$$z = \exp(a + b L) \quad (12.9)$$

where z denotes the cost of buying the minimum calorie intake L (which is assumed to be 2250 kcal per adult equivalent). Estimating equation (12.8) using ordinary or weighted least squares, one can determine the relationship between x and k .

We estimate equation (12.8) using the Malawi dataset, by making a logarithm transformation of the calorie per adult equivalent. (We weight the observations by the household size to take into account economies of scale within the household.) Our estimated coefficients are $\hat{a} = 2.158$ and $\hat{b} = 0.328$. Then the poverty line based on FEI method is given as:

$$Z = \exp(2.158 + 0.328 * 7.718) = 107.93 \quad (12.10)$$

Thus, using this method, the poverty line is determined as a total expenditure of 107.93 kwacha per person per month.

Ravallion (1998) points out the following problems with this method. First, the relationship between food energy intake and income will shift according to the differences in tastes, relative prices, publicly provided goods or other determinants of affluence besides consumption expenditure. For example, relative prices can differ across locations, which alter the demand behavior at a given real expenditure level. The prices of certain non-food items are usually lower relative to food items in urban areas than rural areas. This may imply that the demand for food and food energy intake will be lower in urban areas relative

to rural areas for a given level of real income. However, this does not mean that urban households are poorer at a given expenditure level. The real income at which an urban resident typically attains a given level of caloric requirement is higher than in rural areas even if the cost of basic consumption needs are not different between rural and urban areas. The problem with the FEI method is that the poverty lines may not be defined in terms of the command over commodities. Access to publicly provided goods with the FEI method can also result in inconsistency of poverty estimates. For example, in urban areas, access to better health care and schooling can mean that individuals tend to consume a diet that is nutritionally better balanced with fewer calories and more micronutrients. In this case, using the FEI method, more people will be considered as poor in urban areas with a higher poverty line.

Secondly, mobility from rural to urban areas (such as migration) can result in poverty lines being higher in urban than rural areas using this method. For example, suppose that an individual who is above the FEI poverty line in the rural sector moves to the urban sector and obtains gainful employment. Though the person is better off (in the sense of greater purchasing power over commodities), the aggregate measure of poverty across sectors will show an increase since the migrant is deemed as poor. This is because the FEI poverty line has higher purchasing power in terms of basic needs in urban than in rural areas. Thus, using this method one can arrive at a measured increase in poverty in the urban sector when, in fact, none of the poor are worse off and at least some are better off. To address the above problems, the cost of basic needs (CBN) approach to poverty is given below. Ravallion (1994, 1998) and Ravallion and Bidani (1994) have demonstrated that the cost of basic needs approach does not suffer from the problem of inconsistent poverty comparisons when the food energy intake method is used to set poverty lines.

Cost of basic needs method (CBN)

This method stipulates a consumption bundle that is considered to be adequate for basic consumption needs and then the cost to each of the subgroups is considered for generating a poverty profile. This method can be interpreted in two distinct ways. First, it can be interpreted as the ‘cost of utility’ under special assumptions about preferences. The second interpretation is a socially determined normative minimum for avoiding poverty. Among the infinite number of consumption vectors that yield any given set of basic needs, a vector is chosen that is consistent with the choices actually made by some reference group (say the bottom 60 per cent of the population). Poverty is then measured by comparing actual expenditures to the cost of basic needs.

The derivation of the total poverty line at the national level can be organized in three main parts:

1. identifying regions for the definition of poverty lines
2. steps in the construction of the food poverty lines
3. construction of the non-food poverty lines.

Identifying regions

Defining a single poverty line in nominal terms for a country where standards of living vary greatly by regions is not a useful strategy. This is because markets are not often spatially integrated and there are substantial variations in regional prices. Since consumption patterns vary widely due to differences in relative prices across regions, differences in consumption patterns should be considered in assessing cost of living differentials. Thus, an appropriate level of spatial disaggregation is critical for constructing the poverty lines.

In constructing region-specific poverty lines, two considerations are important. First, a rural–urban distinction is necessary since consumption expenditure varies greatly between the rural and urban areas. Second, provinces or regions need to be grouped together which are relatively homogeneous. (See Simler et al. (2004) for an illustration of deriving regional specific poverty lines. This section closely follows procedures given in this publication.)

Constructing the food poverty lines

In the cost of basic needs approach, the food poverty line is constructed by determining the calorie intake requirements of the poor, the calorie content of a typical diet of the poor in the region and the average cost of a calorie when consuming that diet. The food poverty line is computed as the product of the average daily per capita caloric requirement and the average cost per composite calorie. In other words, the food poverty line is the cost of meeting the ‘minimum caloric requirements’ when consuming the average food bundle for the poor in a particular region.

The immediate consideration that arises is the minimum per capita calorie requirements in each region. For example, a region with a large proportion of children will typically require fewer calories per capita than a region with a higher proportion of middle-aged adults, since children usually have lower caloric requirements. In principle, while computing caloric requirements, one needs to take into account the age and sex composition of the population and the physical activity level of women (i.e. whether they are pregnant or are in the first 6 months of breastfeeding). For the sake of simplicity, the average per capita calorie requirement could be set at 2100 kcal per person per day. In deriving the *average price or cost per calorie*, it is critical to define the poorer households’ consumption bundle. Poorer households are generally defined as the bottom 60 per cent of the population in terms of per capita expenditure, often known as the ‘reference group’. In this method, detailed consumption data including the total food expenditure levels and the quantities of the food items actually consumed are necessary.

For operationalizing this method, in the first step, the resulting consumption data need to be aggregated at the household level, with the price per calorie determined. In the second step, the household level dataset can be further aggregated to the regional level, which will give the mean price per calorie for each region. The food poverty line will then be the product of the mean cost per calorie and the minimum calorie requirements.

Constructing the non-food poverty lines

The non-food poverty line is derived by looking at the non-food consumption among those households whose per capita total expenditure was equal to the food poverty line. This is also known as the lower bound of the non-food poverty line. An upper bound can be similarly constructed by looking at households whose per capita food expenditure was equal to the food poverty line. The rationale for using this method is that if a household's total consumption was only sufficient to purchase the minimum amount of calories for a typical food bundle consumed by the poor, then any expenditure on non-foods is possibly displacing food expenditure or forcing the household to buy a food bundle that is inferior to the bundle usually consumed by the poor. In either case, the non-food consumption of such a household displaces typical food consumption and thus can be considered as 'essential' (Simler et al., 2004).

The neighborhood where per capita total consumption was equal to the food poverty line is defined as 80–120 per cent of the food poverty line. The cost of the minimum food bundle is then estimated as the weighted average of non-food expenditure. Using a kernel estimation procedure with triangular weights (Datt et al., 2001), observations that were closer to the food poverty line are given a higher weight. (For an extensive discussion on kernel estimation, the following website is useful: <http://www.quantlet.com/mdstat/scripts/anr/html/anrhtmlnode11.html>.)

For example, households whose consumption was within 2 per cent of the food poverty line is given a relative weight of 10, whereas households whose consumption is between 18 and 20 per cent of the food poverty line is given a weight of 1. Observations which are more or less than 20 per cent of the food poverty line are given a weight of 0, since these households are presumed to be further away from the food poverty line. The weighted average of the non-food consumption per capita for each of the regions is determined by weighting the household level observations by the expansion factor, which is the product of the sampling weight and the triangular weights. Having information on per capita consumption and a poverty line, one could proceed to determine an appropriate aggregate measure of poverty.

New measures of poverty based on the Engel curve

While the calorie intake method and the CBN methods are extremely popular in measuring poverty, a recent approach by Kumar et al. (2008) tries to measure poverty based on the Engel curve of a community.

The approach considers an individual as a member of a community and the situation of the individual within the community that determines the norm that individuals set for themselves. While any point on an Engel curve depicts the average consumption for a given level of income for that community, a *saturating Engel curve* depicts the average consumption of an essential commodity if the individual is not constrained by low income. The cumulative shortfall of actual consumption of an essential commodity from this norm thus constitutes

consumption deprivation. The consumption deprivation of an entire community with respect to all essential commodities constitutes the poverty of the commodity.

While this poverty line is subjectively chosen by the researcher, the deprivation index is determined by the socioeconomic setting where the household is situated. The index is objectively derived from the observed Engel curve and not on nutritional or other normative considerations. Secondly, while the traditional measures of poverty are related to consumption deprivation through an indirect link between income and consumption deprivation, the index is such that if there are more households with greater consumption deprivation, greater is the contribution of the group to poverty. The index thus measures severity of deprivation.

Although this approach has only been applied to Indian households, it can be used for other countries in different socioeconomic settings.

Measures of poverty

There are a number of aggregate poverty measures that can be computed based on the assumption that the survey was a random sample drawn from the population (Foster et al., 1984). They are as follows.

Headcount measure

The headcount index is the proportion of the population that is counted as poor and is often denoted by P_0 . Formally, it is given as follows:

$$P_0 = \frac{1}{N} \sum_{i=1}^N I(y_i \leq z) = \frac{N_p}{N} \quad (12.11)$$

where N is the total population and $I(\cdot)$ is an indicator function that takes on a value of 1 if expenditure (y_i) is less than the poverty line (z) and is 0 otherwise. N_p denotes the total number of poor. The main advantage of this measure is that it is simple to construct and easy to comprehend. However, this measure does not take into account the intensity of poverty. For example, consider the following two income distributions of two hypothetical regions within a country, where the poverty line is 130.

	Expenditures for individuals				P_0
Region A's expenditure	90	110	200	200	50%
Region B's expenditure	115	125	200	200	50%

From the above example, it is evident that there is greater poverty in region A. However, the headcount index does not capture this phenomenon. Second, the index violates the transfer principle. In other words, if a somewhat poor household transferred some income to another poor household, the index would remain unaltered, although one can presume that overall poverty has been

reduced. Finally, the index does not indicate how poor the poor are and thus does not change if people below the poverty line become poorer.

Poverty gap index

This is a popular measure of poverty and shows the extent to which individuals fall below the poverty line and computes that as percentage of the poverty line (Foster et al., 1984). Formally, let the poverty gap (G_n) be defined as follows:

$$G_n = (z - y_i)I(y_i \leq z) \quad (12.12)$$

Then the poverty gap index can be written as:

$$P_1 = \frac{1}{N} \sum_{i=1}^N \frac{G_n}{z} \quad (12.13)$$

The above measure is the mean proportionate gap in the population (where the non-poor have zero poverty gap). Some researchers consider this measure as the cost of eliminating poverty, since it shows how much money needs to be transferred to the poor so that their income (or expenditure) can be brought up to the poverty line. However, the minimum cost of eliminating poverty using targeted transfers is the sum of all poverty gaps within a population. However, policy makers do not always have enough information to make the transfers to the targeted segments of the population.

The advantage of this measure is that there is no discontinuity in the poverty line. However, an important drawback of this measure is that it may not capture the differences in the severity of poverty among the poor. For example, consider two regional income distributions of a country as follows: Region A = (1, 2, 3, 4) and Region B = (2, 2, 2, 4) and let the poverty line $z = 3$. Then the poverty gap index for both the regions is 0.25. However, the poorest person in region A has only half the consumption of the poorest in region B. Thus, one can consider B being generated from A by a transfer from the least poor of the poor persons (individual with an expenditure of 3 in A) to the poorest. Thus, the main drawback is that it ignores inequality among the poor.

In summary, the poverty gap index is the average of all the individuals of the gaps between poor people's standard of living and the poverty line, expressed as a ratio to the poverty line. The smaller the poverty gap index, the greater is the potential to allocate budget in identifying the characteristics of the poor so as to target benefits and programs.

Squared poverty gap index

In order to address the problem of inequality among the poor, the squared poverty gap index is often used (Foster et al., 1984). This is a weighted sum of poverty gaps (as a proportion of the poverty line) where the weights are directly proportional to the poverty gaps themselves. For example, a poverty gap of 20 per cent of the poverty line is given a weight of 20 per cent, whereas a poverty gap of

60 per cent of the poverty line is given a weight of 60 per cent. By squaring the poverty gap index, the measure imposes more weight on observations that fall well below the poverty line. Formally, this is defined as follows:

$$P_2 = \frac{1}{N} \sum_{i=1}^N \left(\frac{G_n}{z} \right)^2 \quad (12.14)$$

The advantage of this measure is that it reflects the severity of poverty and is sensitive to the distribution among the poor. However, the measure lacks intuitive appeal and is harder to interpret.

All the above measures of poverty can be thought of as being generated by a family of measures proposed by Foster et al. (1984), also called the FGT measure. Formally, it can be defined as follows:

$$P_\alpha = \frac{1}{N} \sum_{i=1}^N \left(\frac{G_n}{z} \right)^\alpha \quad \text{with } \alpha \geq 0 \quad (12.15)$$

where the parameter α is a measure of sensitivity of the index to poverty. The poverty gap for individual j is given by $G_j = z - y_j$ (with $G_j = 0$ if $y_j > z$). When the parameter $\alpha = 0$, the measure in equation (12.15) boils down to the headcount index. When $\alpha = 1$, we have the poverty gap index P_1 , and when $\alpha = 2$, we have (12.15) boiling down to the poverty severity index.

Properties of P_α

1. For all $\alpha > 0$, P_α is strictly decreasing in the living standard of the poor.
2. For $\alpha > 1$, increase in measured poverty due to a fall in the standard of living will be greater the poorer one is. In other words, it is said to be 'strictly convex' in incomes.

The measures of depth and severity of poverty give us complementary information on the incidence of poverty. Thus, some income groups might have higher poverty incidence but low poverty gap, while other income groups might have lower poverty incidence but higher poverty gap. Thus, interventions needed to help these two groups will have to be different in nature.

Computing poverty measures for Malawi

We now demonstrate how the various measures of poverty are computed using equations (12.11), (12.13) and (12.14) respectively. Table 12.1 gives the poverty headcount, the poverty gap index and the poverty severity index for the full sample of households of all the regions combined together and for Mzuzu, Salima, and Ngabu regions respectively.

The above estimates show that 73.2 per cent of Malawi's population lived in poverty during 1991–92. Although regional comparisons are more difficult to understand, given the confounding effect of the presence of both rural and urban households within a given region, the incidence and severity of poverty was highest in the Salima add-code³ (which is located in the central part of

Table 12.1 Individual poverty measures by regions using the 604 household data set

Regions	Poverty headcount (in per cent)	Poverty gap index	Poverty severity index
Full sample	73.18 (0.01)	0.41 (0.01)	0.28 (0.01)
Mzuzu	62.21 (0.03)	0.28 (0.02)	0.15 (0.01)
Salima	83.04 (0.02)	0.54 (0.02)	0.40 (0.02)
Ngabu	73.89 (0.035)	0.40 (0.027)	0.27 (0.02)

Note: Standard errors are corrected for sample design and are given in parentheses.

Malawi) followed by Ngabu (which is located in the southern part of Malawi)⁴. Relative to these two regions, Mzuzu had a lower proportion (62.2 per cent) of poor people. Additionally, both the poverty gap and severity index was lower in Mzuzu relative to the rest of the regions. A possible reason for this difference in intensity and severity across regions can be attributable to the densely populated areas in the southern and central regions of the country, which have the lowest mean incomes. Having investigated the measures of poverty across regions, let us turn our attention to some of the characteristics of poor households.

Characteristics of poor households

The analysis presented below shows some of the economic and demographic characteristics of the poor households compared to the non-poor households using the cross-tabulation procedure.

Table 12.2 shows that the Malawian smallholders own very few productive assets and have only small plots of land. Compared to only 40 per cent of the households who are not poor and owning less than 1 hectare of land, the poorer households constitute about 59 per cent. The difference was found to be significant using the chi-square tests. The computed chi-square value was 19.44, while the critical value at 1 per cent level of significance is 15.08 (for 5 degrees of freedom). Since the computed value is greater than the critical value, one can conclude that there is significant difference in landholdings by poor and non-poor households. One of the possible conclusions can be that access to more inputs, such as the size of land owned, could raise farm productivity significantly (possibly through adoption of improved agricultural technology) and can be used as a policy measure for lowering poverty.

Dependency ratio is defined as the ratio of the number of children and individuals above 60 years of age to the total household size. From Table 12.3, it is evident that poorer households have a higher percentage (about 57 per cent) of

Table 12.2 Cross-tabulation results of land owned by number of poor people

		No. of people		Total
		Not poor	Poor	
Size of land owned	< 1 hectare	65 40.12%	259 58.6%	324
	1 to 2 hectares	86 53.09%	158 35.75%	244
	> 2 hectares	11 6.79%	25 5.66%	36
Total		162	442	604 = <i>n</i>

Table 12.3 Cross-tabulation results of dependency ratio by the number of poor people

		No. of people		Total
		Not poor	Poor	
Dependency ratio	< 0.5	79 48.77%	189 42.76%	268
	≥ 0.5	83 51.23%	253 57.24%	336
Total		162	442	604 = <i>n</i>

dependents compared to the non-poor households (about 51 per cent). This difference was also found to be significant using the chi-square tests. The computed chi-square value was 83.93, while for 50 degrees of freedom, the area to the right of a chi-square value at 0.01 level of significance is 76.19. One can conclude that there is a significant difference in the dependency ratio between the poor and non-poor households, since the computed value is greater than the critical value. Thus, a higher dependency ratio may be positively correlated with the level of household poverty.

Selected review of studies on determinants of poverty

In this section, we review a few studies that examine the determinants of poverty using a logistic regression framework.

Rodriguez and Smith (1994) examined the factors affecting the levels of poverty among urban, rural, rural-farm and rural non-farm families using several logit models. The choice of Costa Rica (although it was a middle income country during 1993) was primarily motivated by the fact that it was adversely affected by an economic recession during the 1980s, which resulted in reversals in gains in poverty reduction achieved during the previous decade.

The analysis was undertaken using a logistic regression framework. The dependent variable was the poverty status of the family, which assumed two values: one being poor and zero being non-poor. Two models were estimated. The first examined whether employment of the head was a significant determinant of poverty, while the second investigated whether participation of the household head in the labor market affected poverty.

The results from the study point out that poverty is a multidimensional phenomenon and several approaches are needed to address it effectively. On the one hand, trends towards lower child dependency ratio should reduce poverty levels. On the other hand, education and employment policies cannot be considered as separate efforts in reducing poverty, but should be mutually reinforcing. While education and employment-related variables had relatively more influence in reducing urban and rural non-farm poverty, it does not imply that efforts should be less in rural and farm settings. On the contrary, in the presence of large rural to urban migration, farm residents could be better off if they had some education. Thus, in combination with greater regional development, rural and farm families could have a better chance of obtaining gainful employment if they were educated.

Grootaert (1997) assessed the role of household endowments in determining the poverty status of households after controlling for the macroeconomic factors and the household's socioeconomic status. The incidence of poverty greatly increased in Cote d'Ivoire during the 1980s. In the second half of the decade, household consumption declined by more than 30 per cent and poverty rose sharply. Headcount increased from 30 per cent during 1985 to 46 per cent during 1988. By the end of the decade, half of the population was estimated to live in poverty. The data came from the Cote d'Ivoire Living Standards Survey (CILSS), which was conducted annually from 1985 to 1988. Each year, the survey covered a representative sample of 1600 households and detailed information on employment, income, expenditure, assets and other socioeconomic characteristics was collected.

A probit model was used to examine the determinants of poverty to address how the parameters differed across different segments of the distribution. Additionally, the study undertook sensitivity analysis by varying the poverty line and then re-estimating the probit model to determine whether an increase in a given explanatory variable reduced the probability of being poor regardless of the poverty line. The study was undertaken separately for urban and rural regions for two time periods, namely 1985 and 1988.

The main results were that in both years and for both regions, urban and rural, education reduced the probability to be poor. In urban areas, the coefficients were largest at the lowest poverty line while, in rural areas, the effect tended to increase with a higher poverty line. Second, for urban areas in particular, a strong location effect persisted, implying that an otherwise similarly endowed household will be poorer in other cities compared to Abidjan. Finally, the results indicated that the probability for a non-Ivorian household to be poor in rural areas increased between 1985 and 1988.

Justino and Litchfield (2002) examined the impact of trade-related reforms on poverty, controlling for household and community level characteristics. The two important trade-related reforms considered in the study were:

1. liberalization of agricultural markets for outputs and inputs (including removal of price controls on rice and other crops and fertilizers)
2. liberalization of export markets (through removal of export quotas and tariffs).

The study used data from the Vietnam Living Standards Measurement Survey (VLSS), conducted during 1992–93 and 1997–98. Given that data for two time periods were available, it was possible to examine households that remained poor, had moved out of poverty or fell into poverty and determine which household characteristics were associated with these movements. The analysis developed in the paper was based on a panel of 3494 rural households and the standard of living indicator considered was household expenditure per capita, using the food and non-food poverty lines.

A multinomial logit model⁵ was postulated for analyzing household poverty dynamics. Poverty dynamics between the two periods was divided into four mutually exclusive outcomes:

1. being poor in both periods
2. being non-poor in the first period and poor in the second period
3. being poor in the first period and non-poor in the second period
4. being non-poor in both periods.

This model was used to compute the odds ratio of the household escaping and falling into poverty. The log-odds ratio can be computed as $\ln (P_{ij} / P_{i0}) = X'_j (\beta_j - \beta_k)$.

The study empirically examined the impact of trade-related reforms on household poverty dynamics using a multinomial logit regression model. In particular, two important reforms were highlighted:

1. liberalization of agricultural markets and prices of agricultural crops
2. liberalization of export markets followed by the removal of export quotas and tariffs, which influenced employment patterns of households.

The main findings can be summarized as follows:

1. employment effects were positive and had significant poverty reduction effects for households employed in the main export sectors – seafood, food processing, textiles and garments and footwear. These effects benefited not only households that in 1992–93 were involved in the export industries, but also households that increased the number of members employed in 1997–98
2. trade reforms that affected the agricultural sector through an increase in the price of agricultural products had a strong impact on the poorest households. In particular, increases in agricultural diversification between 1992–93 and 1997–98 benefited the rural households significantly. The decrease in poverty was noticeable among households that diversified away from producing rice.

As policy measures, the study recommends further diversification of rural incomes by encouraging the establishment of small-scale farm and non-farm enterprises for reducing poverty further.

Bigsten and Shimeles (2004) addressed factors that are related to the dynamics of income poverty using a unique household panel data for both urban and rural areas of Ethiopia over the period 1994–97. The novelty of the study was to understand vulnerability to poverty, as an integral component in the analysis of poverty. Vulnerability, as defined by Pritchett et al. (2000), is the probability of being below the poverty line at any given year.

Additionally, poverty was decomposed into a chronic and a transient component, where each was defined over a stream of income for an individual over the entire period. The measures of vulnerability were then compared with chronic poverty to understand the persistence of poverty. The dataset consisted of 3000 households both from the urban and rural areas and divided equally between them.

The method used to derive the poverty spell was to compute the probabilities of falling into poverty, given certain states and other characteristics of households. Thus, a duration analysis was undertaken to estimate the entry and exit probabilities for being in poverty.

Formally, let X be a random variable indicating the duration of poverty or the length of time an individual had been in poverty and let the distribution and density functions be:

$$F(x) = Pr(x < X), f(x) = dF(x)/dx$$

The conditional probability is given by:

$$\theta(x) = Pr(x \leq X/X \geq x) = \frac{f(x)}{1 - F(x)}$$

Assuming θ to follow a logistic structure, with $x_{idt} = \alpha_{id} + \beta_{it}Z_{it}$, where the length of the probability depending on the duration effects, and other variables Z that vary across people and time. i , t , and d denotes individuals, time and the number of years in poverty respectively. Then the probability of exiting poverty will be given by the following hazard function:

$$\theta_{idt} = \frac{\exp(\alpha_{id} + \beta_{it}Z_{it})}{1 + \exp(\alpha_{id} + \beta_{it}Z_{it})}$$

The above exit probabilities are estimated by maximizing the relevant log-likelihood function for all observations which are quite similar to the logit estimates.

To complement the analysis of transitory poverty, the study then investigated the determinants of chronic poverty. The main determinant of chronic poverty was the education of the household head. Additionally, chronic poverty was reduced by variables such as crop sales, ownership of assets and market access. An interesting finding was that off-farm activity was associated with higher chronic poverty, suggesting that off-farm activity was a survival strategy and not an indication of a household moving up the income scale.

One of the main results was that poverty was more persistent in urban areas compared to rural areas in Ethiopia. The above result clearly demonstrated that different approaches were required to fight poverty in urban and rural areas. Security issues were more important in rural areas, while expanding opportunities were more appropriate in the urban areas.

Thus, for policy purposes, depending on the nature of poverty (chronic or transitory), different measures need to be undertaken. If the nature of poverty is chronic, one needs to invest in long-run projects and structural reforms. This can include building up of human capital through education and health services apart from investment in physical and financial assets. On the other hand, if poverty was found to be transitory, temporary interventions to support households during bad periods are required. The measures could include different forms of safety nets, credit and insurance schemes.

A recent paper by Rhoe et al. (2008) analyzes poverty in Kazakhstan using LSMS data. Poverty measures based on a food poverty line and total poverty line are compared and the determinants of poverty are analyzed. They find that although there are some variations among the determinants of poverty under the two poverty lines, the explanatory power of the common determinants reduces when non-food expenditures are included in deriving the poverty line.

Determinants of poverty – binary logistic regression analysis

In this section, we analyze the determinants of poverty using a logistic regression model with a binary dependent variable with mutually exclusive and exhaustive outcomes (Tabachnick and Fidell, 2001). The dependent variable is the poverty status of household i , which is 1 if the household is poor and zero otherwise. Let us consider the following levels regression of the form:

$$y_i = \beta x_i + \varepsilon_i \quad (12.16)$$

where y_i is household expenditure per capita, β denotes the vector of parameters, x_i is the vector of household characteristics and ε_i is the error term.

The above equation can be estimated by least squares assuming normally distributed error term. The above specification can, however, be extended in the analysis of household welfare relative to some pre-determined poverty line as follows:

$$\begin{aligned} s_i &= 1 \text{ if } y_i \leq z \\ s_i &= 0 \text{ otherwise} \end{aligned} \quad (12.17)$$

where s_i is the categorical poverty indicator for household i and z is the poverty line. The binary specification can then be written as:

$$\Pi_i = P(y_i = 1) = F(z - \beta x_i) \quad (12.18)$$

where P_i is the probability that the household is poor and F is the cumulative probability function. The above model can then be estimated by probit or logit, assuming logistic distribution of the error term. Before proceeding on to the

main analysis, it may be useful to substantiate on the dichotomous logistic regression model.

Dichotomous logistic regression model

The logistic regression model can be written in terms of the log of the odds (odds are simply defined as the probability of a ‘success’ outcome divided by the probability of a ‘failure’ outcome), called the logit, as follows:

$$\log\left(\frac{\Pi_i}{1 - \Pi_i}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k \quad (12.19)$$

With the above model, the logit is just the natural logarithm of the odds and the range of values that the left-hand side of equation (12.19) are between $-\infty$ and $+\infty$. An alternative way of writing the above model in terms of the odds is that:

$$\frac{\Pr(y = 1)}{\Pr(y = 0)} = \frac{\Pi_i}{1 - \Pi_i} = \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k) \quad (12.20)$$

The range of values is between 0 and ∞ that the right-hand side of (12.20) can assume.

Rearranging (12.20), the underlying probability of a success outcome is given by

$$\Pi_i = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k)}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k)} \quad (12.21)$$

Equations (12.19) to (12.21) are identical in interpretation. However, for practical purposes, equations (12.19) and (12.21) are usually computed, since it provides not only the logit estimates, but also the probability of success.

An example with the Malawi dataset

Suppose we ran a regression similar to equation (12.19) with the probability that the household is poor as the dependent variable and the size of the land owned as the only independent variable. Then the regression equation becomes:

$$\log\left(\frac{\Pi_i}{1 - \Pi_i}\right) = 1.83 - 0.299 \text{ LANDO} \quad (12.22)$$

The probability that an individual is poor using equation (12.21) is given by:

$$P(y = 1) = \frac{\exp(1.83 - .299 \text{ LANDO})}{1 + \exp(1.83 - .299 \text{ LANDO})} \quad (12.23)$$

The probability that a household is poor with a size of land owned = 3 (i.e. owning land between 1 and less than 1.5 hectares) using equation (12.23) is 0.717, while the probability that a household is poor with a size of land

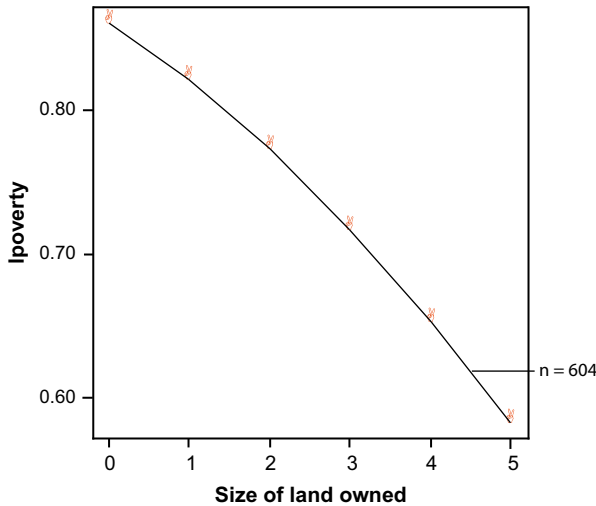


Figure 12.3 Logistic regression plot of the probability of being poor with size of land owned.

owned = 5 (i.e. owning land greater than 2 hectares) is 0.582. The probability of being poor declines as the household owns more land. Figure 12.3 shows the plot of the size of land owned with the probability that the household is poor.

As evident from Figure 12.3, as the size of land owned by the household increases, the probability of being poor decreases monotonically at a decreasing rate. This is due to the functional specification as in equation (12.21), as multiplying successive values of the size of land owned decreases the probability of poverty exponentially.

Expected determinants of household welfare

This section will summarize the expected determinants of household welfare using a logistic specification. The model is as follows:

$$P(y = 1) = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k)}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k)} \tag{12.24}$$

where $y = 1$ if the family is poor and zero if the family is non-poor. A household was found to be poor if its total expenditure was 107.93 kwacha per person per month using the food energy intake method described above. X_1, X_2, \dots, X_k are the set of explanatory variables and β_k is the parameter associated with X_k . The main determinants of household welfare will relate to household and demographic characteristics, area owned (a measure of assets of the household), technology (as measured by maize productivity for the maize growing households), household food security and community variables.

The *household level characteristics and demographic variables* are age of the household head, household size, education of the spouse, gender of the household head and marital status of the household head. The age of the household head can have a significant impact on welfare, since older heads of households are likely to have more experience and respect in the community.

The effect of household size on household welfare can be either positive or negative and depends in part on the degree of rivalry in consumption among household members. If all consumption is public, every marginal increase in consumption benefits all household members. An example of such consumption could be increased security within the community or provision of a tap providing clean drinking water.

In contrast, where all consumption is private (with only one person benefiting from any consumption activity), only one member's welfare increases and not the entire household. An example might be nutrition. In such a case, household welfare decreases with household size.

Moreover, there may be synergies from larger household size, both in production and consumption activities. Working in groups can be more productive through pooling tools and experience, or through higher motivation. Returns to scale can have an impact on household welfare via household size for a given degree of rivalry in production and consumption. Thus, this variable will be included in determining whether rivalry or scale effect dominates in affecting household welfare.

Household education is likely to have a positive effect on household welfare. We include the education of the mother since it generally has a larger positive effect on household food consumption than the male head. The gender of the household head can be an important determinant of household welfare, since female-headed households suffer from the twin constraints of labor supply (time constraint) and caring activities for the children. The twin constraints can reduce their effective time at work and thus affect their wages and other earnings, consequently reducing household welfare.

Land owned (as a measure of asset) can be directly linked to household welfare through the quality and characteristics of the cultivated land and through the total area farmed per household. These characteristics affect household agricultural production, credit opportunities and, indirectly, household labor availability and thus on welfare. The general expectation is that an increase in the area owned by the household will raise welfare.

Increase in *agricultural productivity* is an important determinant of household welfare in the long run by releasing household resource and other constraints. Since the main food crop produced in Malawi is maize, we consider yields from local maize (for only those households that grow maize) as a measure of productivity. This is defined as the total quantity harvested of local maize to household size (PRODLMAIZ). We also include production of composite maize (COMPOSIT) (which is a dummy variable) as an additional measure of productivity.

Intrinsically related to agricultural productivity, household food security can be an important determinant of household welfare. If a household is food insecure, it is more likely that the members of the household are undernourished, which can affect labor productivity adversely. This, in turn, can reduce household welfare. The measure of household food security considered is based on per adult equivalent calorie intake for households. It is defined as households being able to satisfy at least 80 per cent of the requirement for calorie intake.

Finally *community level* variables are expected to be key determinants of household consumption. Both the absence of protected drinking water source and health infrastructure can affect household welfare adversely and the variables captured for these effects are distance to the nearest health clinic (HEALTDST) and distance to a protected drinking water source (DRINKDST). In addition, since private traders can improve market access (through selling staple crops) and thereby ensure regular supply of low cost food to the households, the presence of private trader (PBTRADER) is also included as a community level variable. Finally, we also include a local market dummy variable (which assumes a value of one if the household is located more than 5 km from the nearest market place and zero otherwise) to understand how households' market access affects their welfare.

Empirical results

Two issues that seem critically important in logistic regression estimation are:

1. how good the model fits the data
2. how to interpret the fitted model.

Measuring model fit

The following four statistics are available for assessing overall model fit with two or more independent variables.

1. Log-likelihood ratio

The logistic regression model uses maximum likelihood method⁶ to maximize the equation's log-likelihood (LL) function. Softwares differ in reporting either the LL value or minus twice the value ($-2LL$), which has distributional properties enabling us to apply the chi-square distributions. The LL function is always used in comparison to an alternative equation specification.

A pair of multivariate equations is called '*nested*' if all the parameters included in the first equation also appear in the second equation. In other words, the first equation is '*nested inside*' the second. The difference in $-2LL$ s for a pair of nested equation tests whether the additional parameters specified in the second equation improves the fit to the data over the first equation's fit. In other words, we want to test the following null hypothesis:

$$\begin{aligned} H_0 &: (-2LL_1) - (-2LL_2) = 0 \\ H_1 &: (-2LL_1) - (-2LL_2) > 0 \end{aligned}$$

The log-likelihood ratio for comparing the two nested equations is given by:

$$G^2 = (-2 \ln L_1) - (-2 \ln L_2) \quad (12.25)$$

The G^2 test-statistic is distributed as chi-square with degrees of freedom equal to the difference in the two equations. In our example, the initial $-2LL$ value where the ‘constant only’ equation is estimated is 163.37. The $-2LL$ value at the first iteration step is 135.73. Thus, the difference between these two $-2LL$ values is $163.37 - 135.73 = 27.64$, which is the output in the omnibus tests for model coefficients. The model chi-square has 11 degrees of freedom, since the first model has 1 degree of freedom (for the constant) and the second model has 11 degrees of freedom (the constant plus the 11 predictors). If we set $\alpha = 0.005$, the critical value of $\chi^2_{11} = 26.75$. Since the computed value is greater than the critical value, we reject the null hypothesis and conclude that including the additional parameters specified in the second equation improves the fit to the data over the first equation’s fit (with only the constant term).

2. Hosmer–Lemeshow goodness of fit test

A commonly used test of the overall fit of a model to the observed data is the *Hosmer and Lemeshow test*. The idea is to form groups of cases and construct a ‘goodness of fit’ statistic by comparing the observed and predicted number of events in each group. The cases are first put in order by their estimated probability on the outcome variable. Then the cases are divided into 10 groups according to their estimated probability, i.e. those with estimate probability below 0.1 (in the lowest decile) form one group and so on, up to those with estimated probability 0.9 or higher (in the highest decile).

The next step is to divide the cases into two groups on the outcome variables (namely not poor and poor) to form a 2×10 matrix of observed frequencies. Expected frequencies for each of the 20 cells are obtained from the model. If the logistic regression model fits well, then most of the case with outcome = 1 or the poor are in the higher deciles of risk and most with outcome = 0 or the non-poor are in the lower deciles of risk.

The goodness of fit statistic is then calculated as:

$$GFIT = \sum_{cells} \frac{(f_0 - f_E)^2}{f_E} \quad (12.26)$$

where f_0 and f_E are the observed and the expected numbers in the cell as in [Table 12.4](#). The idea is that closer the expected numbers to the observed, the smaller the value of this statistic and smaller values will indicate that the model is a good fit. The value of this test-statistic with all the explanatory variables (both categorical and continuous) is 4.34, which is compared to the critical value from the chi-square distribution with 8 degrees of freedom (number of groups -2).

Table 12.4 Contingency table for Hosmer and Lemeshow test

		Poor1 = .00		Poor1 = 1.00		Total
		Observed	Expected	Observed	Expected	
Step 1	1	11	11.062	2	1.938	13
	2	9	8.217	4	4.783	13
	3	8	6.501	5	6.499	13
	4	3	4.652	10	8.348	13
	5	3	3.563	10	9.437	13
	6	3	2.548	10	10.452	13
	7	1	1.609	12	11.391	13
	8	2	.979	11	12.021	13
	9	0	.560	13	12.440	13
	10	0	.308	17	16.692	17

The P value is 0.825 and thus we do not reject the null hypothesis that there is no difference between the observed and predicted values. Hence, we conclude that the model appears to fit the data reasonably well.

3. Generalized coefficient of determination

In linear regression models, one measure of usefulness of the model was the statistic R^2 , which gives the proportion of variation in the outcome variable explained by the model. Several statistics have been proposed in the logistic regression framework that is almost equivalent in interpretation to the R^2 in the linear regression model. Cox and Snell (1989) proposed a generalization of the least squares coefficient of determination as:

$$R^2 = 1 - \left(\frac{L_0}{L_1} \right)^{2/N} \quad (12.27)$$

where L_0 is the log-likelihood function for the ‘constant only’ equation, L_1 is the log-likelihood for the equation with one or more predictors and N is the sample size. Nagelkerke (1991) adjusted the above coefficient by rescaling it according to the largest value R^2 can achieve, thus enabling the measure to reach a maximum of 1. This is given as follows:

$$\bar{R}^2 = \frac{R^2}{R_{\max}^2} = \frac{R^2}{1 - (L_0)^{2/N}} \quad (12.28)$$

Both coefficients should be viewed as purely descriptive statistics that provide a rough approximation for judging a model’s predictive efficacy. No statistical test is available in the logistic regression model to test the null hypothesis that $R^2 = 0$ in the population as in the OLS.

From [Table 12.5](#), both the measures of the coefficient of determination improve significantly over stage 1. The interpretation is that the model explains

Table 12.5 Coefficient of determination in successive steps

Coefficient of determination	Step 1*	Step 2**
R^2	0.186	0.31
\bar{R}^2	0.265	0.44

Notes: * Based on comparing the log-likelihood for the constant model and the model with only continuous variables; ** based on comparing the log-likelihood for the model with only continuous variable to the model with both continuous and categorical variables.

about 44 per cent variation in the data. However, as explained before there is no formal test that can tell us whether 44 per cent is sufficient or not.

4. Classification table

Another way of assessing how well the model fits the data is to produce a classification table. This is a simple tool that indicates how good the model is at predicting the outcome variable (namely poor and non-poor). Ordinary least squares (OLS) regression equations are usually used to predict the score of every case, which can then be compared to the observed value to see how accurate the prediction is. The logistic regression procedure, on the other hand, uses the estimated equation to decide if the expected probability is < 0.5 , then the predicted score is 0. On the other hand, if the expected probability is ≥ 0.5 , then the predicted value is 1. The percentages of correctly predicted cases are then calculated and displayed in a classification table. If the equation ‘completely explains’ the variation of the dependent variable, all cases would fall on the main diagonal and the overall percentage correct would be 100 per cent. In other words, cases predicted to be equal to 0 would be observed 0s and predicted 1s would be the observed 1s.

Table 12.6 seems to indicate an impressively high level of correct predictions (82.8 per cent overall). It predicted the poor correctly by 91.5 per cent and the non-poor by 62.5 per cent. Thus, from all the above tests, the model fits the observed data very well.

Interpreting the logistic coefficients and discussion of results

Recall from the discussion of the first part of this section that the logistic regression model can be written on three different scales, namely logit, odds or probability. We will report the results on the logit scale. The null hypothesis that the population value of a given parameter is zero is given by:

$$H_0 : \beta_k = 0$$

$$H_1 : \beta_k \neq 0$$

In the logistic regression model, a *Wald* statistic is computed, to decide on whether to reject the null hypothesis. This statistic is distributed as a

Table 12.6 Classification table

Observed		Predicted			
		poor1		Percentage correct	
		.00	1.00		
Step 1	poor1	.00	25	15	62.5
		1.00	8	86	91.5
	Overall percentage				82.8

chi-square variable with one degree of freedom and is given by the following expression:

$$Wald = \left(\frac{b_j}{S_{b_j}} \right) \quad (12.29)$$

The above formula is just the square of the usual *t*-test (when the tested population parameter is 0). One can also construct the confidence intervals for the β s based on the estimated coefficients and the standard errors. We proceed to the determinants of poverty using equation (12.24). The results are reported in Table 12.7.

Using equation (12.19), the logit model can be written as follows:

$$\begin{aligned} \log\left(\frac{\Pi_i}{1 - \Pi_i}\right) = & 10.64 + 0.05 (\text{MBRAGE}) - 0.001 (\text{MBRAGESQ}) \\ & - 0.112 (\text{EDUCSPOUS}) - 1.74 (\text{HHOLDHED}) \\ & + 0.086 (\text{MSTATUS}) - 0.27 (\text{HHLDQTY}) \\ & - 0.008 (\text{PRODLMAIZ}) - 1.27 (\text{COMPOSIT}) \\ & - 0.471 (\text{OWNED}) - 1.30 (\text{CALREQ}) \\ & - 0.369 (\text{HEALTDST}) + 0.08 (\text{DRINKDST}) \\ & - 0.65 (\text{PBTRADER}) - 2.86 (\text{MKTGT}) \end{aligned}$$

As evident from Table 12.7, household characteristics such as age of the household head, marital status and education of the mother have no significant effect on poverty. This result is possible, as education of the spouse is very low. The household may not find adequate income earning opportunities to improve on its welfare. However, the household head being a male has a significant effect on household welfare. In other words, there is a lower likelihood of being poor if the household head is a male compared to being a female. Having a greater household size reduces the likelihood of being poor, which possibly indicates that the scale effect is dominating over the rivalry effect.

From the estimates of the technology level variables, we find that agricultural productivity has a significant impact on household welfare suggesting that the

Table 12.7 Determinants of poverty: logistic regression results

Variables	Coefficient	Wald-statistic	Significance level (P value)
Intercept	10.64** (4.429)	5.775	0.01
MBRAGE	0.05 (0.20)	0.063	0.80
MBRAGESQ	-0.001 (0.002)	0.184	0.67
EDUCSPOUS	-0.112 (0.197)	0.325	0.568
HHOLDHED	-1.74◇◇ (1.05)	2.739	0.098
MSTATUS	0.086 (0.547)	0.025	0.875
HHLQTY	-0.27◇◇ (0.148)	3.347	0.067
PRODLMAIZ	-0.008** (0.003)	7.29	0.007
COMPOSIT	-1.27 (0.813)	2.457	0.117
OWNED	-0.471◇◇ (0.273)	2.97	0.085
CALREQ	-1.30◇ (0.61)	4.55	0.03
HEALTDST	-0.369 (0.237)	2.42	0.12
DRINKDST	0.08 (0.187)	0.207	0.649
PBTRADER	-0.65 (1.12)	0.336	0.562
MKTGT	-2.86* (0.776)	13.61	0.00

Notes: Values in parentheses are standard errors of the estimated coefficients. * $P < 0.001$; ** $P < 0.01$; ◇ $P < 0.05$; ◇◇ $P < 0.10$.

growth in productivity in the long run remains a key mechanism in alleviating poverty. However, producing a composite crop had no significant impact on the likelihood of moving out of poverty.

It was expected that owning better and higher quality land would improve household welfare. We find evidence that increase in land owned can reduce the likelihood that the household is poor. This is the asset effect on household welfare. Improvement in food security can also be crucial in the long run in alleviating poverty, since better nourished household members can be more productive and have higher income earning capacity. Food security had a positive impact on the likelihood that the household escapes poverty.

Finally, we find no evidence of the community level variables to affect household welfare with the exception of the local market dummy variable. This result possibly indicates that if the household is closer to market, then its food security situation can improve. This indirect linkage can result in the likelihood that the household will not be poor.

Conclusions and implications

The purpose of this chapter was to understand the different dimensions of poverty, the various approaches to measure poverty, the characteristics of the poor and the underlying causes of poverty. While we used a monetary-based approach in measuring poverty, in the future, capability-based approaches and participatory surveys can be supplemented with monetary-based approaches to understand the multidimensional aspects of poverty. This will allow researchers to evaluate the impact of programs on the poor and determine whether these programs achieve the goals with respect to targeting a certain group of households.

Looking at the headcount measure of poverty (along with other measures, such as the poverty gap and squared poverty gap), we found that poverty in Malawi can be classified as deep and pervasive. About 72 per cent of the consumption level of the country's population was deemed insufficient to meet their basic needs. Additionally, by looking at the characteristics of the poor, we found that poorer households owned very few productive assets and had a higher dependency ratio. Thus, given limited resources, it is more desirable to reduce the consumption shortfall of a larger proportion of the poor than to eliminate the shortfall of a smaller proportion.

We next investigated the causes of poverty in Malawi using a logistic regression framework. Our results indicate that poverty reduction in Malawi will not occur unless there is rapid agricultural productivity growth accompanied with better quality and distribution of land for the smallholders. At the same time, it is desirable to improve the economic conditions (such as more equitable distribution of land, better schooling, etc.) of the female-headed households, since they are the vulnerable segments of the population. Thus, asset ownership and human capital formation are extremely relevant if a poverty reduction strategy is to work.

Technical appendices

Technical notes on logistic regression model

A standard multiple linear regression model is inappropriate to use when the dependent variable is binary (Tabachnick and Fidell, 2001). This is because, first, the model's predicted probabilities could fall outside the range 0 to 1. Second, the dependent variable is not normally distributed and, in fact, a binomial distribution would be more appropriate. Third, the normal distribution cannot

be considered as an approximation to the binomial model, since the variance of the dependent variable is not constant.

Now, let us consider y_i as a realization of the random variable Y_i that can take the values 0 and 1 with probabilities Π_i and $(1 - \Pi_i)$. Y_i is called a *Bernoulli distribution* with parameters Π_i and can be written in compact form as:

$$\Pr (Y_i = y_i) = \Pi_i^{y_i} (1 - \Pi_i)^{1-y_i} \quad (12.30)$$

for $y_i = 0, 1$.

If $y_i = 1$, we obtain the probability to be equal to Π_i and, if $y_i = 0$, we obtain the probability to be equal to $(1 - \Pi_i)$. Now, let the logit of the underlying probability be defined as $\text{logit}(\Pi_i) = \log\left(\frac{\Pi_i}{1-\Pi_i}\right)$. Thus, as the probability goes to zero, the logit function approaches $-\infty$. On the other extreme, as the probability approaches 1, the logit function also approaches $+\infty$. (Check that negative logits represent probabilities below one half, while positive logits correspond to probabilities above one half.)

Let us further suppose that the logit of the underlying probability be given by:

$$\text{logit}(\Pi_i) = X_i' \beta \quad (12.31)$$

where X_i is a vector of covariates and β is the vector of regression coefficients. Exponentiating equation (12.31), we obtain the odds ratio as:

$$\frac{\Pi_i}{1 - \Pi_i} = \exp(X_i' \beta) \quad (12.32)$$

The above expression implies that if one changes the j^{th} predictor by one unit holding all the other variables constant, one needs to multiply the odds by $\exp(\beta_j)$. Transforming (12.32) in terms of the probability scale, one obtains:

$$\Pi_i = \frac{\exp(X_i' \beta)}{1 + \exp(X_i' \beta)} \quad (12.33)$$

There is no simple way to express the right-hand side, since it is a non-linear function of the predictors. An approximate effect of the predictor on the probability can only be given for continuous predictors and using the quotient rule for the j^{th} predictor, we obtain:

$$\frac{d\Pi_i}{dx_{ij}} = \beta_j \Pi_i (1 - \Pi_i) \quad (12.34)$$

The effect of the j^{th} predictor on the probability thus depends on the coefficient β_j and the value of the probability. The result thus approximates the effect of the covariate near the mean of the response.

A brief description of the maximum likelihood estimation procedure in the logistic regression framework is also warranted. Suppose in equation (12.30) there are n independent Bernoulli observations for the random variable Y_i .

Then the likelihood function is the product of the densities given by equation (12.30). Taking logs the likelihood function can be expressed as follows:

$$\log L(\beta) = \sum_{j=1}^n \left(y_j \log(\Pi_j) + (n - y_j) \log(1 - \Pi_j) \right) \quad (12.35)$$

Substituting (12.33) for the value of Π_j , the logarithm of the likelihood function can be expressed alternatively as:

$$\log L(\beta) = \sum_i \beta_i \sum_j y_j x_{ij} - \sum_j \log\{1 + \exp(X'_j \beta)\} \quad (12.36)$$

One can then find the maximum likelihood estimates by differentiating the left-hand side of equation (12.36) with respect to β_j and setting the partial derivative to be equal to zero and solving for the non-linear equations for β_j .

Exercises

1. What are the various approaches to measure poverty? What are the key differences in the concepts and indicators used in the income-based and capability-based approaches?
2. Describe in your own words the characteristics and causes of poverty. Identify the main causes of poverty in your own country.
3. What is the rationale for measuring poverty?
4. Define poverty line. What is meant by the referencing and identification problems in deriving a poverty line?
5. Define headcount measure, poverty gap index and squared poverty gap index. Discuss the advantages and drawbacks of each measure.
6. Convert the following probabilities into logits:

$$\Pi_1 = 0.1, \Pi_2 = 0.3, \Pi_3 = 0.5, \Pi_4 = 0.65.$$

7. Suppose you have the following logit equation specifying household poverty to educational attainment of the spouse as follows:

$$\log\left(\frac{\Pi_i}{1 - \Pi_i}\right) = -5.3 + 0.3 (\text{EDUCSPOUS}).$$

Calculate the predicted probability that the household is poor when EDUCSPOUS = 2 and when EDUCSPOUS = 7. Interpret your results.

8. Suppose from the logistic regression equation you wanted to predict the probability of a household being poor using the following equation:

$$\begin{aligned} \log\left(\frac{\Pi_i}{1 - \Pi_i}\right) = & 10.64 - 0.27 (\text{HHLDQTY}) - 0.008 (\text{PRODLMAIZ}) \\ & - 0.471 (\text{OWNED}) - 1.30 (\text{CALREQ}) \end{aligned}$$

First, assume the following values for the explanatory variables: HHLDQTY = 3, PRODLMAIZ = 40, OWNED = 2 and CALREQ = 0. What is the expected

probability that the household is poor? Next assume the following values for the explanatory variables $\text{HHLDQTY} = 5$, $\text{PRODLMAIZ} = 180$, $\text{OWNED} = 5$ and $\text{CALREQ} = 1$. What is the expected probability given that the household is poor? Compare both scenarios and interpret your results in the light of the discussion on determinants of poverty.

9. After studying the paper by Justino and Litchfield (2003), critically discuss the advantages and drawbacks of the logit and least-squares regression models in analyzing the determinants of poverty. What are the differences in the results obtained from using these two alternative approaches? In other words, discuss the difference in the determinants of household welfare.

Notes

1. The indirect utility function is obtained by maximizing the utility function subject to a budget constraint and then substituting the commodity bundle as a function of income and prices back into the utility function. This function gives the maximum utility achievable for a given level of prices and income.
2. In subjective poverty line construction, the respondent is asked questions such as, ‘what income level do you personally consider to be absolutely minimal?’. We will not discuss this issue in the current chapter, since we are interested in objective poverty lines. Second, in most developing country studies, objective poverty lines have been constructed, while a few attempts have been made for OECD countries for the construction of subjective poverty lines. For an extensive discussion of how poverty lines are constructed using this approach, see Ravallion (1998).
3. This result is also consistent with Babu and Chapasuka, (1997), since the measure of poverty is based on insufficient food expenditure to meet the daily nutritional requirement of 2250 kcal. They found the estimates of headcount to be 38.5, 67.8 and 62.9 per cent respectively for the Mzuzu, Salima, and Ngabu regions based on their sample of households. In other words, the relative ranking of the poverty headcount has not changed in our sample.
4. This result is consistent with the poverty profile report of the World Bank, which indicated that poverty was deep and severe in the central region.
5. These regression models are used to model processes that involve a single outcome among several alternatives which cannot be ordered such as occupational choices, modes of traveling, etc. The multinomial model determines the probability that household i experiences one of the j outcomes. This probability is given by $P(Y_i = j) = \exp(\beta_j X_i) / \sum_{k=1}^J \exp(\beta_k X_i)$ for $j = 0, 1, 2, \dots, J$, where Y_i is the outcome experienced by the i^{th} household, X_i includes household characteristics as well as choices.
6. The maximum likelihood estimation (ML) maximizes a log-likelihood function, whose core expression is $-\sum_{i=1}^N (Y_i - \mu)^2$, where Y is the dependent variable and μ is a measure of central tendency of the parameter distribution. The second derivative of the above expression identifies the location of the parameter’s maximum value. For additional details on the ML estimation procedure, see Freund and Walpole (1986).

13 Classifying households on food security and poverty dimensions – application of K-mean cluster analysis

The seven deadly sins ... food, clothing, firing, rent, taxes, respectability and children. Nothing can lift those seven millstones from Man's neck but money; and the spirit cannot soar until the millstones are lifted.

George Bernard Shaw, famous playwright of the UK.

Introduction

The relationship between food insecurity and poverty is complex. As pointed out by Smith et al. (2000), an important development goal is not only to improve food security, but to improve it in a manner that can be sustainable for the maximum number of people. From an analysis of a sample of developing countries during the 1990s, they found that poverty was the most binding constraint in improving food security. In addition to poverty, many countries faced problems of national food availability (especially the sub-Saharan African countries), while other countries faced nutrition insecurity problems linked to health and care (particularly South Asian countries). Policy objectives should be devised in such a way that synergies can be obtained using multiple interventions where there are multiple causes of problems (related to food insecurity and nutrition insecurity). An example where multiple interventions can have a synergistic effect is combining income generating activities with nutrition education (von Braun et al., 1993).

The issue of addressing multiple policy objectives is critically important, since there may be trade-offs in reaching competing policy goals and an optimal balance is necessary for achieving such goals. A focus on food availability issues (ensuring food security) may lead to the direction of investment in new technology to increase food production in high-potential areas. On the other hand, a focus on poverty reduction can lead to investments that raise the incomes of poor people who often live in resource poor and low potential areas, where large amounts of food may not exist. Thus, policy combinations need to be optimally designed so that improvement in food and nutrition security can enhance long-run sustainable poverty reduction.

In this chapter, a cluster analysis method is undertaken to group households on the basis of food security and poverty dimensions. Clustering is a process of grouping data into classes so that objects within a class have high similarity in comparison to one another, but are very dissimilar with respect to objects in other clusters. Cluster analysis will thus allow us to identify households that are vulnerable in the dimensions of food insecurity alone (such as lack of access to food), households that are vulnerable in the dimensions of poverty (such as access to productive assets such as land owned) and households that might possibly be vulnerable on both dimensions. The patterns of income, expenditure, assets and other related socio-economic variables offer an insight into the dynamic and interrelated nature of poverty and food security that is lost in traditional multivariate analysis. Thus, with a more integrated analysis, interventions can be designed more effectively, so as to strengthen and complement households' own efforts to manage diversity. Cluster analysis can help policy makers better to understand the complexity of individual and households' lives and can guide them to the design of poverty alleviation strategies that take this complexity into account. This sort of exercise could also be useful in providing the basis for long-term monitoring of panels of households and the impact of interventions on their welfare.

The chapter is organized as follows: In the next section we critically examine the different theoretical approaches to cluster analysis. We then review a few studies that highlight the linkages between food insecurity and poverty using cluster analysis. We also point out some of the studies that have used this method to analyze dietary patterns and determinants of child health. We next undertake the empirical analysis with our household dataset using a *K*-means cluster analysis. The final section makes some concluding remarks and draws some implications from the current research.

Cluster analysis: various approaches

The goal of a cluster analysis is to find an optimal grouping for which the observations or objects within each cluster are similar, but are dissimilar to the objects in other clusters. Cluster analysis has been widely applied to data in many disciplines, such as market research, biology, medicine, economics and engineering. For example, in biology, one can categorize genes with similar functions and gain insight into structures inherent in populations. On the other hand, for business, this analytical method can help a market researcher in identifying distinct groups of customers and characterize them based on their purchasing trends. There are two common approaches to cluster analysis: hierarchical and partitioning. Both approaches deal with the fundamental assumption of within-group and between-group similarity. Correlation, distance and association measures are the main ways to measure similarity and will be discussed in this section. In the *hierarchical* procedure,

one starts with a situation where all the cases form their own cluster. The procedure then identifies the two most similar cases which form the first cluster. In the next stage, the two closest cases are grouped into another cluster. The procedure continues until all the cases are members of one group consistent with all cases in the analysis. In the *partitioning (K-means)* procedure, the cases are randomly assigned to the number of clusters that the analyst wants depending on the definition of the cluster characteristics. For each case, the distance between cluster centers is computed and each case is assigned to the nearest cluster such that the error sum of squares does not change.

Hierarchical clustering method

Hierarchical clustering allows one to find ‘good’ clusters in a dataset. The main idea behind this technique is to start with each cluster comprising of exactly one object and then combine the two nearest clusters until there is just one cluster left consisting of all the objects. In a large dataset, searching for all possible clusters is a tedious task. Let $X(m, b)$ be the number of ways one can separate out m items to form b clusters (the derivation of this equation can be found in Jensen (1969) and Seber (1984)). Then,

$$X(m, b) = \frac{1}{b!} \sum_{i=1}^b \binom{b}{i} (-1)^{b-i} i^n \quad (13.1)$$

The expression $\frac{b^n}{b!}$ provides an approximation for equation (13.1). Thus, with the hierarchical method one can arrive at a meaningful solution without searching for all possible solutions.

There are two kinds of hierarchical clustering algorithms: (a) agglomerative and (b) divisive. The divisive procedure is not discussed in additional detail, since SPSS uses the agglomerative hierarchical algorithm in the computation of clusters. The reader can refer to Rencher (2002) for further details. In the *agglomerative* procedure, a cluster of observations is merged into another cluster. In this sequence, the number of clusters decreases, but the clusters themselves increase in size. Thus, in an agglomerative procedure, one ends with one single cluster containing the whole dataset, even though the procedure starts with m clusters.

On the other hand, in the divisive method, we start with one large cluster with all the m items and end up with m clusters containing each item as a cluster of its own. In what follows, we introduce three key methods of hierarchical clustering approach.

Single linkage (nearest neighbor method)

In this method, the distance between any two clusters is defined as the distance between the nearest pair of objects in the two clusters. If cluster A is the set of

objects x_1, x_2, \dots, x_m and cluster B is the set of objects y_1, y_2, \dots, y_n , then the single linkage distance between A and B is given by:

$$d(A, B) = \min \left\{ d(x_i, y_j), \text{ for } x_i \in A \text{ and } y_j \in B \right\} \quad (13.2)$$

To begin with, we calculate the distance $d(A, B)$ for each pair of clusters. Then we merge any two clusters with smallest distance. We repeat the process with the merged clusters and calculate cluster distances again among cluster pairs. Once again, we merge two clusters with smallest distance into one single cluster. When one single cluster is obtained, the procedure comes to an end.

Complete linkage (farthest neighbor method)

In this approach, the distance between cluster A and cluster B is defined as the maximum distance between a point in cluster A and a point in cluster B . Similar to the single linkage method, the distance function between A and B is given by:

$$d(A, B) = \max \left\{ d(x_i, y_j), \text{ for } x_i \in A \text{ and } y_j \in B \right\} \quad (13.3)$$

This method tends to generate clusters at the early stages that have objects within a narrow distance from each other.

Average linkage method

In this approach, the average distance between all possible pairs of objects with one object in each pair belonging to a distinct cluster gives the distance between two clusters. Thus, the distance between any two clusters A and B is defined as the average of the mn distances between the m points in A and n points in B and is given as:

$$d(A, B) = \frac{1}{mn} \sum_{i=1}^m \sum_{j=1}^n d(x_i, y_j) \quad (13.4)$$

There are other methods in agglomerative clustering, such as centroid, median and Ward approaches. They are not discussed here. For further details, the reader is referred to Rencher (2002).

K-means method

The K -means method of cluster analysis is popular due to its simplicity. In this method, clusters are formed by specifying the number of clusters, say k , and assigning each object to one of the k -clusters in order to minimize the sum of distances from the mean of each cluster.

The algorithm for K -means clustering begins with an initial partition of the cases into k -clusters. In subsequent steps, the partition of cases is modified to reduce the sum of the distances for each case from the mean of the cluster to which the case belongs. This leads to a new partition for which the sum of distances is strictly smaller than before. This method is extremely fast and there

is a possibility that the improvement in the steps leads to less than k -partitions. In general, the number of clusters in the data is not known in advance. Thus, it may be a good idea to run the algorithm with different values of k in order to determine how the sum of distances reduces with increase in the value of k (Bacher, 2002).

In this chapter, we use the K -means method to demonstrate the use of cluster analysis for classifying households among different dimensions of assets, income and food security.

Review of selected studies using cluster analysis

Cluster analysis is primarily used for poverty mapping exercises¹. For example, households tend to cluster together in villages or other small geographic and administrative units, which are relatively homogeneous. In other words, households that are close together tend to be more similar than households far apart, allowing the researcher to specify a regression model of household welfare of a cluster to be dependent on household characteristics and household level error within the cluster.

The rationale behind such an analysis is threefold:

1. aggregate (national level) indicators provide an impression that conditions within a country are uniform. However, evidence suggests otherwise. There remains significant geographic variation in the incidence of poverty, which can be attributable to differences in resource endowments, educational levels, health services, etc. As one maps the relevant administrative units, the geographic variability in the aggregate data becomes apparent
2. poverty maps are an important tool for targeting resources and interventions. Detailed information on the location of the target groups can facilitate resources to be used more effectively so that the most needy groups are reached effectively
3. maps encourage visual comparison and it becomes easier to look at spatial trends, clusters or other patterns in the data. Disaggregated information provides local decision makers with the facts that are necessary for local decision making.

In addition to its use in poverty mapping, cluster analysis has also been used for examining dietary and nutrition patterns of a particular segment of the population (for example, children or the elderly). This is because the cluster analysis approach is very useful for summary and descriptive purposes, although the results depend on local situations that make it difficult to transfer to other populations. A number of studies have examined dietary patterns by estimating the usual daily intake from the food frequency questionnaires (see, for example, Wirfalt and Jeffrey (1997), Greenwood et al. (2000), Millen et al. (2001)). It is important to note that these studies have been undertaken mainly for developed countries such as the USA and European countries.

The general findings of these studies indicate that there exist distinct dietary patterns within a given population. The analytical method can thus provide a rationale for developing intervention strategies aimed at preventing and

managing chronic health conditions such as obesity, colon cancer and cardiovascular disease.

The food intake pattern of elderly individuals has been studied both for southern European countries (SENECA investigators, 1996; Leite et al., 2003) and the USA (Akin et al., 1986). For Italy, the overall intake of fish, fruits and vegetables is similar to that reported in Portugal and Spain, while the consumption of dairy and animal products for Italy, such as milk, eggs and meats, is similar to that of France. The overall food group intakes among elderly Americans revealed some important differences. They consume a higher intake of high-fat meats and other animal fats compared to countries in Southern Europe, while the consumption of fruits and vegetables is greater in Southern Europe relative to that in the USA. We now review some of the studies that use cluster analysis in order to classify households on the various dimensions of poverty.

Deininger et al. (2004) examined the effects of targeting asset redistribution (land reform²) on poverty alleviation in Zimbabwe. The analysis was done in two main steps. First, the target groups were identified through clustering techniques by generating household groups that closely resembled each other in multiple dimensions. In the second step, the trajectories of income and asset of the groups of households were traced over time.

The main result from the analysis demonstrated that land reform could uplift the disadvantaged households significantly. However, it takes time for the benefits of land reform to accrue. Land reform can alter the lives of individuals in many dimensions and the benefits could come from the combination of access to resources, technology, institutional support, social capital, learning opportunities and much more. Over time, it seems that the majority of the households in the panel had made impressive gains.

Shinns and Lyne (2003) identified different dimensions of poverty that affected the current and future well-being of households within a community of land reform beneficiaries in the Midlands of Kwazulu-Natal in South Africa. The study used objectively measured variables representing the broader symptoms of poverty, namely, the quality of housing, health, income and household wealth. A cluster analysis methodology was undertaken to classify households according to their poverty profiles. A census survey of 38 land reform beneficiary households – members of a communal property association established to purchase Clipstone (a 630 hectare farmland which was sold to the beneficiary households by the owners of Clipstone) – was conducted during May 2002.

Although no explicit statements can be made about the underlying causes of poverty using cluster analysis, the study reveals dimensions of poverty that can help in distinguishing between short-term and long-term strategies in alleviating poverty. The study provided some strategies (both short and long term) and estimated the annual net costs to the government in implementing them.

Summarizing, cluster analysis is primarily done for grouping households on the basis of certain economic characteristics (such as their income or asset situations) or when certain program interventions are desirable (such as land reforms) to improve their economic conditions. The purpose of this sort of analysis is mainly

for targeted interventions by policy makers or program managers and not in understanding the underlying causes of food insecurity or poverty. In the first step, the target groups (the income poor or food insecure households) are identified through clustering techniques by generating household groups that closely resemble each other in multiple dimensions. In the second step, the trajectories of certain economic variables (such as income and assets) of the groups of households are traced over time. In the next section, we demonstrate this method using the Malawi dataset.

Empirical analysis: K-means clustering

In hierarchical clustering, one requires a distance of similarity matrix between all pairs of cases, which can be a huge matrix given that we have 604 households. The clustering method that does not require computation of all possible distances among cases is the *K*-means clustering method. In this method, one starts with an initial set of means and classifies the cases based on their distance to the means. The cluster means are computed again, using the cases that are assigned to the cluster and then the cases are reclassified based on the new set of means. This process is repeated until the cluster means do not change much between successive steps.

In this section, we want to classify households based on their food security and poverty dimensions along with the correlates of food security (such as productivity of maize) and poverty (such as land owned and livestock possessed). The purpose is to classify households among different dimensions of assets, income and food security.

Data description

The variables used in the present analysis are as follows:

1. **FOODSEC**: this is a measure of food security and is a weighted average of three components: namely the number of livestock owned (**LIVSTOCKSCALE**), the number of meals consumed per day (**NBR**) and stocks of food running out (**RUNDUM**). It is a continuous variable with higher values of index denoting food secure households. The index ranges between 0 and 1, with 0 denoting completely food insecure households
2. **per capita expenditure (PXTOTAL)**: a proxy for income level of the household, since consumption expenditure by households is a better indicator of lifetime welfare than income
3. **size of land owned (LANDO)**: a variable which measures assets of the household. The values range from 0 to 6, with higher values indicating that the household has greater amounts of land available
4. **LIVSTOCKSCALE**: another measure of assets of the household and is measured in tropical livestock units (described in Chapter 2). It is a continuous variable scaled from 0 to 1, with 0 indicating that the household owns no livestock.
5. **PRODLMAIZ**: a measure of yield or technology which can affect food security in a favorable way. The ratio of total quantity harvested of local maize to household size

is considered as a measure of yield (since local maize is the main crop produced and consumed in Malawi).

Initial partitions and optimum number of clusters

In order to choose the initial cluster means, a hierarchical method (on the lines of Bacher, 2002) was used for the starting configuration. We ran the cluster and saved the membership of the variables as Z-scores. In other words, all the variables were converted with zero mean and a standard deviation of unity. The procedure was adopted since variables were measured in different units (for example, land was measured in hectares, while livestock was measured in TLU terms). If standardized units were not undertaken, we had to worry about the variables that had large values to have a large impact on the distance compared to variables that had smaller values. We renamed the new membership variable to Cluster_ and computed the cluster centers (means) using the AGGREGATE command. We stored the means in a new data file, reread the original data and specified the quick cluster command that reads the saved centers as the starting partition.

The procedure, however, still does not determine the optimum number of clusters. We thus undertake the *F-max* statistic

$$F - MAX_k = \frac{SSB(k)/(k - 1)}{SSW(k)/(n - k)}$$

which analyzes the null hypothesis that a solution with k is not improved by a solution with $(k + 1)$ clusters. We allowed for a systematic variation of the number of clusters from $k = 2$ to $k = 8$. By the *F-max* criterion, the solution with the highest *F-max* value needs to be chosen for the optimum number of clusters. We found $k = 4$ as having the highest value for the *F-max* statistic. However, this solution was not chosen in the final specification, since we could not classify the households on all the three dimensions of asset, income and food security. We chose the value $k = 7$, which provided the next highest value for the *F-max* statistic as the optimum number of clusters, since it gave us a better classification of the households based on the asset, income and food security configurations.

Descriptive characteristics of the cluster of households

First, we look at the mean value of the above variables for each of the cluster of households to understand how they can be characterized on the basis of food security, assets and income (Table 13.1). We do not report the households belonging to the seventh cluster, since there are only two members and characteristics such as food security and livestock ownership are missing.

The first group (group 1) of households can be termed as income rich but a relatively asset poor and food insecure group of households. The per capita expenditure exceeds the average per capita expenditure for all the households (17.27 kwacha per household size). This group of households is relatively more

Table 13.1 Mean values of selected variables for clusters of households in Malawi

Variables	Group 1 n=73	Group 2 n=23	Group 3 n=280	Group 4 n=92	Group 5 n=10	Group 6 n=124
PXTOTAL	43.07	18.37	10.33	10.45	114.86	12.09
FOODSEC	0.35	0.58	0.30	0.59	0.59	0.30
LANDO	2.51	4.26	1.61	3.05	3.20	3.93
LIVSTOCKSCALE	0.06	0.28	0.05	0.85	0.66	0.07
PRODLMAIZ	136.26	554.66	66.29	83.41	268.70	88.95

asset poor (own average land size and own almost no livestock units) and are, on average, food insecure. Although the yields of local maize generate some income, their average distance to the market place is quite high. Thus, it is likely that lack of market access coupled with lack of assets is not enabling these households to be food secure.

The second group of households can be significantly distinguished from the first in that they are relatively asset rich and food secure but are still relatively income poor. They are also significantly more productive in local maize (the average productivity is 106.56 per household), but are still income poor. This may be because adequate food in a region may not guarantee freedom from hunger. It may be the case that undiversified production and lack of control over land, labor and prices all contribute to households being unable to meet their income needs.

The third group of households is poor in all dimensions (namely in income, assets and food security) and constitutes a significant portion of the sample. These households are the ones trapped in chronic poverty and require the most attention both from government agencies and the international donor community. It is likely that constrained by the extremely low incomes, these households have not accumulated any assets and may not be able to finance adequate nutrition.

The fourth group of households is food secure, own significant amount of assets (both livestock and land), but are income poor and less productive. What distinguishes these households from group 2 is their productivity of local maize is below the average and is significantly lower than group 2. It appears that producing only local maize may not generate enough income in the long run and a broader strategy of crop diversification should be conceived in generating higher incomes in the long term. Additionally, production of more food for home consumption and increasing output of marketed products that increase farm income should be carefully thought of by policy makers.

Turning to group 5, we find that this group of households is rich in all dimensions (namely income, food security and assets). However, the number of individuals in this group being so small ($n = 10$), suggests that poverty in Malawi is both chronic and widespread.

Finally, looking at group 6, we find that this group can be termed as land rich, but both income poor and food insecure. The characteristic that distinguishes

these households from group 4 is that, in spite of having a significant amount of land, these households are less productive, more food insecure and are income poor. It may be the case that these households are located in a remote area where there is not much fertile land and thus there is less scope for income generating activities. Additionally, we find that these households are located far from an ADMARC center (the mean SADMDIST was found to be 2.47). Thus, lack of market access could have acted as an additional bottleneck for the households to sell their products during periods of crisis.

Cluster centers

In order to arrive at the ideal number of clusters in the final solution, Ward's technique was used. The Ward's method³ joins those clusters whose combination leads to a minimum increase in within cluster sum of squares, while maximizing the between cluster sum of squares. Second, using the output from Ward's procedure as initial subgroup seeds, the *K*-means was applied to determine the final case location in the separate subgroups. The *K*-means clustering is an iterative partitioning procedure that reproduces the *k* number of disjoint clusters through minimizing the sum of squared distances from the cluster centroid means.

The first step in the *K*-means clustering is to find the *k* centers. This is done iteratively. The initial set of centers is reported in Table 13.2.

After the initial cluster centers have been selected, each household (or case) is assigned to the closest cluster, based on its distance from the cluster centroids.

Table 13.2 Initial cluster centers

	Cluster					
	1	2	3	4	5	6
Z-PXTOTAL Z-score: per capita expenditure	-0.03738	0.37477	-0.20655	-0.13189	2.64974	-0.41473
Z-LIVSTOCKSCALE Z-score (LIVSTOCKSCALE)	-0.15277	0.34213	-0.48009	2.40895	-0.46962	-0.51123
Z-FOODSEC Z-score (FOODSEC)	0.02057	1.26577	-0.48766	1.47719	-0.31929	-0.82172
Z-LANDO Z-score: Size of land owned	0.52405	1.00929	-0.79451	0.38942	0.49160	1.02663
Z-PRODLMAIZ Z-score (PRODLMAIZ)	0.04398	1.74494	-0.13471	0.08025	0.20773	-0.35410

Note: We do not report the values of the variables for cluster number 7, since there are very few households in this cluster.

After all the cases have been assigned to clusters, the cluster centers are computed again based on all the cases in the cluster. The case assignment is done again, using the updated cluster center. The iteration stops when no cluster center changes appreciably. We look at the final cluster centers to determine how the households can be classified.

Table 13.3 reports the final cluster centers. It is evident that cluster 1 has a higher average value for per capita expenditure (in terms of Z-scores) but a lower than average value for the rest of the variables, confirming our earlier insight (from the descriptive statistics) that this cluster can be coined as income rich, asset poor and food insecure households. Similarly, looking at cluster 3, we can identify that the households belonging to this cluster have lower than average values for all the variables suggesting that they are poor in all dimensions.

Table 13.3 thus confirms the description of Table 13.1, by grouping households in asset, income and food security dimensions. One can also look at the distance among the cluster centroids to determine how far the cluster centers are from each other. Table 13.4 gives us the distance among the various cluster centers.

Table 13.4 provides a precise picture as to which clusters are similar to each other based on the distance between the cluster centers. We find from the above matrix that households belonging to cluster 1 are similar to households belonging to clusters 3 and 6. This is possibly because the dimensions along which households become vulnerable are more or less similar. For cluster 3, households are income poor, asset poor and food insecure (i.e. they are poor in all the dimensions), whereas in cluster 1 households are income rich but asset poor and food insecure. Similarly, households in cluster 6 are land rich but both

Table 13.3 Final cluster centers

	Cluster					
	1	2	3	4	5	6
Z-PXTOTAL Z-score: per capita expenditure	1.32836	0.04799	-.36927	-0.36269	5.04967	-0.27773
Z-LIVSTOCKSCALE Z-score (LIVSTOCKSCALE)	-0.43871	0.26500	-.46422	2.09280	1.47314	-0.39858
Z-FOODSEC Z-score (FOODSEC)	-0.09215	1.36556	-.38002	1.43801	1.43283	-0.39102
Z-LANDO Z-score: Size of land owned	-0.17688	1.32855	-.94295	0.29302	0.41803	1.04236
Z-PRODLMAIZ Z-score (PRODLMAIZ)	0.17930	2.65315	-.23435	-0.13315	0.96240	-0.10037

Note: We do not report the values of the variables for cluster number 7, since there are very few households in this cluster.

Table 13.4 Distances between cluster centers

Cluster	1	2	3	4	5	6
1		3.556	1.930	3.454	4.560	2.058
2	3.556		4.153	3.514	5.493	3.361
3	1.930	4.153		3.374	6.300	1.993
4	3.454	3.514	3.374		5.558	3.182
5	4.560	5.493	6.300	5.558		6.061
6	2.058	3.361	1.993	3.182	6.061	

income poor and food insecure. One can interpret the results as if the underlying causes of vulnerability may be similar between clusters 1, 3, and 6.

Conclusion and implications

The purpose of the present chapter was to classify (cluster) households among the various dimensions of vulnerability. The dimensions of vulnerability chosen were assets, income and household food security. The analysis was undertaken using a *K-means* cluster analysis. The advantage of this method over hierarchical cluster analysis is that it can provide clusters that can satisfy some optimality criteria when the number of clusters is known. While determining the optimum number of clusters is somewhat arbitrary, we used the *F-max* statistic for various values of *k*. The value of *k* was chosen, where the *F-max* statistic was the second maximum. Additionally, in a hierarchical clustering method, one requires a distance of similarity matrix between each pair of cases, which can be a huge matrix given that our sample consists of 604 households.

While no explicit statements can be made about the underlying causes of poverty or the ways in which the fundamentals can be addressed, we can understand the various dimensions of vulnerability to help distinguish the strategies that can relieve the symptoms of vulnerability. From the present analysis, we find that households belonging to clusters 1, 3 and 6 are vulnerable in different dimensions. While in the short term, improvement in market access, distribution of land and other assets can be one set of policy measures, in the long run, crop diversification is likely to help households move out of chronic poverty. At the same time, improvement in infrastructure, such as construction of new roads, can facilitate market expansion, which can reduce input prices, raise the output prices of crops and benefit the producers and consumers at the same time.

Exercises

1. What is the purpose of cluster analysis and when is it appropriate to use instead of factor analysis? Under what condition is hierarchical or non-hierarchical cluster analysis appropriate?

2. What is meant by agglomerative and divisive method in cluster analysis?
3. Undertake a two-step cluster analysis (instead of K -means) with the following categorical variables included: FEMHHH, SADMDIST, HEALTDST, DRINKDST along with the continuous variables included in the current chapter. Determine the optimum number of clusters using the Schwarz Bayesian criterion (BIC). Examine the composition of clusters, and the importance of the individual variables in the formation of clusters.

Hint: to do this go to the Analyze menu and choose Classify/Two step cluster. Move FEMHHH, SADMDIST, HEALTDST, DRINKDST into the categorical variable list. Also move LANDO, PXTOTAL, FOODSEC, PRODLMAIZ and LIVSTOCKSCALE in the continuous variable list. In the *plots* subdialog box, select Rank of variable importance and then select confidence level. Click *Continue* and then click on *Output*. In the Output subdialog box, select descriptives by cluster, *cluster frequencies* and *Information criterion (BIC)* in the Statistics group, and select Create cluster membership variable. Click on continue, and then click on OK.

4. After studying the paper by Shinns and Lyne, discuss critically the short- and long-term strategies that can be adopted in alleviating poverty.

Notes

1. It is beyond the scope of the present chapter to discuss in detail the various methodologies of poverty mapping. For an extensive discussion, see Hentschel et al. (2000).
2. The main objectives of the land reform program were as follows: (i) to alleviate population pressure in the communal areas; (ii) to improve the base for productive agriculture for the peasant farming sector; (iii) to improve the standard of living of the poorest segments of the population; (iv) to bring underutilized land into full production for implementing an equitable program of land redistribution; (v) to improve the infrastructure of economic production; and (vi) to achieve national stability and progress of the country that had only recently emerged from the turmoil of war.
3. The algorithm starts with an initial partition of the cases into k -clusters. In subsequent steps, the partition of cases is modified to reduce the sum of the distances for each case from the mean of the cluster to which the case belongs. This leads to a new partition for which the sum of distances is smaller than before. It is a good idea to run the algorithm with different values of k , in order to determine how the sum of distances reduces with increase in the value of k .

14 Household care as a determinant of nutritional status – application of instrumental variable estimation

Parents should have the right to choose how their pre-school children are cared for and educated. Young children should also have the right to be protected from an imposed system which harnesses their development to prescribed targets, and which may well force them into inappropriate early learning.

Dr Richard House, Senior University Lecturer in Psychotherapy.

Introduction

One of the strongest and most consistent findings in the health economics literature is the positive relationship between maternal schooling and child health. This empirical relationship has been confirmed across different time periods, countries and measures of child health (Behrman and Deolalikar, 1988; Strauss and Thomas, 1995). Furthermore, the international literature clearly shows that inadequacy of early care and feeding practices and the presence of infections are major determinants of undernutrition after birth (Haddad et al., 1996; Ruel, 2001). Thus, adequate child-care practices, timely availability of food and well-placed environmental and health conditions could reverse undernutrition.

For the past 20 years or so, child health and nutrition interventions have benefited from the advances of the new approaches in dealing with the prevalence of infectious diseases, the newly identified role of micronutrients in the nutritional status and in conceptualizing child-care practices (Engle et al., 1999). In the fourth report on the World Nutrition Situation (UN, ACC/SCN 2000), the frequent nutritional problems in developing countries were identified by the following factors: fetal undernutrition, stunting, wasting and underweight in children less than 5 years of age. This report also addressed micronutrient deficiency and showed that, worldwide, approximately 11.7 million newborns have weights below 2500 g, which reflects fetal undernutrition. Additionally,

micronutrient deficiencies coexist with poor nutritional status. This affects a large number of people in developing countries. Around 250 million children under the age of 5 are clinically deficient in vitamin A and almost 740 million people are iodine deficient.

The issue is clearly important since there is an increasing recognition that feeding practices (such as breastfeeding and complementary feeding practices) can serve as examples of care practices that are essential for improving child nutrition (Engle et al., 2000). First, there is a general consensus that increasing income alone is not sufficient for improving children's nutritional outcomes. Development projects that increase men's income relative to women have demonstrated that its impact on child nutritional outcomes is small and often negligible (Kennedy and Garcia, 1993). Second, several studies (Christian et al., 1988; Ruel et al., 1992) have convincingly established that behavioral factors, such as a mother's ability to plan and organize her time, can have a significant impact on child nutritional status. In other words, if the time constraints on the mother are reduced, there can be significant improvement in child health outcomes. Finally, international agencies, such as UNICEF, have taken the lead in advocating the role of child-care for child nutrition.

During the 1990s, UNICEF (1990) proposed a conceptual framework which emphasized that care for women and children was equally important for child survival as are food security and health care services. The proposed framework argued that food, health and care were all necessary for child health outcomes, but none of them alone was sufficient for healthy growth and development. For example, breastfeeding is a practice that provides food, health and care simultaneously. While care was not defined till 1990, its importance was obvious. The initial definition consisted of actions of care-givers that converted food and health services to positive health outcomes for the child. While originally the outcome measure of interest was child survival, later outcomes of growth and development were also included.

In this chapter, we use an instrumental variable estimation technique since child-care practices are essentially endogenous. In other words, child-care practices are determined by a set of independent variables and the instrumental variables. This approach is appropriate since child-care practices need to be instrumented out by a set of exogenous variables that are correlated with child-care practices, but are not correlated with the child outcome variable, namely weight for age. Then, in the second stage, we regress the outcome variable (namely weight for age) on the predicted child-care variable along with other control variables. Ordinary least squares (OLS) estimation of the regression with child nutritional status as an outcome variable and food, health and care as the proximate variables could be biased for two reasons. First, there may be unobserved variables that are part of the error term but are correlated with the variables included on the right side. Second, explanatory variables may exist that are endogenous or jointly determined with the outcome variable and hence are correlated with the error term. The approach to address the above problems is to use the instrumental variables (IV) approach. The credibility of this approach

will rest on the ability to find variables that are correlated with the suspected endogenous explanatory variables, but are not correlated with the outcome variable.

This chapter is organized as follows: in the next section, we briefly discuss the literature of how child-care and maternal nutritional knowledge are critically important in determining children nutritional outcomes such as weight for age. The third section presents the empirical model and discusses the results, while the final section makes some concluding remarks and research agenda on child-care practices on child nutritional outcomes.

Review of selected studies

Since the conceptual and measurement issues on child-care practices have been illustrated in Chapter 7, we will not reiterate them here. We now review some of the case studies that emphasize the role of child-care and maternal nutritional knowledge (in addition to maternal schooling) on child health outcomes.

Garrett and Ruel (1999) explored in depth the question of whether the factors that determine food and nutrition security are different between the rural and urban areas and the implications of these differences for the design and operation of food and nutrition programs. The study answered these questions using a data set from a 1996–97 national household survey of living conditions in Mozambique. The information was collected at the level of the province and capital, Maputo, for 8274 households. Anthropometric measures of height, along with age in months were also collected for children below 5 years.

Following the standard household utility maximization model, a demand function for calories and a production function for child nutritional status were specified. The demand function for calories was a function of prices, income (instrumented out by assets) and other exogenous factors including demographic characteristics. The nutrition function was determined by care-giving behaviors, health status and household characteristics and calorie availability at the household level. Since income was endogenous, using least squares estimates would produce biased and inconsistent estimates. Thus, instrumental variable (IV) estimation was used to eliminate the correlation between the explanatory variable and the error term. A two-stage least squares (2SLS) approach was used to control for this endogeneity with an index of household assets as the identifying instrument, in combination with other exogenous variables in the first stage equation.

The study demonstrated that income was an essential determinant of calorie availability and child nutritional outcomes in both rural and urban areas. Thus, investment in education, increasing agricultural productivity and investment in rural infrastructure were the key determinants of poverty reduction strategies. Women's education was also important in improving child nutritional status. In the long run, improving girls' formal education and women's literacy and job skills would raise household incomes. In Mozambique, not only did maternal

education have a positive effect on young children's nutritional status above and beyond the income effect, but it enhanced the positive effect for the young children (less than 2 years of age). It is likely that maternal education affected child nutrition through its effect on greater nutrition knowledge and improved care-giving practices.

Overall, the results indicated that the determinants of food security and nutritional status were not very different between the rural and urban areas. However, policy makers and program administrators should not simply transfer programs from the rural to the urban areas, since community level specific conditions need to be identified for a program to be successful.

In a comprehensive study, Glewwe (1999) explored the mechanisms through which mothers' education raised child health. The study analyzed three channels through which mothers' education influences child health:

1. direct acquisition of basic health knowledge in school
2. literacy and numeracy skills learned in school could enhance mothers' abilities to treat child illnesses and could also help mothers increase their stock of knowledge after leaving school
3. exposure to modern society via schooling could change women's attitudes towards traditional methods of raising children and treating their health problems.

The study used data from the 1990–91 Moroccan LSMS household surveys conducted by the World Bank to assess the relative importance of these three mechanisms through which mothers' education affects child health. An important aspect of the data related to information pertaining to health knowledge of the mother. The tests for health knowledge included were:

1. five questions on health knowledge
2. twelve questions on general knowledge
3. an oral mathematics test of ten questions
4. a set of written mathematics tests with varying degrees of difficulty
5. a set of Arabic reading and writing tests
6. a set of French reading and writing tests.

A sample of 2171 households between the ages of 9 and 69 were surveyed, with the final sample of children being 1495.

The main conclusions of the study can be summarized as follows:

1. health knowledge was the most important skill through which mothers are better prepared to improve children's health
2. schooling affected mothers' health knowledge in Morocco indirectly – health knowledge was learned using literacy and numeracy skills acquired in school.

The above conclusions have direct policy implications for Morocco. First, health knowledge should be directly taught in the schools. They should be taught at an early age since girls dropping out early can never acquire sufficient numeracy and literacy skills that will help them in acquiring health knowledge. Second, school quality should not be neglected since women will be unable to raise their

level of health knowledge if they leave school without basic literacy and numeracy skills.

Block (2003)¹ addressed the following set of questions:

1. how nutrition knowledge affects household budget allocation between food and non-food expenditures?
2. within the food budget, does nutrition knowledge affect the allocation of spending on micronutrient rich foods² versus staples?
3. how do key demand parameters differ as a function of maternal nutrition knowledge?

The motivation for this study lies in the fact that nutrition knowledge might operate in increasing the demand for micronutrient rich foods. The critical demand parameters included were budget shares, as well as income and own price elasticities of demand for micronutrient rich foods. The data were obtained from a detailed survey by the Hellen Keller International (an NGO that undertakes social marketing campaigns) and covered the entire province of Central Java. The survey began in December 1995 and involved regular collection of information on dietary diversity, expenditures, asset ownership, demographics and nutritional status. For each round, a random sample of 7200 households was chosen and each time a total of 30 villages was selected from each of the province's six agro-ecological zones.

The study demonstrated that the households' inclination to reduce expenditures on high quality foods was a function of nutritional knowledge of the mother. The estimated cross-price elasticity between micronutrients and eggs was substantial. It was negative for households lacking nutrition knowledge and was zero for households with nutrition knowledge. Thus, maternal nutrition knowledge emerged as the most important factor for coping with the consequences of macroeconomic crises.

Blunch (2005) examined the impact of maternal literacy and numeracy skills on the production of children's health in Ghana. Ghana is an ideal candidate for investigating these issues as its education system is one of the most developed in sub-Saharan Africa. Second, an important priority of the Government of Ghana has been to provide basic literacy and numeracy skills through adult literacy programs for individuals who never attended school. Multiple paths to literacy and numeracy skills can thus be studied. The analysis considered both child health inputs and outputs and examined the determinants of vaccinations, postnatal care and mortality. The Ghana Living Standards Survey (GLSS) was a nationally representative household survey which was conducted over four cross-sections. These surveys were conducted in 1987/88, 1988/89, 1991/92 and 1998/99. The most recent round was used for analysis in the current study. The surveys contained information on educational attainment, participation in adult literacy courses, literacy and numeracy skills and information on background variables such as age, gender, ethnicity, etc., which were important determinants of human capital formation. The community questionnaire contained information on access to facilities, including schools and adult literacy programs.

Instrumental variable (IV) estimation was undertaken to account for the potential endogeneity of skills, schooling and adult literacy participation rates. For comparison purposes, least squares estimates were also presented, where skills and schooling were taken as given. The models were estimated for the full sample and for three different sub-samples, namely rural and urban areas and mothers who did not complete any formal schooling.

The study found a positive impact of maternal formal schooling on child health input demand and child mortality, which was consistent with the previous literature. Additionally, the study found a substantial impact from adult literacy course participation and also some impact from literacy and numeracy skills. The estimated impacts from maternal adult literacy program participation were often substantial compared to the estimated impacts from formal maternal education.

The implication of the findings was the potentially important role of adult literacy programs in promoting child health, possibly through the inclusion of health topics in the curriculum. One reason for the differential impact of formal and non-formal education is that adult literacy programs could effectively provide knowledge by introducing topics to mothers such as immunization, safe motherhood and child-care and safe drinking water. Thus, promoting more adult literacy courses could help in improving child health conditions in the future.

From the above studies, it is reasonable to conclude that maternal nutrition knowledge (working through both formal and non-formal education) and child-care practices (such as breastfeeding and complementary feeding practices) could effectively improve child health outcomes in the long run. Since both maternal nutrition knowledge and child-care practices are essentially endogenous, running least squares estimates on the health outcome variable would produce biased and inconsistent estimates. Thus, it is appropriate to control for endogeneity by undertaking instrumental variable estimation.

Empirical analysis

We undertake the analysis in two steps. In the first stage, we estimate the determinant of child-care practices by using the instrumental variable technique while, in the second stage, the predicted value of child-care practices along with other controls (such as household and community characteristics) are included to determine the impact on child health outcomes (weight for age Z-scores).

Stage 1: Estimating child-care practices

The first stage requires instruments to predict child-care practices. We include breastfeeding practices as an instrument of child-care practices. This is a dichotomous variable indicating whether the child is breastfed or not during his or her infancy. The explanatory variable is how many times the child attends clinic (ATTCLINI). This is a continuous variable denoting how many

times the mother took the child to a clinic during his or her sickness. The instruments that are used are:

1. MKTGT5: a dichotomous variable assuming a value of 1 if the local market is at a distance of greater than 5 km and is zero otherwise
2. AGEMNTH and AGESQ: the age of the child in months and its square. It can be expected that the younger the child (below 24 months), the greater is the need for breastfeeding
3. FOODAVAI: a categorical variable assuming values from 1 to 3, with a value of 1 indicating that adequate food is available, 2 denoting food is not adequate, while 3 denotes when the respondent was not sure whether food was adequate or not
4. SELPOINT: a categorical variable assuming values from 0 to 5, representing the distance of the household to a private traders' selling point. While this variable determines food security, it is exogenous in determining the child health outcome
5. STAPLEFT: a dichotomous variable assuming two values 0 and 1. The variable measures whether any staple food was left for the household or not. A value of 1 denotes some staple food was left over, while a value of 0 denotes no staple food being left over. This variable can also be considered as exogenous in the determination of child health outcome
6. Child0_5: a continuous variable denoting the number of children in the household. This variable indirectly measures birth spacing. If there are more children in the household, it signifies that the mother is time constrained and may not be able to provide good child-care practices
7. LOCMKT: a categorical variable, assuming values from 1 to 5. This variable represents the distance of the household to the local market and is a measure of market access
8. DIARRHEA: a dichotomous variable which indicates the household environment of sanitation conditions indirectly. A value of 1 denotes the presence of diarrhea, while a value of 0 indicates absence of diarrhea. This variable can negatively influence child-care practices since, with a poorer household/community environment, it is more likely that the mother will have less time to care for the child.

Thus, in order to obtain the two-stage least squares solution, we choose from the menus:

Analyze

Regression

2-Stage Least Squares

►Dependent: BFEEDNEW

►Explanatory: ATTCLINI

►Instrumental: MKTGT5, AGEMNTH, AGESQ, FOODAVAI, SELPOINT, STAPLEFT, Child0_5, LOCMKT, DIARRHEA

Table 14.1 shows the two-stage least squares results.

From Table 14.1, we find that the number of times the mother took the child to a clinic was a significant predictor of child-care practices as measured by breastfeeding practices. Additionally, from the Hausman exogeneity test, which is distributed as $F(J, n-k)$ degrees of freedom, where J is the set of linear restrictions in this regression model (in this example is just 1), n is the number of observations

Table 14.1 Two-stage least squares regressions on child-care practices

Variable	Coefficient	<i>t</i> -stat	<i>P</i> value	Hausman endogeneity test (<i>F</i> -test)	<i>R</i> ²
Constant	-0.193	-0.703	0.482	$F(1, 290) = 41.88$	0.126
ATTCLINI	1.348	6.472*	0.00		

Notes: Hausman (1978) endogeneity test; H_0 : accept exogeneity, i.e. OLS should be used; H_1 : reject exogeneity, i.e. IV should be used.

*Denotes statistically significant at the 1 per cent level.

and k is the number of instruments in the model. The critical value of $F(1, 290)$ at the 1 per cent level is 6.63. Since the computed value of $F = 41.88$ is much greater than the critical value, we can reject the null hypothesis of exogeneity and conclude that instrumental variable (IV) estimation should be used instead of OLS. Let us call this predicted value of child-care practices as FIT_1.

Stage 2: Estimating the determinants of child health (Weight for age Z-scores)

In this stage, we run a reduced form demand function for child nutritional status based on weight for age as the dependent variables (see equation (10.9) of Chapter 10 for how the reduced form specification is undertaken). The coefficients are estimated using least squares, which results in the smallest sum of squares differences between the observed and the predicted values of the dependent variable. Table 14.2 gives the estimated coefficients. We compare these results with the OLS estimates from Chapter 10, so as to provide a comparative picture of the difference in these estimates.

Table 14.2 compares the OLS estimates with the IV estimates (question: why is the estimated coefficient of ATTCLINI not reported in the IV estimate?) of the individual, household and community characteristics on child health outcomes as measured by weight for age Z-score. The estimated coefficients are of the correct sign and the IV estimates are measured with more precision. However, the magnitude of the estimated impact significantly differs between the two specifications. For the IV estimates, the impact of maternal education on one standard deviation weight for age Z-scores increases from 0.156 to 0.17. This is possibly because maternal health endowments such as maternal age or maternal height are not controlled for. Similarly, the estimated impact of diarrhea increases in absolute magnitude. A one unit increase in the prevalence of diarrhea reduces the weight for age Z-score by 0.68 standard deviation points, whereas in the OLS estimate, the impact was 0.62 standard deviation points. One possible reason for this result can be that the prevalence of diarrhea affects child-care practices initially (in the first stage regression) and this reduction of child-care feeds back into lowering the levels of child health outcomes.

Table 14.2 Using predicted breastfeeding practices on weight for age Z-scores

Variables	OLS	IV
Constant	-2.93* (-5.95)	-2.65* (-5.43)
EDUCSPOUS	0.156* (2.70)	0.17* (2.93)
ATTCLINI	0.439* (3.10)	
DRINKDST	-0.147* (-2.938)	-0.133* (-2.63)
LATERINE	0.152 (1.03)	0.141 (0.944)
AGEMNTH	-0.08* (-4.28)	-0.059* (-3.27)
AGESQ	0.001* (3.386)	0.001** (2.60)
CLINFEED	0.699* (3.91)	0.723* (3.98)
DIARRHEA	-0.62* (-3.126)	-0.682* (-3.41)
BFEEDNEW or FIT_1	0.625* (2.79)	0.364 ^{b,*} (3.44)
HEALTDST	-0.06 (-0.85)	-0.03 (-0.527)
R ²	0.256	0.232
F	7.47	7.23

Notes:

*Denotes at 1 per cent level of significance.

**Denotes at 5 per cent level of significance.

^bDenotes the endogenous variable, the fitted value of breastfeeding. The terms in the parentheses denote *t*-statistic.

Similarly, the estimated impact of feeding the child in clinic (CLINFEED) also increases the weight for age Z-score more in the IV estimate compared to the OLS - 0.72 standard deviation units in the former versus 0.69 standard deviation units in the latter.

The most interesting result, however, is that the estimated impact of breastfeeding practices substantially differs in the two specifications. In the OLS specification, the estimated impact of breastfeeding practices was 0.625, whereas the predicted breastfeeding practices increase weight for age Z-scores by 0.36 standard deviation units. This substantial difference can be attributed to the fact that OLS was overestimating the impact of breastfeeding practices on child health outcomes. Once breastfeeding practices were instrumented out, by the relevant instrument variables, the effect is much more precisely estimated.

Overall, one can infer that the IV estimates are more precisely estimated than the OLS specification.

From the above results, it is reasonable to conclude that both maternal education and child-care practices are important determinants of child health outcomes. This is consistent with the empirical literature as we have seen before. However, child-care practices are essentially endogenous and one needs to instrument out child-care practices as done in the present chapter. In addition, we can also infer that individual characteristics (such as age of the child) and community characteristics (such as distance to a protected water source and prevalence of diarrhea) are extremely important determinants of child health outcome.

Conclusions

Numerous studies (Behrman and Deolalikar, 1988; Strauss and Thomas, 1995; Glewwe, 1999; Blunch, 2005) have demonstrated that both maternal education and nutrition knowledge generated mostly through non-formal education, such as adult literacy programs, can improve child nutritional outcomes through the mediating effect of improved child-care practices.

The present chapter demonstrates the importance of maternal education and child-care practices using child-care as an endogenous variable. This is done by pursuing an IV-based (2SLS) estimation strategy in the spirit of Garrett and Ruel (1999) and Blunch (2005). Our analysis demonstrates that child-care practices are an important determinant of child nutritional outcomes. However, the estimated impact of child-care practices on child nutritional outcomes substantially declines in magnitude in the IV estimate relative to the OLS specification. The result indicates that child-care practices are overestimated in the latter specification and thus one needs to control for endogeneity of child-care practices. Additionally, we found women's education was critical in improving children's nutritional status, which is consistent with previous findings. The IV estimates showed that the impact of maternal education on one standard deviation weight for age Z-scores was 0.17. Thus, in the long run, it is extremely important to improve women's formal education and women's literacy and job skills that can raise household income. Higher levels of women's education in the long run may also lead to reductions in fertility and lengthen the time between births, which will result in lower household sizes.

Furthermore, we found that younger children were more prone to malnutrition and more attention should be directed to attenuate these conditions. Community characteristics, such as distance to a water source and the prevalence of diarrhea, were also important determinants of child nutritional outcomes. Thus, programs should concentrate on providing sanitation and clean water to households, especially those with children below the age of 5.

In conclusion, the results of this chapter can provide general guidelines to program managers, government officials, as well as researchers, as to what sort

of interventions are necessary and when to undertake them in improving child health and nutritional outcomes in the short and long term. Creating programs and making policies that are flexible and sustainable, given the needs and resources of the community, can be extremely beneficial for administrators to reduce malnutrition.

Exercises

- Define the following terms without reference to the present chapter:
 - endogenous variables
 - simultaneity bias
 - two-stage least squares
 - identification.
- What are the properties of the IV estimate? When is IV estimation useful? (Answer them in your own words).
- Which of the equations in the following systems are simultaneous? Be sure to specify the variables that are endogenous and the ones that are exogenous.
 - $$Y_{1t} = f_1(Y_{2t}, X_{1t}, X_{2t-1})$$

$$Y_{2t} = f_2(Y_{3t}, X_{3t}, X_{4t})$$

$$Y_{3t} = f_3(Y_{1t}, X_{1t-1}, X_{4t-1})$$
 - $$Y_{1t} = f_1(Y_{2t}, X_{1t}, X_{2t})$$

$$Y_{2t} = f_2(Y_{3t}, X_{5t})$$
- From the existing literature as explained in this chapter, describe in your own words how child-care practices can influence child nutritional outcomes. What are the channels through which maternal formal schooling and nutritional knowledge influence child nutritional outcomes?
- Suppose that your colleague recently estimated a simultaneous equation and found that the OLS results were almost identical to the 2SLS results.
 - What is the value of 2SLS in such a case?
 - Does the similarity between the 2SLS and OLS estimates indicate a lack of bias?
- Undertake a 2SLS estimate (as the present chapter) with height for age Z-score as the dependent variable and the same explanatory variables. Treat breastfeeding practices as the endogenous variable.
 - Compare the 2SLS estimated coefficients with the OLS estimates as found in Chapter 10. In particular, determine which coefficients differ substantially in both the specifications.
 - How does the R^2 differ between these two models?

Notes

- While this study does not examine the impact of nutritional knowledge on anthropometric outcomes, it is important as it studies how nutritional knowledge affects the demand for micronutrient rich foods.
- 'Micronutrient rich foods' refers to a composite commodity constructed from the household survey data. This composite commodity consists of beef, fish, chicken, vegetables, fruits, milk and eggs.

15 Achieving an ideal diet – modeling with linear programming

Nothing will benefit human health and increase the chances for survival of life on Earth as much as the evolution to a vegetarian diet.

Albert Einstein.

Introduction

Micronutrient deficiency continues to be a serious development challenge in many developing countries. The diets of poor people in these countries are usually deficient in key nutrients such as iron, zinc, calcium, vitamin A and vitamin C. This deficiency can be explained by either a shortage of micronutrient-dense foods (foods with a high concentration of nutrients in relation to energy) in their diets or an inappropriate selection of local foods. The above two possibilities have different programmatic implications. If deficiency is caused by shortage of micronutrients, it can be improved by increasing the availability of nutrient-rich foods – either via food-fortification or through agricultural programs that introduce new crop varieties. On the other hand, if micronutrient deficiency is caused by inappropriate selection of foods, nutrition education programs that emphasize the best use of locally available nutrient rich foods should be given priority (Darmon et al., 2002).

The issues that underline the above alternative programmatic possibilities can be addressed as follows:

1. is it possible to design a diet that fulfils the nutritional recommendations through the use of locally available foods?
2. if such a diet is feasible, what is the best combination of these foods (the minimum cost) that can achieve a nutrient-dense diet?

The above issues can be answered using a ‘trial and error’ approach or by ‘expert’ guessing. However, an efficient and rigorous method based on linear programming can address the above questions. Linear programming is an approach that examines the compatibility of different mathematical inequalities using simple mathematics to solve the problem of the type discussed above (Ferguson et al., 2006).

The importance of this method can be understood from a developing country perspective, where households have limited income but need to meet the

nutritional requirements with that income. Thus, they have to minimize their total expenditure while, at the same time, attain minimum nutritional requirements. Thus, determining the optimal diet (at the minimum cost) is important so that individuals can attain the daily nutritional requirements of their body with their limited income.

In this chapter, we introduce the basic elements of linear programming as it is applied to solve the diet/nutrition problem. It is a powerful tool for analyzing the cost of a nutritionally adequate ration prepared from different locally available foods. The method could be further refined by taking into account costs that were not included in the present study, such as the cost of targeting food distribution, of administrative overheads, or of training food aid staff.

The sensitivity of linear programming to selected constraints is its major weakness. This approach should not be used in isolation and the validity of the conclusions should always be field-tested. The chosen set of nutritional constraints should be based on internationally accepted nutritional recommendations, such as ones published by international organizations. The food consumption constraints should be derived from the food consumption data collected in the community of interest. Building up an international database of food consumption constraints for different age groups, especially for nutrient-dense foods, would facilitate the application of this method. The validity of these constraints could then be confirmed and, if necessary, adjusted on the basis of a series of simple observations.

This chapter is organized as follows: in the next section, we review some of the recent case studies that use this approach for achieving an optimal diet. The third section illustrates the principles of the linear programming model along with its underlying assumptions. We then demonstrate the use of the Excel solver to determine the least expensive food combination that respects multiple nutritional constraints. The method shows how modern computer applications can be used to answer very practical questions. The final section provides a summary of the linear programming applications for nutrition programming.

Review of the literature

The application of linear programming to determine the minimum cost of achieving the recommended daily nutrients is not a new idea. This tool started with the seminal work of Stigler (1945). Stigler posed the following question: for a moderately active individual weighing 154 pounds, how much of each of the 77 foods should be eaten on a daily basis so that the individual's nutrient intakes will be at least equal to the recommended dietary allowances (RDAs)¹? Stigler's RDAs of interest were calories, protein, calcium, iron, vitamin A, thiamine, riboflavin, niacin and ascorbic acid. The nutrient contents of the 77 foods were obtained from the 1940 publication of the US Department of Agriculture (USDA).

The study used a trial and error method to solve the 9×77 set of inequalities. Based on the cost and nutrient content of foods, the original 77 foods were

brought down to 15. These 15 food items had no meat except beef liver and excluded all sugars, beverages and planted cereals. The minimum cost of the diet during 1939 was found to be \$39.93 per year and included varying amounts of wheat flour, evaporated milk, cabbage, spinach and dried navy beans. The optimum diet consisted of foods that most individuals would find unappetizing such as pork liver, spinach, dried beans, evaporated milk and wheat flour. The above diet could be considered as the combination that makes up the human dog biscuit. However, human nutritionists did not seriously investigate the application of linear programming to determine an optimum diet till the late 1990s. We present some of the case studies from the economics and nutrition literature that apply linear programming to study food and nutrition problems.

Silberberg (1985) developed a hypothesis of tastes by humans with regard to food consumption using the law of diminishing marginal product. Since dog foods cannot be consumed by humans due to taste considerations, Silberberg introduced taste in the LP models. The main hypothesis postulated was as follows: as income rises, expenditure on 'pure nutrition' declines as a percentage of overall food expenditure and the importance of taste increases.

The analysis starts with the assumption that foods purchased in the market were inputs which could be used in the production of meals that provide both pleasing taste and nutrition. The data were obtained from the USDA's food consumption surveys and consisted of approximately 15 000 households for the period 1977 and 1978.

The minimum cost level diets found in the study were such that it could be given to slaves, although the calorie levels could be elevated. The various aspects of consumer behavior that are amenable in this framework could be the automobile or housing markets. Cars, in general, provide varying degrees of styles and comfort. Thus, one could expect diminishing returns to the pure transport function of cars. In other words, as income increased, a greater fraction of the price of a car could be attributable to style and comfort and less to pure transportation.

For housing, one could expect rapidly diminishing returns to pure shelter component as income increased. As income increases, a greater proportion of housing expenses could be directed towards more space and less towards pure shelter. Applying theory in the above manner could provide interesting implications of consumer behavior in general and analyzing nutrition behavior of households.

Athanasios et al. (1994) assessed the impact of food for work program (FFW) on consumption and nutrition of the households. A two-step procedure was undertaken. First, a linear programming model was used to estimate the marginal nutrient prices of four nutrients, namely calories, protein, fat and carbohydrates. The main hypothesis was that changes in food commodity prices would affect the nutrient demand by affecting the nutrient shadow prices. Second, an econometric model was specified to estimate the own and cross-price elasticities and income elasticity of demand for each of the four nutrients. The data used in the study were collected from Baringo district in the Rift valley

province of Kenya for the period August 1983 to February 1984. A random sample of 252 households was selected, out of which 100 were found to be participants in the FFW projects. The data included all the production and consumption activities of households and the data on FFW included beans, corn, and vegetable oil.

In the first step, a linear programming model was specified and run for each household. Every household had a different set of food items consumed and paid a different set of food prices. In the second step, a household's nutrient demand was specified as a function of nutrient shadow prices and other household characteristics and was estimated econometrically.

The study found that there were significant nutritional gains to FFW participants via food transfers compared to an equivalent net income transfer to the participating households. While previous research on the impact of FFW on nutrition suggested that lower income households had significant income gains due to participation in the FFW projects, the study demonstrated that even the poorest participant households had nutritional gains of 32.46 per cent more than the gain by all participants. The implication of these results is that significant nutritional gains can occur through food transfers as compared to an equivalent net income transfer to the participant households. Thus, the food for work program could be used as an instrument to improve the general nutrition conditions of the population.

Conforti and D'Amicis (2000) assessed the effect of adoption of a nutritionally correct food behavior on average food patterns and related expenditure. In other words, the basic question addressed was what would happen if households (Italian households) switched from their actual food pattern to one that met the nutritional requirements as defined by nutritionists. The main objective of this paper was to describe in detail what the average food pattern looks like and how much it would cost if the population followed the recommended daily allowances (RDAs) rather than to indicate how RDAs should be met. A linear programming model was formulated by minimizing food expenditures subject to the intake of given maximum and/or minimum levels of nutrients, vector of prices, vectors of maximum and minimum requirements and a food composition matrix.

Some important conclusions were derived from this study. First, the LP exercise supported the idea that consumers normally chose foods rather than nutrients. In other words, most food expenditure paid for tastes and habits in consumption in the Italian case. This was the reason for including the food habit constraints. Second, the pattern generated by including both the RDAs and food habit constraints showed several patterns of consumption trends that matched reality. The generated pattern with the actual trend in behavior suggested that consumption by Italians has been moving toward a healthier pattern over the years. Third, a trend toward a healthier diet does not imply per se an increase in food expenditure. Finally, the model suggests that the costs associated with an imbalanced average food pattern could have far reaching implications, which goes beyond consumption. From the epidemiological studies, the association

between food intake and health status has demonstrated that even a small decrease in the risk of contracting food-related diseases could significantly affect both health care expenditures and labor productivity.

Briend et al. (2001) demonstrated how the linear programming technique could be applied in estimating the economic benefits from the introduction of different fortified foods, using local food prices. The paper compared the economic value of a classical blended food with that of a nutrient-dense spread known as ‘foodlet’, a highly fortified food that can be regarded as a big tablet for childhood diets in Chad.

The economic value of two food supplements (a traditionally blended flour and a highly nutrient-dense spread known as ‘foodlet’) were used in the study to illustrate the application of linear programming. For the nutrient-dense spread, fortification levels were chosen from previous research in Algeria. High fortification levels were made possible in this spread by the attractive taste of peanut, which could easily hide high levels of unpalatable vitamins and minerals. The flour was a blend of maize and cowpea flours with sugar, fortified with a standard mineral and vitamin mix.

The analysis also showed that a proposed program has a ratio of amount saved to amount spent less than 1, which implied that the money saved by the families will be below the amount spent by the donor. This is likely to be the case for unfortified blended flour prepared from locally available foods. These foods were more expensive than the sum of the basic ingredients used in their composition and had no superior nutritional value compared with the meal a mother would prepare at home with the same ingredients.

Garille and Gass (2001) first took the original data in 1939 used by Stigler and replicated the LP results. The data were then updated to include price changes, revised values of the RDAs and current evaluations of the nutrient content of the 77 foods. In extending Stigler’s original problem, the upper bounds of these nutrients were set that were known to be toxic or to have other undesirable properties.

The purpose of this study was to solve the diet problem for five different sets of data:

1. Stigler’s original problem was updated for a 25–50-year-old man
2. for a 25–50-year-old woman
3. the extended Stigler problem, where the constraints were incorporated for all of the current RDAs for a 25–50-year-old man
4. for a 25–50-year-old woman
5. Stigler’s problem using current RDAs and food nutrient contents with 1939 prices.

Additionally, for each of the problems, the minimum cost diet was solved where no excess nutrients were allowed.

The study used the nutritive content of foods in the form that would most likely be eaten, to make the problem more realistic. The 77 food items were all included in the study. However, the Bureau of Labor Statistics (BLS) list only includes about 30 of the original 77 foods. For the data set to be consistent, the

prices of the food items were included from the Giant food supermarket chain in the Washington, DC area for April 1998.

The optimal solution to this excess Stigler diet problem was \$40.92 annually during 1939 and was \$481.16 in April 1998. The updated excess diet included wheat flour, evaporated milk, cabbage and sweet potatoes and was a different diet than Stigler's original model (which only included spinach and navy beans but no sweet potatoes). The following minimum requirements were not satisfied with this diet: polyunsaturated fatty acids, vitamin B₆, vitamin B₁₂, pantothenic acid, sodium, potassium, magnesium, zinc, copper, iodine, vitamin D and vitamin E. The upper limit for manganese was exceeded. All the foods in this diet were also on Stigler's reduced list of foods and the annual cost of this diet was only \$0.99 more than the annual cost of Stigler's 1939 diet.

The trial and error method of Stigler's original (9×77) problem proved that the simplex method works in practice. The concept of a diet problem led the way to many minimum cost applications, such as cattle and chicken feed, chemical and fertilizer blending. However, the inadequacy of the Stigler's diet problem to produce a nutritious and palatable human diet caused researchers to extend the analysis to menu planning which, in turn, raised new research questions in integer and goal programming. The advantage of the LP model was that the assumptions and concepts (such as additivity, proportionality, non-negativity, duality) could be easily explained. Stigler's pre-linear programming approach to modeling human diet can now be used for the following purposes:

1. to evaluate the nutritional content of diets for school children
2. plan menus for institutions (such as hospitals, jails)
3. manage food-systems.

Linear programming model

The first solution of a diet problem using linear programming was by Smith (1959). An LP problem consists of several essential elements. First, there are *decision variables* (X_j), the level of which denotes the amount undertaken of the respective unknowns, of which there are n ($j = 1, 2, \dots, n$). Next, is the *linear objective function* whose total objective value (Z) equals $c_1X_1 + c_2X_2 + \dots + c_nX_n$. Here, c_j is the contribution of each unit of X_j to the objective function.

There are m *linear constraints*. An algebraic expression of the i^{th} constraint is given by the following expression: $a_{i1}X_1 + a_{i2}X_2 + \dots + a_{in}X_n \leq b_i$ ($i = 1, 2, \dots, m$), where b_i denotes the upper limit or the right-hand side imposed by the constraint and a_{ij} is the use of the i^{th} constraint by one unit of X_j . The c_j , b_i and a_{ij} are the exogenous parameters of the model. The LP problem then is to choose X_1, X_2, \dots, X_n so as to maximize the following function (Hazell and Norton, 1986):

$$\begin{aligned}
 & \text{Max } c_1X_1 + c_2X_2 + \dots + c_nX_n \\
 & a_{11}X_1 + a_{12}X_2 + \dots + a_{1n}X_n \leq b_1 \\
 & a_{21}X_1 + a_{22}X_2 + \dots + a_{2n}X_n \leq b_2 \\
 \text{s.t.} & \\
 & a_{m1}X_1 + a_{m2}X_2 + \dots + a_{mn}X_n \leq b_m \\
 & X_j \geq 0
 \end{aligned}
 \tag{15.1}$$

The above formulation can be expressed in matrix notation as follows:

$$\begin{aligned}
 & \text{Max } cX \\
 \text{s.t. } & AX \leq b \\
 & X \geq 0
 \end{aligned}
 \tag{15.2}$$

The model described either by equation (15.1) or by (15.2) has some important underlying assumptions. They are as follows:

1. optimization: it is assumed that an appropriate objective function is either maximized or minimized
2. fixedness: at least one constraint has a non-zero right-hand side coefficient
3. finiteness: there are only a finite number of activities and constraints so that a solution can be found
4. determinism: all the parameters c_j , b_i , and a_{ij} are assumed to be constants
5. continuity: resources can be used and activities produced in quantities that are fractional units
6. homogeneity: all units of the same resource or activity are identical
7. additivity: the activities are assumed to be additive in the sense that when two or more are used, their total product is the sum of their individual products. In other words, interaction between activities is not permitted
8. proportionality: the gross margin and resource requirements per unit of activity are assumed to be constant regardless of the level of activity. For example, a constant gross margin per unit of activity assumes a perfectly elastic demand curve for the product. On the other hand, constant resource requirements per unit of activity are equivalent to a Leontief production function.

The assumptions of linearity and proportionality together define the linearity in activities, thereby giving rise to the name linear programming. However, the assumptions underlying the LP model are stringent, since both the objective function and the constraints are assumed to be linear. This only implies that the optimum solution will lie in one of the corners of the constraint. We will demonstrate in the next section the graphical procedure of obtaining a solution.

Solution procedures

This section illustrates the solution procedure of the linear programming by using both the graphical and the simplex method. The characteristic that makes linear programs easy to solve is their simple geometric structure. A solution for

a linear program is any set of numerical values for the variables. These values need not be the best values and do not even have to satisfy the constraints. A ‘feasible solution’ is a solution that satisfies all of the constraints. The ‘feasible set’ is the set of all feasible solutions. An ‘optimal solution’ is the feasible solution that produces the best objective function value.

Graphical solution approach

Consider the data in [Table 15.1](#).

The problem is to select the least cost combination of potato and beef that will supply 2000 calories or more, less than or equal to 1500 mg of calcium and exactly 50 g of protein. Thus, in the LP formulation, the problem can be rewritten as:

$$\begin{aligned} &\text{Minimize } 0.1 X_1 + 1.3 X_2 \\ &\text{s.t. } 76 X_1 + 242 X_2 \geq 2000 \\ &0.3 X_1 + 3 X_2 = 50 \\ &7 X_1 + 11 X_2 \leq 1500 \\ &\text{and } X_1, X_2 \geq 0. \end{aligned}$$

The constraints $X_1, X_2 \geq 0$ restricts us to the points on or to the right of the vertical axis and to the points on or above the horizontal axis. Next, we draw the individual constraints. In order to find the points that satisfy the first constraint ($76 X_1 + 242 X_2 \geq 2000$), we construct the line $76 X_1 + 242 X_2 = 2000$ by finding the two points that lie on the line and then constructing a line through these points. First, set $X_1 = 0$ and solve for X_2 . This yields the point ($X_1 = 0$ and $X_2 = 8.264$). Then we set $X_2 = 0$ and solve for X_1 . This yields the point ($X_1 = 26.315$ and $X_2 = 0$). This line is plotted in [Figure 15.1](#). Now, we have to determine which side of the line the point satisfies the constraint. If one point satisfies the constraint, then all the points on the same side of the line satisfy the constraint. Analogously, if one point does not satisfy the constraint, then no point on that side of the line satisfies the constraint. Suppose we choose the point ($X_1 = 0$ and $X_2 = 0$). This point does not satisfy the constraint $76 X_1 + 242 X_2 \geq 2000$. Hence, all the points to the lower left will also not

Table 15.1 Summary of data for linear programming

	X_1 Potato	X_2 Beef	Constraint
Calories (kcal/100 g)	76	242	≥ 2000
Protein (g/100 g)	0.3	3.0	$= 50$
Calcium (mg/100 g)	7.0	11.0	≤ 1500
Cost (\$/100 g)	0.1	1.3	

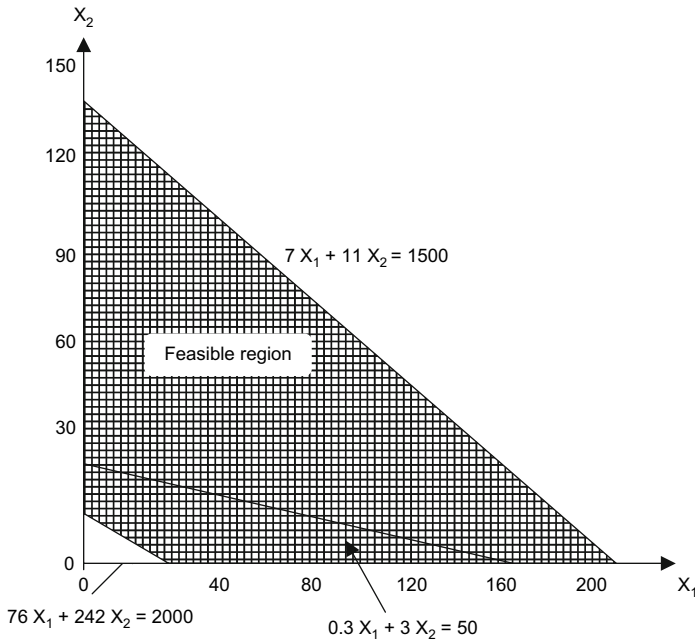


Figure 15.1 Feasible region of the above LP problem.
(Source: from Anderson and Earle, 1983)

satisfy the constraint. Thus, points above the upper right of this line will satisfy the constraint.

We do the same thing for the protein constraint $0.3 X_1 + 3 X_2 = 50$. Since this is an equality, we first set $X_1 = 0$ and solve for X_2 . This yields the point $(X_1 = 0$ and $X_2 = 16.67)$. Next, we set $X_2 = 0$ and solve for X_1 . This yields the point $(X_1 = 166.67$ and $X_2 = 0)$. Now, if we choose a point such as $(X_1 = 0$ and $X_2 = 0)$, we find that the constraint is not satisfied. Hence, the solution must lie on the line and neither above or below it. Finally, we choose the calcium constraint $7 X_1 + 11 X_2 \leq 1500$. We find two points on the line $7 X_1 + 11 X_2 = 1500$. We first set $X_1 = 0$ and solve for X_2 . This yields the point $(X_1 = 0$ and $X_2 = 136.36)$. Next, we set $X_2 = 0$ and solve for X_1 . This yields the point $(X_1 = 214.28$ and $X_2 = 0)$. This gives us the line on the upper right-hand side. Now, if we choose a point such as $(X_1 = 0$ and $X_2 = 0)$, we find that the constraint is satisfied. Therefore, all the points to the lower left also do. The shaded area represents the feasible set. The feasible set for a linear program will always have a shape like the one in Figure 15.1, with edges being straight lines and corners where the edges meet. The corners of the feasible set are called *extreme points*. Note that each extreme point is formed by the intersection of two or more constraints.

Thus, the fundamental theorem of linear programming can be stated as follows: if a finite optimal solution exists, then at least one extreme point is optimal. In this rather simple example, we know that the solution must lie at the

point where the line $0.3 X_1 + 3 X_2 = 50$ has an intercept on the X_1 axis. We want to find the optimum values of X_1 and X_2 such that the objective function $0.1 X_1 + 1.3 X_2$ is as small as possible. This is obtained if we set $X_2 = 0$. In this case, $X_1 = 166.67$. Substituting these values of X_1 and X_2 in the constraint functions, we obtain the optimum number of calories, protein and calcium to be 12666.67, 50.001 and 1166.67 respectively.

Some qualifications about the optimum

The fundamental theorem of linear programming states that if a finite optimum exists, there exists an extreme point which is optimal. However, this optimal solution may not be unique. Two or more adjacent extreme points (that share a common edge) may tie for the best solution. In this case, not only are extreme points optimal, but all the points on the edge connecting them are also optimal. In such a case, we have a situation of *multiple optima*.

In addition, sometimes a linear program can have an unbounded solution. In such a situation, the objective function can achieve a value of positive infinity for a maximization problem and negative infinity for a minimization problem. Consider the following problem:

$$\begin{aligned} & \text{Maximize } X_1 + 2 X_2 \\ & \text{s.t. } X_1 \leq 10 \\ & 2 X_1 + X_2 \geq 5 \\ & \text{and } X_1, X_2 \geq 0. \end{aligned}$$

As long as X_1 is kept less than or equal to 10, X_2 can be increased without limit and the objective function will increase without bound. Thus, in this example, there is no finite optimum. We call such a solution an *unbounded solution*. Unboundedness refers to the objective function value and not the constraint set. When an unbounded problem occurs, the modeler should carefully study the situation to determine the limitations that exist and which are not explicitly stated in the constraints. We now demonstrate the above results using Microsoft Excel solver program to show how computer software can be used to solve an LP problem.

Using Solver in Excel to obtain an LP solution

There are numerous software packages that can be used to solve linear programming problems – LINDO and GAMS being the most popular ones. All these packages are usually DOS based and intended for a niche market.

In recent years, however, several business packages such as spreadsheets have started to include an LP solving option. The inclusion of an LP solving capability in a program such as Excel is attractive for two reasons. First, Excel is perhaps the most popular spreadsheet that is used in business organizations and

universities and thus is accessible. Second, the spreadsheet offers very convenient data entry and editing features that can allow the student to gain better understanding of how to construct linear programs. We demonstrate in this section how to use the Solver function to solve the diet problem in the above section.

First, to use Excel, the Solver Add-In must be included. To add this facility to your Tools menu, one needs to carry out the following steps:

1. select the menu option Tools and then hit Add_Ins (which will take a few moments)
2. from the dialog box presented check the box for Solver Add-In
3. on clicking OK, you can then access the Solver option from the new menu option Tools and then hit on Solver.

We now illustrate the steps that are necessary in order to solve the diet problem.

The best approach to entering the problem into Excel is first to list in a column the names of the objective function, decision variables and constraints. Then enter some arbitrary starting values in the cells for the decision variables, usually zero. Excel will vary the values of the cells as it determines the optimal solutions. Having assigned the decision variables with some arbitrary starting values, one can use cell references explicitly in writing the formulae for the objective function and the constraints.

Step 1: Setting the problem in Excel

Entering the formulae for the objective and constraints, the objective function in B5 is given by $0.1 * B9 + 1.3 B10$. The constraints will be given by putting the right-hand side values in adjacent cells (Figure 15.2).

$$\text{Calories (B14)} = 76 * B9 + 242 * B10$$

$$\text{Protein (B15)} = 0.3 * B9 + 3 * B10$$

$$\text{Calcium (B16)} = 7 * B9 + 11 * B10$$

$$\text{Non-negativity 1 (B17)} = B9$$

$$\text{Non-negativity 2 (B18)} = B10$$

Now selecting the menu option tools and hitting on Solver, Figure 15.3 is revealed.

Step 2: Solving the parameters of the model

Select whether you wish to maximize or minimize the problem. In this example, set the target cell B5 to a Min. Next enter the range of cell that you want Solver to vary – the decision variables. Click on the white box (By Changing Cells) and select cells B9 and B10. Next, you can enter the constraints by first clicking the ‘Add’ button and add each constraint of the equation. Having added all the constraints, click the ‘OK’ button and the Solver dialog box would look like the one shown in Figure 15.3. Before clicking ‘Solve’, it is important to go to the Options button and check the ‘Assume Linear Model’ to make the model linear. This step is necessary for a solution to exist and for generating the relevant

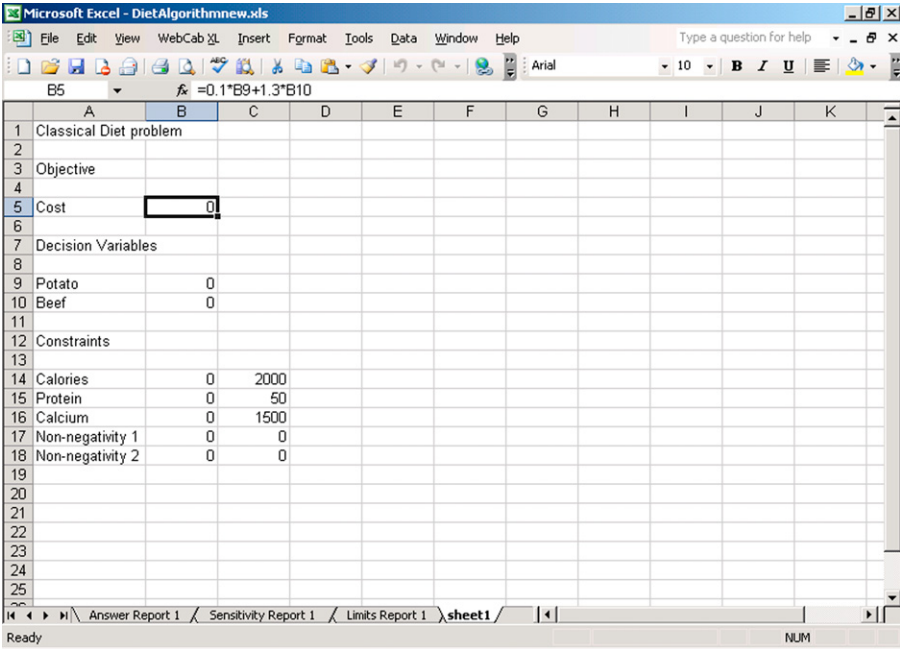


Figure 15.2 Excel box.

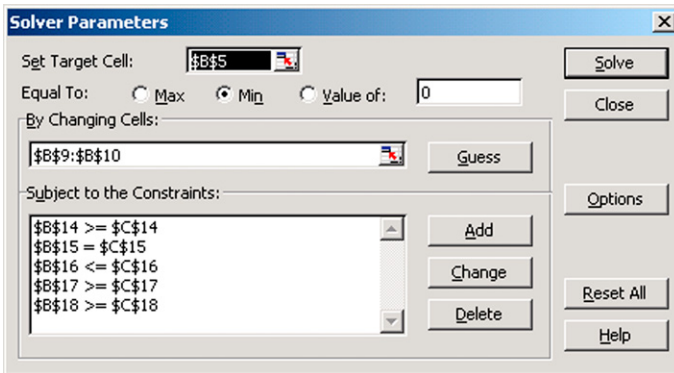


Figure 15.3 Solver parameters box.

sensitivity report. After selecting this option, click ‘Solve’ and the Solver will find the optimal values of the decision variables. Observe that Solver has altered all the values in your spreadsheet and replaced them with the optimal results.

One can use the Solver Results dialog box to generate three reports. To select all the three at once, hold down the CTRL button of the keyboard and drag the mouse over all three. Figure 15.4 should appear.

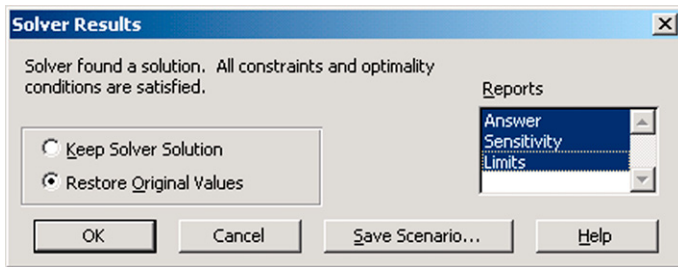


Figure 15.4 Solver results box.

Step 3: Deriving the results

It is a good practice to get Solver to restore the original values in the spreadsheet so that adjustments can be made to the model. Three reports are now generated in new sheets in the current workbook of Excel. The Answer report (Figure 15.5) gives details of the solution. In our case, the cost of the diet is minimized at 16.67 when 0 units of beef and 166.67 units of potatoes are consumed. Recall, this was the solution² obtained graphically in the previous section. Finally, the sensitivity report provides information about how sensitive the solution is to changes in the constraints given in Figure 15.6.

The sensitivity report given in Figure 15.6 is fairly standard and provides information on shadow prices, reduced cost and the upper and lower limits for the decision variables and constraints. In conclusion, Excel Solver is a simple but effective tool for allowing users to explore linear programs. It can be used for large problems with hundreds of variables and constraints and can be done relatively quickly. However, for teaching purposes, a small problem can provide important insights about the structure of an LP. One of the main limitations of this method is that the tableaus generated at each iteration cannot be found. Other programs such as Lindo allow this.

Summary

Since the seminal work of Stigler in 1945, the concept of a diet or blending problem led the way to many minimum cost applications, such as cattle and chicken feed, chemical and fertilizer blending. The inadequacy of the Stigler's diet problem to produce a palatable and a nutritious human diet caused researchers to extend the approach to menu plans in schools which, in turn, raised new research questions in integer and goal programming. The LP model of the basic diet problem can be used to explain all the concepts of linear programming. As pointed out by Garille and Gass (2001), it is a classic example of a correct mathematical model of a real world problem that does not produce a valid solution.

Linear programming is a tool for analyzing the cost of a nutritionally adequate ration prepared from different locally available foods. The general

Microsoft Excel 11.0 Answer Report**Worksheet: [DietAlgorithmnew.xls]sheet1****Report Created: 4/28/2005 10:44:43 AM**

Target Cell (Min)

Cell	Name	Original Value	Final Value
\$B\$5	Cost	0	16.66666667

Adjustable Cells

Cell	Name	Original Value	Final Value
\$B\$9	Potato	0	166.6666667
\$B\$10	Beef	0	0

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
\$B\$14	Calories	12666.66667	\$B\$14>=\$C\$14	Not Binding	10666.66667
\$B\$15	Protein	50	\$B\$15=\$C\$15	Not Binding	0
\$B\$16	Calcium	1166.666667	\$B\$16<=\$C\$16	Not Binding	333.3333333
\$B\$17	Non-negativity 1	166.6666667	\$B\$17>=\$C\$17	Not Binding	166.6666667
\$B\$18	Non-negativity 2	0	\$B\$18>=\$C\$18	Binding	0

Figure 15.5 Optimized values of decision variables and constraints.

principles and a selected application of this approach were presented in this chapter. From a nutritionist perspective, very practical questions on complementary feeding have been debated over many years with no clear solution. Without the help of linear programming, it is impossible to use intuition and trial and error approaches to arrive at solutions to problems that required solving hundreds of equations simultaneously. Linear programming should clarify these important issues. Additionally, everyone agrees that nutrient recommendations by different expert committees are difficult to implement in practice. In fact, few practitioners have been successful in providing recommendations that are realistic and consistent with the recommended nutrient intakes. It is often the case that diets based on current food recommendations do not provide the recommended nutrients. Linear programming can make major progress in this area.

Microsoft Excel 11.0 Sensitivity Report**Worksheet: [DietAlgorithmnew.xls]sheet1****Report Created: 4/28/2005 10:44:43 AM**

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
\$B\$9	Potato	166.6666667	0	0.1	0.03	1E+30
\$B\$10	Beef	0	0	1.3	1E+30	0.3

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
\$B\$14	Calories	12666.66667	0	2000	10666.66667	1E+30
\$B\$15	Protein	50	0.333333333	50	14.28571429	42.10526316
\$B\$16	Calcium	1166.666667	0	1500	1E+30	333.3333333
\$B\$17	Non-negativity 1	166.6666667	0	0	166.6666667	1E+30
\$B\$18	Non-negativity 2	0	0.3	0	16.66666667	5.649717514

Figure 15.6 Sensitivity report and shadow prices.

In conclusion, linear programming could be a powerful tool for formulating sound nutritional advice, especially in the context of complementary feeding practices in poor countries. It has the potential to improve infant and young children's nutrition with behavior change and effective communication strategies. This approach to human nutrition is long overdue³. This method has wide applications for different types of nutrition intervention programs, including supplementation, fortification and agriculture programs. Despite its limitations due to the underlying assumptions, linear programming clearly provides useful information for evaluating the economic benefits of different nutrition intervention programs for the poor.

Exercises

1. What are the three primary components of a constrained optimization model? Explain the difference between a parameter and a decision variable. What are the primary assumptions underlying a linear programming model?
2. What does it mean when a problem has an unbounded solution? What does it mean to perform sensitivity analysis?

3. You are given the following diet problem:

$$\text{Min } C = 0.6 X_1 + X_2$$

$$\text{s.t. } 10 X_1 + 4 X_2 \geq 20 \text{ (calcium constraint)}$$

$$5 X_1 + 5 X_2 \geq 20 \text{ (protein constraint)}$$

$$2 X_1 + 6 X_2 \geq 12 \text{ (vitamin A constraint)}$$

$$\text{and } X_1, X_2 \geq 0.$$

Solve the problem using Excel Solver. What are the optimum quantities of X_1 and X_2 that you obtain? What is the minimum cost of the above diet?

4. Solve the following linear program problem graphically:

$$\text{Maximize } z = X_1 + 2 X_2$$

$$\text{s.t. } 6 X_1 + 3 X_2 \leq 15$$

$$2 X_1 - X_2 \geq 4$$

$$\text{and } X_1, X_2 \geq 0.$$

Notes

1. RDAs are the levels of intake of essential nutrients that, on the basis of scientific knowledge, are considered by the Food and Nutrition Board to be adequate to meet the known nutrient needs of all healthy individuals.
2. The method used by Excel to solve the LP problem is called the simplex method. For an excellent discussion of this method, see the following website: <http://cba.fu.edu/dsis/davidsoj/Supplement%20B.pdf>
3. Unfortunately, this technique has not been part of the curriculum in most of the universities specializing in nutrition sciences and, thus, nutritionists have not used this technique to determine the minimum cost of achieving an optimal diet.

Statistical tables

Tables of the Normal Distribution

Probability content from $-\infty$ to Z



Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990

Far right tail probabilities



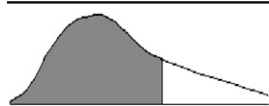
Z	P{Z to ∞}	Z	P{Z to ∞}	Z	P{Z to ∞}	Z	P{Z to ∞}
2.0	0.02275	3.0	0.001350	4.0	0.00003167	5.0	2.867 E-7
2.1	0.01786	3.1	0.0009676	4.1	0.00002066	5.5	1.899 E-8
2.2	0.01390	3.2	0.0006871	4.2	0.00001335	6.0	9.866 E-10
2.3	0.01072	3.3	0.0004834	4.3	0.00000854	6.5	4.016 E-11
2.4	0.00820	3.4	0.0003369	4.4	0.000005413	7.0	1.280 E-12
2.5	0.00621	3.5	0.0002326	4.5	0.000003398	7.5	3.191 E-14
2.6	0.004661	3.6	0.0001591	4.6	0.000002112	8.0	6.221 E-16
2.7	0.003467	3.7	0.0001078	4.7	0.000001300	8.5	9.480 E-18
2.8	0.002555	3.8	0.00007235	4.8	7.933 E-7	9.0	1.129 E-19
2.9	0.001866	3.9	0.00004810	4.9	4.792 E-7	9.5	1.049 E-21

Source: obtained from <http://www.math.unb.ca/~knight/utility/NormTble.htm>

T-distribution table

df	$\alpha = 0.1$	0.05	0.025	0.01	0.005	0.001	0.0005
∞	$t_{\alpha} = 1.282$	1.645	1.960	2.326	2.576	3.091	3.291
1	3.078	6.314	12.706	31.821	63.656	318.289	636.578
2	1.886	2.920	4.303	6.965	9.925	22.328	31.600
3	1.638	2.353	3.182	4.541	5.841	10.214	12.924
4	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	1.476	2.015	2.571	3.365	4.032	5.894	6.869
6	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	1.314	1.703	2.052	2.473	2.771	3.421	3.689
28	1.313	1.701	2.048	2.467	2.763	3.408	3.674

Critical points of the chi-square distribution



Cumulative probability

D. F.	0.005	0.010	0.025	0.05	0.10	0.25	0.50	0.75	0.90	0.95	0.975	0.99	0.995
1	0.39E-4	0.00016	0.00098	0.0039	0.0158	0.102	0.455	1.32	2.71	3.84	5.02	6.63	7.88
2	0.0100	0.0201	0.0506	0.103	0.211	0.575	1.39	2.77	4.61	5.99	7.38	9.21	10.6
3	0.0717	0.115	0.216	0.352	0.584	1.21	2.37	4.11	6.25	7.81	9.35	11.3	12.8
4	0.207	0.297	0.484	0.711	1.06	1.92	3.36	5.39	7.78	9.49	11.1	13.3	14.9
5	0.412	0.554	0.831	1.15	1.61	2.67	4.35	6.63	9.24	11.1	12.8	15.1	16.7
6	0.676	0.872	1.24	1.64	2.20	3.45	5.35	7.84	10.6	12.6	14.4	16.8	18.5
7	0.989	1.24	1.69	2.17	2.83	4.25	6.35	9.04	12.0	14.1	16.0	18.5	20.3
8	1.34	1.65	2.18	2.73	3.49	5.07	7.34	10.2	13.4	15.5	17.5	20.1	22.0
9	1.73	2.09	2.70	3.33	4.17	5.9	8.34	11.4	14.7	16.9	19.0	21.7	23.6
10	2.16	2.56	3.25	3.94	4.87	6.74	9.34	12.5	16.0	18.3	20.5	23.2	25.2
11	2.60	3.05	3.82	4.57	5.58	7.58	10.3	13.7	17.3	19.7	21.9	24.7	26.8
12	3.07	3.57	4.40	5.23	6.30	8.44	11.3	14.8	18.5	21.0	23.3	26.2	28.3
13	3.57	4.11	5.01	5.89	7.04	9.3	12.3	16.0	19.8	22.4	24.7	27.7	29.8
14	4.07	4.66	5.63	6.57	7.79	10.2	13.3	17.1	21.1	23.7	26.1	29.1	31.3
15	4.60	5.23	6.26	7.26	8.55	11.0	14.3	18.2	22.3	25.0	27.5	30.6	32.8
16	5.14	5.81	6.91	7.96	9.31	11.9	15.3	19.4	23.5	26.3	28.8	32.0	34.3
17	5.70	6.41	7.56	8.67	10.1	12.8	16.3	20.5	24.8	27.6	30.2	33.4	35.7
18	6.26	7.01	8.23	9.39	10.9	13.7	17.3	21.6	26.0	28.9	31.5	34.8	37.2
19	6.84	7.63	8.91	10.1	11.7	14.6	18.3	22.7	27.2	30.1	32.9	36.2	38.6
20	7.43	8.26	9.59	10.9	12.4	15.5	19.3	23.8	28.4	31.4	34.2	37.6	40.0

21	8.03	8.90	10.3	11.6	13.2	16.3	20.3	24.9	29.6	32.7	35.5	38.9	41.4
22	8.64	9.54	11.0	12.3	14.0	17.2	21.3	26.0	30.8	33.9	36.8	40.3	42.8
23	9.26	10.2	11.7	13.1	14.8	18.1	22.3	27.1	32.0	35.2	38.1	41.6	44.2
24	9.89	10.9	12.4	13.8	15.7	19.0	23.3	28.2	33.2	36.4	39.4	43.0	45.6
25	10.5	11.5	13.1	14.6	16.5	19.9	24.3	29.3	34.4	37.7	40.6	44.3	46.9
26	11.2	12.2	13.8	15.4	17.3	20.8	25.3	30.4	35.6	38.9	41.9	45.6	48.3
27	11.8	12.9	14.6	16.2	18.1	21.7	26.3	31.5	36.7	40.1	43.2	47.0	49.6
28	12.5	13.6	15.3	16.9	18.9	22.7	27.3	32.6	37.9	41.3	44.5	48.3	51.0
29	13.1	14.3	16.0	17.7	19.8	23.6	28.3	33.7	39.1	42.6	45.7	49.6	52.3
30	13.8	15.0	16.8	18.5	20.6	24.5	29.3	34.8	40.3	43.8	47.0	50.9	53.7
31	14.5	15.7	17.5	19.3	21.4	25.4	30.3	35.9	41.4	45.0	48.2	52.2	55.0
32	15.1	16.4	18.3	20.1	22.3	26.3	31.3	37.0	42.6	46.2	49.5	53.5	56.3
33	15.8	17.1	19.0	20.9	23.1	27.2	32.3	38.1	43.7	47.4	50.7	54.8	57.6
34	16.5	17.8	19.8	21.7	24.0	28.1	33.3	39.1	44.9	48.6	52.0	56.1	59.0
35	17.2	18.5	20.6	22.5	24.8	29.1	34.3	40.2	46.1	49.8	53.2	57.3	60.3
36	17.9	19.2	21.3	23.3	25.6	30.0	35.3	41.3	47.2	51.0	54.4	58.6	61.6
37	18.6	20.0	22.1	24.1	26.5	30.9	36.3	42.4	48.4	52.2	55.7	59.9	62.9
38	19.3	20.7	22.9	24.9	27.3	31.8	37.3	43.5	49.5	53.4	56.9	61.2	64.2
39	20.0	21.4	23.7	25.7	28.2	32.7	38.3	44.5	50.7	54.6	58.1	62.4	65.5
40	20.7	22.2	24.4	26.5	29.1	33.7	39.3	45.6	51.8	55.8	59.3	63.7	66.8
41	21.4	22.9	25.2	27.3	29.9	34.6	40.3	46.7	52.9	56.9	60.6	65.0	68.1
42	22.1	23.7	26.0	28.1	30.8	35.5	41.3	47.8	54.1	58.1	61.8	66.2	69.3
43	22.9	24.4	26.8	29.0	31.6	36.4	42.3	48.8	55.2	59.3	63.0	67.5	70.6
44	23.6	25.1	27.6	29.8	32.5	37.4	43.3	49.9	56.4	60.5	64.2	68.7	71.9
45	24.3	25.9	28.4	30.6	33.4	38.3	44.3	51.0	57.5	61.7	65.4	70.0	73.2
	0.005	0.010	0.025	0.05	0.10	0.25	0.50	0.75	0.90	0.95	0.975	0.99	0.995

Source: obtained from <http://www.math.unb.ca/~knight/utility/chitable.html>

95% points for the F distribution

		Numerator degrees of freedom											
		*	1	2	3	4	5	6	7	8	9	10	*
Denominator degrees of freedom	1	161	199	216	225	230	234	237	239	241	242		1
	2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4		2
	3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79		3
	4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96		4
	5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74		5
	6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06		6
	7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64		7
	8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35		8
	9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14		9
	10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98		10
	11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85		11
	12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75		12
	13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67		13
	14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60		14
	15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54		15
	16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49		16
	17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45		17
	18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41		18
	19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38		19
	20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35		20
	21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32		21
	22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30		22
	23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27		23
	24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25		24
	25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24		25
	26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22		26
	27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20		27
	28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19		28
	29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18		29
	30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16		30
	35	4.12	3.27	2.87	2.64	2.49	2.37	2.29	2.22	2.16	2.11		35
	40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08		40
	50	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07	2.03		50
	60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99		60
	70	3.98	3.13	2.74	2.50	2.35	2.23	2.14	2.07	2.02	1.97		70
80	3.96	3.11	2.72	2.49	2.33	2.21	2.13	2.06	2.00	1.95		80	
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97	1.93		100	
150	3.90	3.06	2.66	2.43	2.27	2.16	2.07	2.00	1.94	1.89		150	
300	3.87	3.03	2.63	2.40	2.24	2.13	2.04	1.97	1.91	1.86		300	
1000	3.85	3.00	2.61	2.38	2.22	2.11	2.02	1.95	1.89	1.84		1000	

Numerator degrees of freedom												
	*	11	12	13	14	15	16	17	18	19	20	*
Denominator degrees of freedom	1	243	244	245	245	246	246	247	247	248	248	1
	2	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	2
	3	8.76	8.74	8.73	8.71	8.70	8.69	8.68	8.67	8.67	8.66	3
	4	5.94	5.91	5.89	5.87	5.86	5.84	5.83	5.82	5.81	5.80	4
	5	4.70	4.68	4.66	4.64	4.62	4.60	4.59	4.58	4.57	4.56	5
	6	4.03	4.00	3.98	3.96	3.94	3.92	3.91	3.90	3.88	3.87	6
	7	3.60	3.57	3.55	3.53	3.51	3.49	3.48	3.47	3.46	3.44	7
	8	3.31	3.28	3.26	3.24	3.22	3.20	3.19	3.17	3.16	3.15	8
	9	3.10	3.07	3.05	3.03	3.01	2.99	2.97	2.96	2.95	2.94	9
	10	2.94	2.91	2.89	2.86	2.85	2.83	2.81	2.80	2.79	2.77	10
	11	2.82	2.79	2.76	2.74	2.72	2.70	2.69	2.67	2.66	2.65	11
	12	2.72	2.69	2.66	2.64	2.62	2.60	2.58	2.57	2.56	2.54	12
	13	2.63	2.60	2.58	2.55	2.53	2.51	2.50	2.48	2.47	2.46	13
	14	2.57	2.53	2.51	2.48	2.46	2.44	2.43	2.41	2.40	2.39	14
	15	2.51	2.48	2.45	2.42	2.40	2.38	2.37	2.35	2.34	2.33	15
	16	2.46	2.42	2.40	2.37	2.35	2.33	2.32	2.30	2.29	2.28	16
	17	2.41	2.38	2.35	2.33	2.31	2.29	2.27	2.26	2.24	2.23	17
	18	2.37	2.34	2.31	2.29	2.27	2.25	2.23	2.22	2.20	2.19	18
	19	2.34	2.31	2.28	2.26	2.23	2.21	2.20	2.18	2.17	2.16	19
	20	2.31	2.28	2.25	2.22	2.20	2.18	2.17	2.15	2.14	2.12	20
	21	2.28	2.25	2.22	2.20	2.18	2.16	2.14	2.12	2.11	2.10	21
	22	2.26	2.23	2.20	2.17	2.15	2.13	2.11	2.10	2.08	2.07	22
	23	2.24	2.20	2.18	2.15	2.13	2.11	2.09	2.08	2.06	2.05	23
	24	2.22	2.18	2.15	2.13	2.11	2.09	2.07	2.05	2.04	2.03	24
	25	2.20	2.16	2.14	2.11	2.09	2.07	2.05	2.04	2.02	2.01	25
	26	2.18	2.15	2.12	2.09	2.07	2.05	2.03	2.02	2.00	1.99	26
	27	2.17	2.13	2.10	2.08	2.06	2.04	2.02	2.00	1.99	1.97	27
	28	2.15	2.12	2.09	2.06	2.04	2.02	2.00	1.99	1.97	1.96	28
	29	2.14	2.10	2.08	2.05	2.03	2.01	1.99	1.97	1.96	1.94	29
	30	2.13	2.09	2.06	2.04	2.01	1.99	1.98	1.96	1.95	1.93	30
	35	2.07	2.04	2.01	1.99	1.96	1.94	1.92	1.91	1.89	1.88	35
	40	2.04	2.00	1.97	1.95	1.92	1.90	1.89	1.87	1.85	1.84	40
	50	1.99	1.95	1.92	1.89	1.87	1.85	1.83	1.81	1.80	1.78	50
	60	1.95	1.92	1.89	1.86	1.84	1.82	1.80	1.78	1.76	1.75	60
	70	1.93	1.89	1.86	1.84	1.81	1.79	1.77	1.75	1.74	1.72	70
	80	1.91	1.88	1.84	1.82	1.79	1.77	1.75	1.73	1.72	1.70	80
	100	1.89	1.85	1.82	1.79	1.77	1.75	1.73	1.71	1.69	1.68	100
	150	1.85	1.82	1.79	1.76	1.73	1.71	1.69	1.67	1.66	1.64	150
	300	1.82	1.78	1.75	1.72	1.70	1.68	1.66	1.64	1.62	1.61	300
	1000	1.80	1.76	1.73	1.70	1.68	1.65	1.63	1.61	1.60	1.58	1000

		Numerator degrees of freedom											
		*	21	22	23	24	25	26	27	28	29	30	*
Denominator degrees of freedom	1	248	249	249	249	249	249	249	250	250	250	250	1
	2	19.4	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	2
	3	8.65	8.65	8.64	8.64	8.63	8.63	8.63	8.63	8.62	8.62	8.62	3
	4	5.79	5.79	5.78	5.77	5.77	5.76	5.76	5.76	5.75	5.75	5.75	4
	5	4.55	4.54	4.53	4.53	4.52	4.52	4.51	4.51	4.50	4.50	4.50	5
	6	3.86	3.86	3.85	3.84	3.83	3.83	3.82	3.82	3.82	3.81	3.81	6
	7	3.43	3.43	3.42	3.41	3.40	3.40	3.39	3.39	3.39	3.38	3.38	7
	8	3.14	3.13	3.12	3.12	3.11	3.10	3.10	3.10	3.09	3.08	3.08	8
	9	2.93	2.92	2.91	2.90	2.89	2.89	2.88	2.87	2.87	2.87	2.86	9
	10	2.76	2.75	2.75	2.74	2.73	2.72	2.72	2.71	2.71	2.70	2.70	10
11	2.64	2.63	2.62	2.61	2.60	2.59	2.59	2.58	2.58	2.57	2.57	11	
12	2.53	2.52	2.51	2.51	2.50	2.49	2.48	2.48	2.47	2.47	2.47	12	
13	2.45	2.44	2.43	2.42	2.41	2.41	2.40	2.39	2.39	2.38	2.38	13	
14	2.38	2.37	2.36	2.35	2.34	2.33	2.33	2.32	2.31	2.31	2.31	14	
15	2.32	2.31	2.30	2.29	2.28	2.27	2.27	2.26	2.25	2.25	2.25	15	
16	2.26	2.25	2.24	2.24	2.23	2.22	2.21	2.21	2.20	2.19	2.19	16	
17	2.22	2.21	2.20	2.19	2.18	2.17	2.17	2.16	2.15	2.15	2.15	17	
18	2.18	2.17	2.16	2.15	2.14	2.13	2.13	2.12	2.11	2.11	2.11	18	
19	2.14	2.13	2.12	2.11	2.11	2.10	2.09	2.08	2.08	2.07	2.07	19	
20	2.11	2.10	2.09	2.08	2.07	2.07	2.06	2.05	2.05	2.04	2.04	20	
21	2.08	2.07	2.06	2.05	2.05	2.04	2.03	2.02	2.02	2.01	2.01	21	
22	2.06	2.05	2.04	2.03	2.02	2.01	2.00	2.00	1.99	1.98	1.98	22	
23	2.04	2.02	2.01	2.01	2.00	1.99	1.98	1.97	1.97	1.96	1.96	23	
24	2.01	2.00	1.99	1.98	1.97	1.97	1.96	1.95	1.95	1.94	1.94	24	
25	2.00	1.98	1.97	1.96	1.96	1.95	1.94	1.93	1.93	1.92	1.92	25	
26	1.98	1.97	1.96	1.95	1.94	1.93	1.92	1.91	1.91	1.90	1.90	26	
27	1.96	1.95	1.94	1.93	1.92	1.91	1.90	1.90	1.89	1.88	1.88	27	
28	1.95	1.93	1.92	1.91	1.91	1.90	1.89	1.88	1.88	1.87	1.87	28	
29	1.93	1.92	1.91	1.90	1.89	1.88	1.88	1.87	1.86	1.85	1.85	29	
30	1.92	1.91	1.90	1.89	1.88	1.87	1.86	1.85	1.85	1.84	1.84	30	
35	1.87	1.85	1.84	1.83	1.82	1.82	1.81	1.80	1.79	1.79	1.79	35	
40	1.83	1.81	1.80	1.79	1.78	1.77	1.77	1.76	1.75	1.74	1.74	40	
50	1.77	1.76	1.75	1.74	1.73	1.72	1.71	1.70	1.69	1.69	1.69	50	
60	1.73	1.72	1.71	1.70	1.69	1.68	1.67	1.66	1.66	1.65	1.65	60	
70	1.71	1.70	1.68	1.67	1.66	1.65	1.65	1.64	1.63	1.62	1.62	70	
80	1.69	1.68	1.67	1.65	1.64	1.63	1.63	1.62	1.61	1.60	1.60	80	
100	1.66	1.65	1.64	1.63	1.62	1.61	1.60	1.59	1.58	1.57	1.57	100	
150	1.63	1.61	1.60	1.59	1.58	1.57	1.56	1.55	1.54	1.54	1.54	150	
300	1.59	1.58	1.57	1.55	1.54	1.53	1.52	1.51	1.51	1.50	1.50	300	
1000	1.57	1.55	1.54	1.53	1.52	1.51	1.50	1.49	1.48	1.47	1.47	1000	

Numerator degrees of freedom												
	*	31	32	33	34	35	36	37	38	39	40	*
Denominator degrees of freedom	1	250	250	250	251	251	251	251	251	251	251	1
	2	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	2
	3	8.61	8.61	8.61	8.61	8.60	8.60	8.60	8.60	8.60	8.59	3
	4	5.74	5.74	5.74	5.73	5.73	5.73	5.72	5.72	5.72	5.72	4
	5	4.49	4.49	4.48	4.48	4.48	4.47	4.47	4.47	4.47	4.46	5
	6	3.80	3.80	3.80	3.79	3.79	3.79	3.78	3.78	3.78	3.77	6
	7	3.37	3.37	3.36	3.36	3.36	3.35	3.35	3.35	3.34	3.34	7
	8	3.07	3.07	3.07	3.06	3.06	3.06	3.05	3.05	3.05	3.04	8
	9	2.86	2.85	2.85	2.85	2.84	2.84	2.84	2.83	2.83	2.83	9
	10	2.69	2.69	2.69	2.68	2.68	2.67	2.67	2.67	2.66	2.66	10
	11	2.57	2.56	2.56	2.55	2.55	2.54	2.54	2.54	2.53	2.53	11
	12	2.46	2.46	2.45	2.45	2.44	2.44	2.44	2.43	2.43	2.43	12
	13	2.38	2.37	2.37	2.36	2.36	2.35	2.35	2.35	2.34	2.34	13
	14	2.30	2.30	2.29	2.29	2.28	2.28	2.28	2.27	2.27	2.27	14
	15	2.24	2.24	2.23	2.23	2.22	2.22	2.21	2.21	2.21	2.20	15
16	2.19	2.18	2.18	2.17	2.17	2.17	2.16	2.16	2.15	2.15	16	
17	2.14	2.14	2.13	2.13	2.12	2.12	2.11	2.11	2.11	2.10	17	
18	2.10	2.10	2.09	2.09	2.08	2.08	2.07	2.07	2.07	2.06	18	
19	2.07	2.06	2.06	2.05	2.05	2.04	2.04	2.03	2.03	2.03	19	
20	2.03	2.03	2.02	2.02	2.01	2.01	2.01	2.00	2.00	1.99	20	
21	2.00	2.00	1.99	1.99	1.98	1.98	1.98	1.97	1.97	1.96	21	
22	1.98	1.97	1.97	1.96	1.96	1.95	1.95	1.95	1.94	1.94	22	
23	1.95	1.95	1.94	1.94	1.93	1.93	1.93	1.92	1.92	1.91	23	
24	1.93	1.93	1.92	1.92	1.91	1.91	1.90	1.90	1.90	1.89	24	
25	1.91	1.91	1.90	1.90	1.89	1.89	1.88	1.88	1.88	1.87	25	
26	1.89	1.89	1.88	1.88	1.87	1.87	1.87	1.86	1.86	1.85	26	
27	1.88	1.87	1.87	1.86	1.86	1.85	1.85	1.84	1.84	1.84	27	
28	1.86	1.86	1.85	1.85	1.84	1.84	1.83	1.83	1.82	1.82	28	
29	1.85	1.84	1.84	1.83	1.83	1.82	1.82	1.81	1.81	1.81	29	
30	1.83	1.83	1.82	1.82	1.81	1.81	1.80	1.80	1.80	1.79	30	
35	1.78	1.77	1.77	1.76	1.76	1.75	1.75	1.74	1.74	1.74	35	
40	1.74	1.73	1.73	1.72	1.72	1.71	1.71	1.70	1.70	1.69	40	
50	1.68	1.67	1.67	1.66	1.66	1.65	1.65	1.64	1.64	1.63	50	
60	1.64	1.64	1.63	1.62	1.62	1.61	1.61	1.60	1.60	1.59	60	
70	1.62	1.61	1.60	1.60	1.59	1.59	1.58	1.58	1.57	1.57	70	
80	1.59	1.59	1.58	1.58	1.57	1.56	1.56	1.55	1.55	1.54	80	
100	1.57	1.56	1.55	1.55	1.54	1.54	1.53	1.52	1.52	1.52	100	
150	1.53	1.52	1.51	1.51	1.50	1.50	1.49	1.49	1.48	1.48	150	
300	1.49	1.48	1.48	1.47	1.46	1.46	1.45	1.45	1.44	1.43	300	
1000	1.46	1.46	1.45	1.44	1.43	1.43	1.42	1.42	1.41	1.41	1000	

		Numerator degrees of freedom											
		*	45	50	60	70	80	100	120	150	300	1000	*
Denominator degrees of freedom	1	251	252	252	252	253	253	253	253	254	254	1	
	2	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	2	
	3	8.59	8.58	8.57	8.57	8.56	8.55	8.55	8.54	8.54	8.53	3	
	4	5.71	5.70	5.69	5.68	5.67	5.66	5.66	5.65	5.64	5.63	4	
	5	4.45	4.44	4.43	4.42	4.41	4.41	4.40	4.39	4.38	4.37	5	
	6	3.76	3.75	3.74	3.73	3.72	3.71	3.70	3.70	3.68	3.67	6	
	7	3.33	3.32	3.30	3.29	3.29	3.27	3.27	3.26	3.24	3.23	7	
	8	3.03	3.02	3.01	2.99	2.99	2.97	2.97	2.96	2.94	2.93	8	
	9	2.81	2.80	2.79	2.78	2.77	2.76	2.75	2.74	2.72	2.71	9	
	10	2.65	2.64	2.62	2.61	2.60	2.59	2.58	2.57	2.55	2.54	10	
	11	2.52	2.51	2.49	2.48	2.47	2.46	2.45	2.44	2.42	2.41	11	
	12	2.41	2.40	2.38	2.37	2.36	2.35	2.34	2.33	2.31	2.30	12	
	13	2.33	2.31	2.30	2.28	2.27	2.26	2.25	2.24	2.23	2.21	13	
	14	2.25	2.24	2.22	2.21	2.20	2.19	2.18	2.17	2.15	2.14	14	
	15	2.19	2.18	2.16	2.15	2.14	2.12	2.11	2.10	2.09	2.07	15	
	16	2.14	2.12	2.11	2.09	2.08	2.07	2.06	2.05	2.03	2.02	16	
	17	2.09	2.08	2.06	2.05	2.03	2.02	2.01	2.00	1.98	1.97	17	
	18	2.05	2.04	2.02	2.00	1.99	1.98	1.97	1.96	1.94	1.92	18	
	19	2.01	2.00	1.98	1.97	1.96	1.94	1.93	1.92	1.90	1.88	19	
	20	1.98	1.97	1.95	1.93	1.92	1.91	1.90	1.89	1.86	1.85	20	
	21	1.95	1.94	1.92	1.90	1.89	1.88	1.87	1.86	1.83	1.82	21	
	22	1.92	1.91	1.89	1.88	1.86	1.85	1.84	1.83	1.81	1.79	22	
	23	1.90	1.88	1.86	1.85	1.84	1.82	1.81	1.80	1.78	1.76	23	
	24	1.88	1.86	1.84	1.83	1.82	1.80	1.79	1.78	1.76	1.74	24	
	25	1.86	1.84	1.82	1.81	1.80	1.78	1.77	1.76	1.73	1.72	25	
	26	1.84	1.82	1.80	1.79	1.78	1.76	1.75	1.74	1.71	1.70	26	
	27	1.82	1.81	1.79	1.77	1.76	1.74	1.73	1.72	1.70	1.68	27	
	28	1.80	1.79	1.77	1.75	1.74	1.73	1.71	1.70	1.68	1.66	28	
	29	1.79	1.77	1.75	1.74	1.73	1.71	1.70	1.69	1.66	1.65	29	
	30	1.77	1.76	1.74	1.72	1.71	1.70	1.68	1.67	1.65	1.63	30	
35	1.72	1.70	1.68	1.66	1.65	1.63	1.62	1.61	1.58	1.57	35		
40	1.67	1.66	1.64	1.62	1.61	1.59	1.58	1.56	1.54	1.52	40		
50	1.61	1.60	1.58	1.56	1.54	1.52	1.51	1.50	1.47	1.45	50		
60	1.57	1.56	1.53	1.52	1.50	1.48	1.47	1.45	1.42	1.40	60		
70	1.55	1.53	1.50	1.49	1.47	1.45	1.44	1.42	1.39	1.36	70		
80	1.52	1.51	1.48	1.46	1.45	1.43	1.41	1.39	1.36	1.34	80		
100	1.49	1.48	1.45	1.43	1.41	1.39	1.38	1.36	1.32	1.30	100		
150	1.45	1.44	1.41	1.39	1.37	1.34	1.33	1.31	1.27	1.24	150		
300	1.41	1.39	1.36	1.34	1.32	1.30	1.28	1.26	1.21	1.17	300		
1000	1.38	1.36	1.33	1.31	1.29	1.26	1.24	1.22	1.16	1.110	1000		

Critical values for $F_{MAX} (S^2_{MAX}/S^2_{MIN})$ distribution for $\alpha = .05$ and $.01$

$\alpha = .05$

k											
df	2	3	4	5	6	7	8	9	10	11	12
4	9.60	15.5	20.6	25.2	29.5	33.6	37.5	41.1	44.6	48.0	51.4
5	7.15	10.8	13.7	16.3	18.7	20.8	22.9	24.7	26.5	28.2	29.9
6	5.82	8.38	10.4	12.1	13.7	15.0	16.3	17.5	18.6	19.7	20.7
7	4.99	6.94	8.44	9.70	10.8	11.8	12.7	13.5	14.3	15.1	15.8
8	4.43	6.00	7.18	8.12	9.03	9.78	10.5	11.1	11.7	12.2	12.7
9	4.03	5.34	6.31	7.11	7.80	8.41	8.95	9.45	9.91	10.3	10.7
10	3.72	4.85	5.67	6.34	6.92	7.42	7.87	8.28	8.66	9.01	9.34
12	3.28	4.16	4.79	5.30	5.72	6.09	6.42	6.72	7.00	7.25	7.48
15	2.86	3.54	4.01	4.37	4.68	4.95	5.19	5.40	5.59	5.77	5.93
20	2.46	2.95	3.29	3.54	3.76	3.94	4.10	4.24	4.37	4.49	4.59
30	2.07	2.40	2.61	2.78	2.91	3.02	3.12	3.21	3.29	3.36	3.39
60	1.67	1.85	1.96	2.04	2.11	2.17	2.22	2.26	2.30	2.33	2.36
∞	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

$\alpha = .01$

k											
df	2	3	4	5	6	7	8	9	10	11	12
4	23.2	37	49	59	69	79	89	97	106	113	120
5	14.9	22	28	33	38	42	46	50	54	57	60
6	11.1	15.5	19.1	22	25	27	30	32	34	36	37
7	8.89	12.1	14.5	16.5	18.4	20	22	23	24	26	27
8	7.50	9.9	11.7	13.2	14.5	15.8	16.9	17.9	18.9	19.8	21
9	6.54	8.5	9.9	11.1	12.1	13.1	13.9	14.7	15.3	16.0	16.6
10	5.85	7.4	8.6	9.6	10.4	11.1	11.8	12.4	12.9	13.4	13.9
12	4.91	6.1	6.9	7.6	8.2	8.7	9.1	9.5	9.9	10.2	10.6
15	4.07	4.9	5.5	6.0	6.4	6.7	7.1	7.3	7.5	7.8	8.0
20	3.32	3.8	4.3	4.6	4.9	5.1	5.3	5.5	5.6	5.8	5.9
30	2.63	3.0	3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2
60	1.96	2.2	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7
∞	1.00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Note: S^2_{MAX} is the largest and S^2_{MIN} the smallest in a set of k independent mean squares, each based on degrees of freedom (df).

Source: Adapted from Table 31 in *Biometrika Tables for Statisticians*, vol. 1, 3rd edn., edited by E. S. Pearson and H. O. Hartley (New York: Cambridge University Press, 1958). Reproduced with the permission of the *Biometrika* trustees.

Source: obtained with permission from Allyn and Bacon (2001).

Test for equal covariance matrices, $\alpha = .05$

<i>V</i>	<i>k</i> = 2	<i>k</i> = 3	<i>k</i> = 4	<i>k</i> = 5	<i>k</i> = 6	<i>k</i> = 7	<i>k</i> = 8	<i>k</i> = 9	<i>k</i> = 10
<i>p</i> = 2									
3	12.18	18.70	24.55	30.09	35.45	40.68	45.81	50.87	55.86
4	10.70	16.65	22.00	27.07	31.97	36.75	41.45	46.07	50.64
5	9.97	15.63	20.73	25.57	30.23	34.79	39.26	43.67	48.02
6	9.53	15.02	19.97	24.66	29.19	33.61	37.95	42.22	46.45
7	9.24	14.62	19.46	24.05	28.49	32.83	37.08	41.26	45.40
8	9.04	14.33	19.10	23.62	27.99	32.26	36.44	40.57	44.64
9	8.88	14.11	18.83	23.30	27.62	31.84	35.98	40.05	44.08
10	8.76	13.97	18.61	23.05	27.33	31.51	35.61	39.65	43.64
11	8.67	13.81	18.44	22.85	27.10	31.25	35.32	39.33	43.29
12	8.59	13.70	18.30	22.68	26.90	31.03	35.08	39.07	43.00
13	8.52	13.60	18.19	22.54	26.75	30.85	34.87	38.84	42.76
14	8.47	13.53	18.10	22.42	26.61	30.70	34.71	38.66	42.56
15	8.42	13.46	18.01	22.33	26.50	30.57	34.57	38.50	42.38
16	8.38	13.40	17.94	22.24	26.40	30.45	34.43	38.36	42.23
17	8.35	13.35	17.87	22.17	26.31	30.35	34.32	38.24	42.10
18	8.32	13.30	17.82	22.10	26.23	30.27	34.23	38.13	41.99
19	8.28	13.26	17.77	22.04	26.16	30.19	34.14	38.04	41.88
20	8.26	13.23	17.72	21.98	26.10	30.12	34.07	37.95	41.79
25	8.17	13.10	17.55	21.79	25.87	29.86	33.78	37.63	41.44
30	8.11	13.01	17.44	21.65	25.72	29.69	33.59	37.42	41.21
<i>p</i> = 3									
4	22.41	35.00	46.58	57.68	68.50	79.11	89.60	99.94	110.21
5	19.19	30.52	40.95	50.95	60.69	70.26	79.69	89.03	98.27
6	17.57	28.24	38.06	47.49	56.67	65.69	74.58	83.39	92.09
7	16.59	26.84	36.29	45.37	54.20	62.89	71.44	79.90	88.30
8	15.93	25.90	35.10	43.93	52.54	60.99	69.32	77.57	85.73
9	15.46	25.22	34.24	42.90	51.33	59.62	67.78	75.86	83.87
10	15.11	24.71	33.59	42.11	50.42	58.57	66.62	74.58	82.46
11	14.83	24.31	33.08	41.50	49.71	57.76	65.71	73.57	81.36
12	14.61	23.99	32.67	41.00	49.13	57.11	64.97	72.75	80.45
13	14.43	23.73	32.33	40.60	48.65	56.56	64.36	72.09	79.72
14	14.28	23.50	32.05	40.26	48.26	56.11	63.86	71.53	79.11
15	14.15	23.32	31.81	39.97	47.92	55.73	63.43	71.05	78.60
16	14.04	23.16	31.60	39.72	47.63	55.40	63.06	70.64	78.14
17	13.94	23.02	31.43	39.50	47.38	55.11	62.73	70.27	77.76
18	13.86	22.89	31.26	39.31	47.16	54.86	62.45	69.97	77.41
19	13.79	22.78	31.13	39.15	46.96	54.64	62.21	69.69	77.11
20	13.72	22.69	31.01	39.00	46.79	54.44	61.98	69.45	76.84
25	13.48	22.33	30.55	38.44	46.15	53.70	61.16	68.54	75.84
30	13.32	22.10	30.25	38.09	45.73	53.22	60.62	67.94	75.18

Test for equal covariance matrices, $\alpha = .05$

<i>V</i>	<i>k</i> = 2	<i>k</i> = 3	<i>k</i> = 4	<i>k</i> = 5	<i>k</i> = 6	<i>k</i> = 7	<i>k</i> = 8	<i>k</i> = 9	<i>k</i> = 10
<i>p</i> = 4									
5	35.39	56.10	75.36	93.97	112.17	130.11	147.81	165.39	182.80
6	30.06	48.62	65.90	82.60	98.93	115.03	130.94	146.69	162.34
7	27.31	44.69	60.89	76.56	91.88	106.98	121.90	136.71	151.39
8	25.61	42.24	57.77	72.77	87.46	101.94	116.23	130.43	144.50
9	24.45	40.57	55.62	70.17	84.42	98.46	112.32	126.08	139.74
10	23.62	39.34	54.04	68.26	82.19	95.90	109.46	122.91	136.24
11	22.98	38.41	52.84	66.81	80.48	93.95	107.27	120.46	133.57
12	22.48	37.67	51.90	65.66	79.14	92.41	105.54	118.55	131.45
13	22.08	37.08	51.13	64.73	78.04	91.15	104.12	116.68	129.74
14	21.75	36.59	50.50	63.95	77.13	90.12	102.97	115.69	128.32
15	21.47	36.17	49.97	63.30	76.37	89.26	101.99	114.59	127.14
16	21.24	35.82	49.51	62.76	75.73	88.51	101.14	113.67	126.10
17	21.03	35.52	49.12	62.28	75.16	87.87	100.42	112.87	125.22
18	20.86	35.26	48.78	61.86	74.68	87.31	99.80	112.17	124.46
19	20.70	35.02	48.47	61.50	74.25	86.82	99.25	111.56	123.79
20	20.56	34.82	48.21	61.17	73.87	86.38	98.75	111.02	123.18
25	20.06	34.06	47.23	59.98	72.47	84.78	96.95	109.01	120.99
30	19.74	33.59	46.61	59.21	71.58	83.74	95.79	107.71	119.57
<i>p</i> = 5									
6	51.11	81.99	110.92	138.98	166.54	193.71	220.66	247.37	273.88
7	43.40	71.06	97.03	122.22	146.95	171.34	195.49	219.47	243.30
8	39.29	65.15	89.45	113.03	136.18	159.04	181.65	204.14	226.48
9	36.71	61.39	84.62	107.17	129.30	151.17	172.80	194.27	215.64
10	34.93	58.78	81.25	103.06	124.48	145.64	166.56	187.37	208.02
11	33.62	56.85	78.75	100.02	120.92	141.54	161.98	182.24	202.37
12	32.62	55.37	76.83	97.68	118.15	138.38	158.38	178.23	198.03
13	31.83	54.19	75.30	95.82	115.96	135.86	155.54	175.10	194.51
14	31.19	53.23	74.05	94.29	114.16	133.80	153.21	172.49	191.68
15	30.66	52.44	73.01	93.02	112.66	132.07	151.29	170.36	189.38
16	30.22	51.76	72.14	91.94	111.41	130.61	149.66	166.53	187.32
17	29.83	51.19	71.39	91.03	110.34	129.38	148.25	166.99	185.61
18	29.51	50.69	70.74	90.23	109.39	128.29	147.03	165.65	184.10
19	29.22	50.26	70.17	89.54	108.57	127.36	145.97	164.45	182.81
20	28.97	49.88	69.67	88.93	107.85	126.52	145.02	163.38	181.65
25	28.05	48.48	67.86	86.70	105.21	123.51	141.62	159.60	177.49
30	27.48	47.61	66.71	85.29	103.56	121.60	139.47	157.22	174.87

Note: Table contains upper percentage points for

$$-2\ln M = v \left(k \ln |S| - \sum_{i=1}^k \ln |S_i| \right)$$

for *k* samples, each with *v* degrees of freedom. Reject $H_0 : \sum_1 = \sum_2 = \dots = \sum_k$ if $-2\ln M >$ table value.

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