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# Market microstructure: A survey☆

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**Abstract**

Market microstructure studies the process by which investors' latent demands are ultimately translated into prices and volumes. This paper reviews the theoretical, empirical and experimental literature on market microstructure relating to: (1) *price formation*, including the dynamic process by which prices come to impound information, (2) *market structure and design*, including the relation between price formation and trading protocols, (3) *Transparency*, the ability of market participants to observe information about the trading process, and (4) *Applications to other areas of finance* including asset pricing, international finance, and corporate finance. © 2000 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

The last two decades have seen a tremendous growth in the academic literature now known as *market microstructure*, the area of finance that is

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concerned with the process by which investors' latent demands are ultimately translated into transactions. Interest in microstructure and trading is not new[1] but the recent literature is distinguished by theoretical rigor and extensive empirical validation using new databases.

Some recent books and articles offer valuable summaries of important elements of the market microstructure literature. O'Hara's (1995) book provides an excellent and detailed survey of the theoretical literature in market microstructure. Harris (1999) provides a general conceptual overview of trading and the organization of markets in his text, but his focus is not on the academic literature. Lyons (2000) examines the market microstructure of foreign exchange markets. Survey articles emphasize depth over breadth, often focusing on a select set of issues. Keim and Madhavan (1998) survey the literature on execution costs, focusing on institutional traders. Coughenour and Shastri (1999) provide a detailed summary of recent empirical studies in four select areas: the estimation of the components of the bid–ask spread, order flow properties, the Nasdaq controversy, and linkages between option and stock markets. A survey of the early literature in the area is provided by Cohen et al. (1986).

This article provides a comprehensive review of the market microstructure literature, broadly defined to include theoretical, empirical and experimental studies relating to markets and trading. The paper is differentiated from previous surveys in its scope and its attempt to synthesize the diverse strands of the previous literature within the confines of a relatively brief article. My objective is to offer some perspective on the literature for investors, exchange officials, policy makers and regulators while also providing a roadmap for future research endeavors.

Interest in market microstructure is most obviously driven the rapid structural, technological, and regulatory changes affecting the securities industry world-wide. The causes of these structural shifts are complex. In the U.S., they include the substantial increase in trading volume, competition between exchanges and Electronic Communications Networks (ECNs), changes in the regulatory environment, new technological innovations, the growth of the Internet, and the proliferation of new financial instruments. In other countries, globalization and intermarket competition are more important in forcing change. For example, European economic integration means the almost certain demise of certain national stock exchanges, perhaps to be replaced eventually with a single market for the European time-zone. These factors are transforming the landscape of the industry, spurring interest in the relative merits of different trading protocols and designs.

[1] A classic description of trading on the Amsterdam Stock Exchange is provided by De La Vega (1688) who describes insider trading, manipulations, and futures and options trading.

Market microstructure has broader interest, however, with implications for asset pricing, corporate finance, and international finance. A central idea in the theory of market microstructure is that asset prices need not equal full-information expectations of value because of a variety of frictions. Thus, market microstructure is closely related to the field of investments, which studies the equilibrium values of financial assets. But while many regard market microstructure as a sub-field of investments, it is also linked to traditional corporate finance because differences between the price and value of assets clearly affects financing and capital structure decisions. The analysis of interactions with other areas of finance offer a new and exciting dimension to the study of market microstructure, one that is still being written.

The topics examined in this survey are primarily those of interest from the viewpoint of informational economics. Why this particular focus? Academic research emphasizes the importance of information in decision making. Both laboratory experiments and theoretical models show that agents' behavior – and hence market outcomes – are highly sensitive to the assumed information structure. From a practical perspective, many current issues facing the securities industry concern information. Examples include whether limit order books should be displayed to the public or not, whether competition among exchanges reduces informational efficiency by fragmenting the order flow, etc. Further, much of the recent literature, and the aspects of market microstructure that are most difficult to access by those unfamiliar with the literature, concern elements of information economics.

Informational research in microstructure covers a very wide range of topics. For the purposes of this article, it is convenient to think of research as falling into four main categories:

(1) *Price formation and price discovery*, including both static issues such as the determinants of trading costs and dynamic issues such the process by which prices come to impound information over time. Essentially, this topic is concerned with looking inside the 'black box' by which latent demands are translated into realized prices and volumes.
(2) *Market structure and design issues*, including the relation between price formation and trading protocols. Essentially, this topic focuses on how different rules affect the black box and hence liquidity and market quality.
(3) *Information and disclosure*, especially market transparency, i.e., the ability of market participants to observe information about the trading process. This topic deals with how revealing the workings of the black box affects the behavior of traders and their strategies.
(4) *Informational issues arising from the interface of market microstructure* with other areas of finance including corporate finance, asset pricing, and international finance. Models of the black box allow deeper investigations of traditional issues such as IPO underpricing as well as opening up new avenues for research.

These categories roughly correspond to the historical development of research in the informational aspects of microstructure, and form the basis for the organization of this article. Specifically, I survey the theoretical, empirical, and experimental studies in these subject areas, highlighting the broad conclusions that have emerged from this body of research.

Any survey will, by necessity, be selective and this is especially so for a field as large as market microstructure. The literature on trading and financial institutions is so large that one must necessarily omit many influential and important works. This article presents an aerial view of the literature, attempting to synthesize much of the recent work within a common framework rather than summarizing the contributions of individual papers in detail. My hope is that this approach will prove more useful to an interested reader without much prior knowledge of the literature.

The paper proceeds as follows. Section 2 outlines a 'canonical' market microstructure model that allows us to discuss the literature in a unified framework. Section 3 summarizes the literature on price formation with an emphasis on the role of market makers. Section 4 turns to issues of market structure and design. Section 5 looks at the topic of transparency and Section 6 surveys the interface of microstructure with other areas of finance. Section 7 concludes.

## 2. A roadmap

### 2.1. A canonical model of security prices

In this section we begin by introducing a simple model that serves as a roadmap for the rest of the paper. First, we need to introduce some notation. Let $v_t$ denote the (log) 'fundamental' or 'true' value of a risky asset at some point in time $t$. We can think of $v_t$ as the full-information expected present value of future cash flows. Fundamental value can change over time because of variation in expected cash flows or in the discount rate. Denote by $\mu_t = \mathrm{E}[v_t|\boldsymbol{H}_t]$ the conditional expectation of $v_t$ given the set of public information at time $t, \boldsymbol{H}_t$. Further, let $p_t$ denote the (log) price of the risky asset at time $t$.

In the canonical model of (weakly) efficient markets, price reflects all public information. If agents are assumed to possess symmetric information and frictions are negligible – the simplest set of assumptions – then prices simply reflect expected values and we write $p_t = \mu_t$. Taking log differences, we obtain the simplest model of stock returns

$$r_t = p_t - p_{t-1} = \varepsilon_t, \tag{1}$$

where $\varepsilon_t = \mu_t - \mu_{t-1} = \mathrm{E}[v_t|\boldsymbol{H}_t] - \mathrm{E}[v_{t-1}|\boldsymbol{H}_{t-1}]$ is the innovation in beliefs. Since $\mu_t$ follows a martingale process, applying the Law of Iterated Expectations, returns are serially uncorrelated. Markets are efficient in the sense that prices at all points in time reflect expected values.

### 2.2. Incorporating market microstructure effects

In contrast to the model of efficient markets above, market microstructure is concerned with how various frictions and departures from symmetric information affect the trading process. Specifically, microstructure relaxes different elements of the random walk model above.

#### 2.2.1. Trading frictions

The simplest approach allows for unpredictable pricing errors that reflect frictions such as the bid–ask spread. Hence, we write $p_t = \mu_t + s_t$, where $s_t$ is an error term with mean zero and variance $\sigma(s_t)$ that reflects the effect of frictions. It is customary to model $s_t$ as $s_t = sx_t$, where $s$ is a positive constant (representing one-half the bid–ask spread) and $x_t$ represents signed order flow. In the simplest model, we assume unit quantities with the convention that $x_t = +1$ for a buyer-initiated trade, $-1$ for a seller-initiated trade, and 0 for a cross at the midquote. Taking log differences, we obtain

$$r_t = \varepsilon_t + s_t - s_{t-1} = \varepsilon_t + s(x_t - x_{t-1}), \tag{2}$$

where $\varepsilon_t = \mathrm{E}[v_t|\boldsymbol{H}_t] - \mathrm{E}[v_{t-1}|\boldsymbol{H}_{t-1}]$ is the innovation in beliefs. The presumption of much of the early work in finance is that both the variance of $s_t$, $\sigma(s_t)$ and its serial correlation $\rho(s_t, s_{t-1})$ are 'small' in an economic sense. However, if the spread is not insignificant, there will be serial correlation in returns because of bid–ask bounce of the order of $\sigma(s_t)$. This phenomenon is the basis of the implicit spread estimator of Roll (1984).[2] Observe that the covariance between successive price changes for the model given by eq. (2) is

$$\mathrm{Cov}(r_t, r_{t-1}) = -s^2, \tag{3}$$

so that a simple measure of the implicit (round-trip) percentage bid–ask spread is given by inverting this equation to yield

$$\hat{s} = 2\sqrt{-\mathrm{Cov}(r_t, r_{t-1})}. \tag{4}$$

Roll's model is useful because it provides a method to estimate execution costs simply using transaction price data. Execution costs are difficult to measure. In many markets, quoted spreads are the basis for negotiation and hence may overstate true costs for trades by investors who can extract favorable terms from dealers; for other trades, such as large-block trades, quoted spreads may

[2] See also Niederhoffer and Osborne (1966) and Working (1977).

understate true costs as shown by Loeb (1983). Recent extensions of the model (Stoll, 1989; George et al., 1991; Huang and Stoll, 1997; Madhavan et al., 1997) allow for short-run return predictability arising from autocorrelation in order flows, limit orders, asymmetric information and other microstructure effects.

An important set of questions deals with the properties of $s_t$ over time (and across markets) because spreads might be a function of trade size reflecting various frictions such as dealer risk aversion and inventory carrying costs. Indeed, this focus on spreads and their composition dominates much of the early literature and reappeared in the discussion of spread setting behavior by Nasdaq dealers in 1994.

### 2.2.2. *Private information*

Another set of models is concerned with how private information is impounded in the trading process. If some agents possess private information, then the revision in beliefs about asset values from time $t-1$ to time $t$ need not just reflect new information arrivals. Rather, it will be correlated with signed order flow, denoted by $x_t$, since informed traders will buy when prices are below true value and sell if the opposite is the case. Thus, we model $\varepsilon_t = \lambda x_t + u_t$, where $\lambda > 0$ is a parameter that is derived formally below when we discuss information models and $u_t$ is pure noise. When trade size is variable, we interpret $x_t$ as the signed volume, as in Kyle (1985). Observe that the price impact of the trade (the deviation of price from the pre-trade conditional expectation) for a unit purchase is $p_t - \mu_t = s + \lambda$.

This simple model has interesting implications. When order size is variable, the quoted spread is good for a pre-specified depth. Asymmetric information implies that for large orders, the true cost of trading will exceed the quoted (half) bid–ask spread, $s$. While most researchers recognize that quoted spreads are small, implicit trading costs can actually be economically significant because large trades move prices. Empirical research has shown that such costs can be substantial in small capitalization stocks. This is an important issue because the costs of trading can substantially reduce the notional or paper gains to an investment strategy. As an example of how this phenomenon has practical implications, consider the growth of trading in baskets or entire portfolios. Subrahmanyam (1991) observes that information asymmetry is mainly a problem in individual stocks. It is unlikely a trader has market-wide private information, so that the asymmetric information component is not present in a basket of stocks. This provides a rationale for trading in stock index futures.

### 2.2.3. *Alternative trading structures*

Another set of models is concerned with how private information is impounded in the trading process. Several kinds of questions arise in this context. For example, how does market structure affect the size of trading costs measured by $E[|s_t|]$? Are costs larger under some types of structures than others? For example, in a simple auction mechanism with multilateral trading at a single price, there is no spread and $E[|s_t|] = 0$. Further, some markets may not even function under asymmetric information while other structures succeed in finding prices and matching buyers and sellers. Transparency studies how the statistical properties of $s_t$ and the size of $\lambda$ differ as a function not of market structure but of the information provided to traders during the process of price formation.

#### *2.2.4. The interface with other areas of finance*

An increasingly important area of research is the interface between market microstructure and other areas of finance including asset pricing, international finance, and corporate finance. For example, in the field of asset pricing, a growing body of research serves to demonstrate the importance of liquidity as a factor in determining expected returns. Other applications include various return anomalies, and the relation between trading costs and the practicality of investment strategies that appear to yield excess returns. In international finance, observed phenomena such as the high volume of foreign exchange transactions are being explained with innovative microstructure models. Microstructure models have been used in the area of corporate finance (examples include Fishman and Hagerty, 1989; Subrahmanyam and Titman, 1999) and new research offers some promising areas for future study including the link between market making and underwriting and microstructure theories of stock splits.

This broad brush picture of the literature omits many important details and also provides little sense of what has been accomplished and what still remains to be done. In the sections that follow, I will try to explain the historical and intellectual development of the literature in the broad groups listed above. Each section will begin with an overview and end with a summary that stresses the achievements to date and the areas that I still think remain as fertile grounds for further research. I begin with a closer examination of how prices are formed in securities markets and the crucial role of information flows. I then turn to the role of market design and structure in influencing price formation, move on to the issues of transparency, and then discuss the applications of microstructure models in other areas of finance.

## 3. Price formation and the role of information

### *3.1. Overview*

The market microstructure literature provides an alternative to frictionless Walrasian models of trading behavior; models that typically assume perfect competition and free entry. It concerns the analysis of all aspects of the security trading process. One of the most critical questions in market microstructure concerns the process by which prices come to impound new information. To do this, we need models of how prices are determined in securities markets. Much of the early literature is concerned with the operations of agents known as market makers, professional traders who stand willing to buy or sell securities on demand.[3] By virtue of their central position and role as price setters, market makers are a logical starting point for an exploration of how prices are actually determined inside the 'black box' of a security market (see, e.g. Stoll (1976) and Glosten (1989, 1994)). Market makers are also of importance because they provide liquidity to the market and permit continuous trading by over-coming the asynchronous timing of investor orders. This section reviews the literature on market makers and their contributions to the price discovery process, starting with simple models where dealers act as providers of liquidity, and then moving on to more complex models where dealers actively alter prices in response to inventory and information considerations.

### 3.2. *Market makers as suppliers of liquidity*

#### 3.2.1. *The early literature: determinants of the bid–ask spread*

Market makers quote two prices: the bid price, at which they will buy securities and the ask price, at which they will sell. The difference between the bid and the ask price is the market maker's spread. Demsetz (1968) argued that the market maker provides a service of 'predictive immediacy' in an organized exchange market, for which the bid–ask spread is the appropriate return under competition. The market maker has a passive role, simply adjusting the bid–ask spread in response to changing conditions. This is a reasonable first approximation because, as noted by Stoll (1985), market makers such as New York Stock Exchange (NYSE) specialists typically face competition from floor traders, competing dealers, limit orders and other exchanges. (Limit orders are orders to buy (sell) that specify a maximum (minimum) price at which the trader is willing to transact. A market order is an order to buy (sell) at prevailing prices. A stop order is an order that becomes a market order if and when the market reaches a price pre-specified by the trader.)

Empirical research along the lines suggested by Demsetz primarily concerned the determinants of the bid–ask spread. This focus was quite natural, since in the

[3] Market makers and financial intermediaries are distinct. A financial intermediary, such as a bank, transforms and repackages assets by purchasing assets and selling its liabilities. Unlike market makers, who buy and sell the same security (and can sell short), a financial intermediary generally holds long and short positions in different securities. There are, however, some similarities. Indeed, dealers are like simple banks in that they often borrow to finance inventory thus issuing a liability to purchase a primary asset.

Demsetz model the spread was the appropriate measure of performance in the provision of marketability services. These studies use a cross-sectional regression equation of the type below:

$$s_i = \beta_0 + \beta_1 \ln(M_i) + \beta_2(1/p_i) + \beta_3\sigma_i + \beta_4\ln(V_i) + \varepsilon_i, \tag{5}$$

where, for of security $i$, $s_i$ is the average (percentage) bid–ask spread modeled as a function of independent variables: log market capitalization (firm size), $M_i$, price inverse, $1/p_i$, the riskiness of the security measured by the volatility of past returns $\sigma_i$, and a proxy for activity such as log trading volume, $V_i$. Price inverse is typically used because the minimum tick induces a convexity in percentage spreads. Other explanatory variables may include the number of institutional investors holding the stock, again inversely related, proxies for competition and market type (e.g., Nasdaq or NYSE) and variables such as dealer capitalization relative to order flow, designed to capture the influence of characteristics of the market maker.

The results of cross-sectional regressions of the form above yield some interesting insights into market making. Volume, risk, price and firm size appear to explain most of the variability in the bid–ask spread. The coefficient of volume is typically negative, since dealers can achieve faster turnaround in inventory lowering their potential liquidation costs and reducing their risk. However, there do not appear to be economies of scale in market making. Spreads are wider for riskier securities, as predicted.

### *3.2.2. Dealer behavior and security prices: The role of inventory*

The empirical approach above was supplemented by theoretical studies that attempted to explain variation in bid–ask spreads as part of intraday price dynamics. An early focus was on dealer inventory, since this aspect of market making was likely to affect prices and liquidity.

Smidt (1971) argued that market makers are not simply passive providers of immediacy, as Demsetz suggested, but actively adjust the spread in response to fluctuations in their inventory levels. While the primary function of the market maker remains that of a supplier of immediacy, the market maker also takes an active role in price-setting, primarily with the objective of achieving a rapid inventory turnover and not accumulating significant positions on one side of the market. The implication of this model is that price may depart from expectations of value if the dealer is long or short relative to desired (target) inventory, giving rise to transitory price movements during the day and possibly over longer periods.

Garman (1976) formally modeled the relation between dealer quotes and inventory levels based on Smidt (1971). The intuition behind Garman's model can be easily explained in the context of the canonical model above. Recall that $x_t \in \{-1, 0, +1\}$ denotes the signed order flow in period $t$, where for expositional ease we maintain the assumption of unit quantities. Let $I_t$ denote inventory at time $t$ with the convention that $I_t > 0$ denotes a long position and $I_t < 0$ a short position. Then, the market maker's inventory position at the *start* of trading round $t$ is given by

$$I_t = I_0 - \sum_{k=1}^{t-1} x_k, \tag{6}$$

where $I_0$ is the dealer's opening position. Dealers have finite capital $K$ so that we require $|I_t| < K$. Suppose that there are no informed traders and assume that the market maker sets bid and ask prices to equate expected demand and expected supply, i.e., sets $p_t$ so that $\mathrm{E}[x_{t+1}|p_t] = 0$. It follows from eq. (6) that $\mathrm{E}[I_{t+1} - I_t|I_t] = 0$, i.e., inventory follows a random walk with zero drift. Hence, if dealer capital is finite, $\Pr[|I_T| > K] = 1$ for some finite $T$ and eventual market failure is certain. This is the familiar Gambler's Ruin problem. It follows that market makers must actively adjust prices in relation to inventory, altering prices and not simply spreads as in the Demsetz model.

Garman's model highlights the importance of dealer capital and inventory. Again, the model has some important practical implications. For example, if inventory is important, as it must be, then dealers who are already long may be reluctant to take on additional inventory without dramatic price reductions. Thus, we might observe large price reversals following heavy selling on days such as October 19, 1987. Further, the model suggests that one way to reduce excess transitory price volatility would be to require dealers to maintain higher levels of capital.

This intuition drives the models of inventory control developed by Stoll (1978), Amihud and Mendelson (1980), among others. The idea is that as the dealer trades, the actual and desired inventory positions diverge, forcing the dealer to adjust the general level of price. Since this may result in expected losses, inventory control implies the existence of a bid–ask spread even if actual transaction costs (i.e., the physical costs of trading) are negligible.

Models of market maker inventory control over the trading day typically use stochastic dynamic programming. Essentially, these models envision the market maker facing a series of mini-auctions during the day, rather than a stream of transactions. As the number of trading rounds becomes arbitrarily large, the trading process approximates that of a continuous double auction. In a continuous double auction securities can be bought or sold at any time during the day, not necessarily at designated periods as in a straightforward auction. At each auction, markets are cleared, prices and inventory levels change, and at the end of the trading day, excess inventory must be liquidated or stored overnight at cost. Bid and ask prices are set so as to maximize the present expected value of trading revenue less inventory storage costs over an infinite horizon of trading days. Models in this category include those of Zabel

(1981), O'Hara and Oldfield (1986), and Madhavan and Smidt (1993) among others.[4]

In terms of the stylized model developed in Section 2 above, the inventory models can be described as follows. Instead of setting price equal to the expected value of the asset as before, the dealer sets price in such a way as to control inventory. Let $I^*$ denote the dealer's desired or target inventory position. Then, in the prototypical inventory model, we have

$$p_t = \mu_t - \phi(I_t - I^*) + s x_t. \tag{7}$$

Thus, the average of the bid and ask prices need not equal the 'equilibrium price' of the security. The dealer cuts the price at the start of round $t$ if he or she *enters* the trading round with a long position and raises price if short, relative to the inventory target.

Inventory models provide an added rationale for the reliance on dealers. Specifically, just as physical market places consolidate buyers and sellers in *space*, the market maker can be seen as an institution to bring buyers and sellers together in *time* through the use of inventory. A buyer need not wait for a seller to arrive but simply buys from the dealer who depletes his or her inventory. The presence of market makers who can carry inventories imparts stability to price movements through their actions relative to an automated system that simply clears the market at each auction without accumulating inventory.

*3.2.3. Dealer behavior: Asymmetric information*

Recent work in market microstructure links advances in the economics of information, rational expectations and imperfect competition to construct models of the impact of information, including its arrival, dissemination and processing, on market prices. When market makers are considered, these models become even more complex since the behavior of the market maker must also be taken into account. An influential paper by Jack Treynor (writing under the pseudonym of Bagehot (1971)) suggested the distinction between liquidity motivated traders who possess no special informational advantages and informed traders with private information. The concept of an informed trader is distinct from that of an insider, usually defined as a corporate officer with fiduciary obligations to shareholders. Noise traders are liquidity motivated, smoothing their intertemporal consumption stream through portfolio adjustments; alternatively, uninformed traders may simply believe they have current information. Informed traders hope to profit from their information in trades with the

[4] O'Hara and Oldfield (1986) decompose the bid–ask spread into three components: a portion for known limit orders, a portion for expected market orders and a lastly a risk adjustment for order and inventory uncertainty. They show that a risk averse market maker may, depending on the environment, set lower spreads than a risk neutral specialist.

uninformed. While the market maker loses to informed traders on average, but recoups these losses on 'noise' trades, suggesting that the spread contains an informational component as well.

Models of this type have been developed by Glosten and Milgrom (1985), Easley and O'Hara (1987), among many others. In the Glosten and Milgrom model, orders are assumed to be for one round lot, and there are two types of traders $(i, u)$, either informed or uninformed. Let $\Theta$ denote the trader's type ($\Theta = i$ or $u$) and assume that a constant fraction $\omega$ of traders possess some private information. The asset can take on two possible values, high and low, denoted by $v^{\mathrm{H}}$ and $v^{\mathrm{L}}$, with expectation equal to $\bar{v}_t$. Let $\sigma = v^{\mathrm{H}} - v^{\mathrm{L}}$ denote the range of uncertainty. For expositional ease, assume that at time $t$ both states are equally likely so that $\bar{v}_t$ is $(v^H + v^L)/2$. Ignoring inventory and order processing costs, a rational market maker will quoting bid and ask prices that are regret free ex post. Thus, the market makers' ask price is the expected value of the security given that a purchase order has arrived. Formally,

$$p_t^{\mathrm{ask}} = \mathrm{E}[v_t | x_t = 1] = v^{\mathrm{H}} \Pr[\Theta = i | x_t = 1] + \bar{v}_t \Pr[\Theta = u | x_t = 1]. \tag{8}$$

Implicit in this formulation is the idea that the provider of liquidity quotes prices conditional on the direction of the trade, i.e., there is an ask price for a buy order and a bid price for a sell order, a condition known as ex post rationality. Thus, the set of public information includes all information at time $t$ including knowledge of the trade itself. Assuming symmetry, the bid–ask spread is

$$p_t^{\mathrm{ask}} - p_t^{\mathrm{bid}} = \omega\sigma,$$

which is increasing in information asymmetry $\omega$ and in the degree of asset value uncertainty $\sigma$. The market maker must trade off the reduction in losses to the informed from a wider spread against the opportunity cost in terms of profits from trading with uniformed traders with reservation prices inside the spread. Thus, the bid–ask spread may exist even if the market maker has no costs, behaves competitively and is risk neutral.

Kyle (1985) presents a model where a single trader, again with a monopoly on information, places orders over time to maximize trading profit before the information becomes common knowledge. The market maker observes net order flow and then sets a price which is the expected value of the security. Thus, price is set after orders are placed. Only market orders are permitted, as opposed to real world markets where agents can condition their demands on price. Kyle demonstrates that a rational expectations equilibrium exists in this framework and shows that market prices will eventually incorporate all available information. With continuous order quantities taking any value over the real line and appropriate assumptions of normality, the Kyle model can be viewed as a linear regression. Let $q_t$ denote the net order imbalance in auction $t$ (the cumulation of signed orders), and let $\mu_{t-1}$ denote the market maker's prior belief. In the Kyle model, the insider adopts a linear trading strategy so that $q_t$ is a noisy signal of the true value. The price at any point in time is just the expected value of the security, which is a linear projection

$$p_t = \mathrm{E}[v_t|q_t] = \mu_{t-1} + \lambda q_t. \tag{10}$$

In Kyle's model the market maker simply acts as an order processor, setting market clearing prices. If the market maker also behaved strategically, limiting dynamic losses, the model would be a game theoretic one and equilibrium may not exist. Further, it seems unlikely that a single trader would have, or behave as if he had, a monopoly on information. If private information takes the form of signals about the firm's project cash flows, it seems likely that more than one insider will be informed. Indeed, empirical evidence suggests that episodes of insider trading are often associated with multiple insiders. Cornell and Sirri (1992) examine an insider trading case where 38 insiders traded in one episode. See also Meulbroek (1992) for further evidence on this issue. Further, it is not clear that larger order sizes are always associated with more insider trading. Barclay and Warner (1993) find that informed traders concentrate their orders on medium-sized trades.

Holden and Subrahmanyam (1992) generalize Kyle's model to incorporate competition among multiple risk-averse insiders with long-lived private information. They demonstrate the existence of a unique linear equilibrium where competition among insiders is associated with high trading volumes and the rapid revelation of private information. Relative to Kyle's model, markets are more efficient, volumes are higher, and the profits of insiders are much lower. Thus, the extent to which insider trading is a concern for policy makers depends crucially on whether there is competition among such agents or not (see also Spiegel and Subrahmanyam, 1992).

Another extension is considered by Admati and Pfleiderer (1988), who develop a model of strategic play by informed and uninformed traders. They allow some uninformed traders to have discretion as to which time period they will trade in. They show the Nash Equilibrium for their game results in concentrated bouts of trading, similar to the flood of orders observed at the opening and closing of many continuous markets.

An implicit assumption in information models is that the market maker is uninformed. But are there are situations in which the market maker might have better information than the average trader? This is a question that is amenable to empirical analysis. One approach has been to examine the relationship between changes in market maker inventory levels and subsequent price rises. If market makers do have superior information, the correlation should be positive. In fact, studies of the NYSE and OTC markets have shown that the correlation is negative, suggesting that dealers do not possess information superior to that of the average trader. Other evidence comes from studies showing market makers earn less per round trip trade (purchase followed by sale or vice versa) than the quoted spread. This means that market maker purchases tend to be followed by declines in the ask prices while sales are followed by increases in bid prices, the opposite of what one would expect if market makers were informed. Thus, the maintained assumption appears to be reasonable as a first approximation, and attention then turns to the learning process of the market maker in a stochastic environment.

The learning process of market makers is the subject of a study by Easley and O'Hara (1987). The intertemporal trading behavior of informed traders differs from that of noise traders in that the informed will generally trade on one side of the market (assuming no manipulation) until the information. Trade direction (buy or sell) and volume provide signals to market makers who then update their price expectations. Easley and O'Hara show that the adjustment path of prices need not converge to the 'true' price immediately since it is determined by the history of trades which reflects the actions of liquidity motivated traders as well. The speed at which prices adjust is determined by a variety of factors, including market size, depth, volume and variance. Greater depth or larger trading volume may in fact slow the rate of price adjustment, reducing economic efficiency. Finally, the effects on equilibrium of sequential information arrival is another area for research. In this view, informational efficiency is not merely a static concept (i.e., whether $p_t$ is close to $v_t$ on average) but rather a dynamic concept (i.e., whether $p_t$ converges quickly to $v_t$ over time). Generalizations of this model in various forms are contained in Easley and O'Hara (1991, 1992) and Easley et al. (1996a, b, 1997).

### *3.3. Empirical evidence*

#### *3.3.1. Is trading important?*

As a starting point, it is useful to ask if trading is in some sense an important factor for asset returns. The importance of information trading in price determination is brought out by an empirical study of the variability of stock returns over trading and non-trading days by French and Roll (1986). They find that the variance of stock returns from the open to the close of trading is often five times larger than the variance of close-to-open returns, and that on an hourly basis, the variance during trading periods is at least twenty times larger than the variance during non-trading periods.

French and Roll examine three possible hypotheses for the high returns volatility during trading hours. First, public information may arrive more frequently during business hours, when exchanges are open. Second, private information may be brought to the market through the trading of informed agents, and this creates volatility. Lastly, the process of trading itself could be the source of volatility. Based on data for all stocks listed on the NYSE and AMEX for the period 1963–1982, French and Roll conclude that at most 12% of the daily return variance is caused by the trading process itself (mispricing), the remaining attributable to information factors. To distinguish between private and public information, French and Roll examine the variance of daily returns on weekday exchange holidays. Since other markets are open, the public information hypothesis predicts the variance over the two day period beginning with the close the day before the exchange holiday should be roughly double that of the variance of returns on a normal trading day.

In fact, it appears that the variance for the period of the weekday exchange holiday and the next trading day is only 14% higher than the normal one-day return. This evidence is consistent with the hypothesis that most of the volatility of stock returns is caused by informed traders whose private information is impounded in prices when exchanges are open. The increasing availability of refined intraday data has led to more refined tests of market microstructure models. Research at the transaction level (e.g., Harris, 1986; Jain and Joh, 1988; Wood et al., 1985; McInish and Wood, 1992) has uncovered many interesting 'anomalies' or intraday patterns. Madhavan et al. (1997) show that some of these findings (e.g., the U-shaped pattern in bid–ask spreads and volatility, and short-horizon serial correlation) can be explained within. See also Foster and Vishwanathan (1990).

### *3.3.2. Permanent and temporary price changes*

Theory suggests that large trades are associated with price movements resulting from inventory costs and asymmetric information. A simple approach to assessing the relative importance of these effects is to decompose the price impact of a block trade into its permanent and temporary components. Let $p_{t-h}$ denote the (log) pre-trade benchmark, $p_t$ the (log) trade price, and $p_{t+k}$ the (log) post trade benchmark price. The price impact of the trade is defined as $p_t - p_{t-h}$. In turn, the price impact can be decomposed into two components, a permanent component defined as $\pi = p_{t+k} - p_{t-h}$ and a temporary component, defined as $\tau = p_t - p_{t+k}$. The permanent component is the information effect, i.e., the amount by which traders revise their value estimates based on the trade; the temporary component reflects the transitory discount needed to accommodate the block.

The price impacts of block trades have been shown to be large in small cap stocks and are systematically related to trade size and market capitalization (see, e.g., Loeb, 1983; Kraus and Stoll, 1972; Holthausen et al., 1987; Keim and Madhavan, 1996, among others). Barclay and Holderness (1992) summarize the legal aspects of block trades. Loeb (1983), using quotations of block brokers, finds that one-way trading costs can be significant for large trades in low market capitalization stocks. Loeb reports that for stocks with market capitalization less than \$25 million (in 1983) the market impact of a large block transaction often exceeds 15%. For large trades in liquid, large market-cap stocks, however, Loeb finds significantly smaller market impacts, as low as 1%. Keim and Madhavan (1996) develop and test a model of large-block trading. They show that block price impacts are a concave function of order size and a decreasing function of market capitalization (or liquidity), findings that are consistent with Loeb's results.

Keim and Madhavan (1996) also show that the choice of pre-trade benchmark price makes a large difference in the estimated price impact. For example, using a sample of trades made by an institutional trader, they find that the average (one-way) price impact for a seller-initiated transaction is $-4.3\%$ when the benchmark ('unperturbed') price is the closing price on the day before the trade. However, when the benchmark is the price three weeks before the trade, the measured price impact is $-10.2\%$, after adjustment for market movements. While part of the difference in price impacts may be explained by the initiating institutions placing the sell orders after large price declines, Keim and Madhavan find little evidence to suggest that institutional traders act in this manner. Rather, they attribute the difference to information 'leakage' arising from the process by which large blocks are 'shopped' in the upstairs market. If this is the case, previous estimates in the literature of price impacts for block trades are downward biased. They find both permanent and transitory components are significant for small cap stocks, suggesting both inventory and information effects are important.

### 3.3.3. *Estimating intraday models of price formation*

Empirical evidence on the extent to which information traders affect the price process is complicated by the difficulty in identifying explicitly the effects due to asymmetric information. Both inventory and information models predict that order flow will affect prices, but for different reasons. In the traditional inventory model, order flow affects dealers' positions and they adjust prices accordingly. In the information model, order flow acts as a signal about future value and causes a revision in beliefs. Both factors may be important, necessitating a combined model.

To see this, consider a combination of the inventory and information models described above. From Eq. (7), we have an expression for price that depends on the expected value of the asset and the dealer's inventory. From Eq. (8), we see that the dealer's beliefs are dependent on the direction of the trade. Combining these two elements, the ask and bid prices are

$$p_t^{\text{ask}} = \mathrm{E}[v_t|x_t = 1] - \phi(I_t - I^*) + s = \bar{v}_t + (\omega\sigma/2) - \phi(I_t - I^*) + s, \quad (11)$$

$$p_t^{\text{bid}} = \mathrm{E}[v_t|x_t = -1] - \phi(I_t - I^*) - s = \bar{v}_t - (\omega\sigma/2) - \phi(I_t - I^*) - s. \quad (12)$$

The transaction to transaction price change is given by

$$\Delta p_t = \left(\frac{\omega\sigma}{2} + s\right)\Delta x_t - \phi\Delta I_t\,. \quad (13)$$

In a pure dealer market where the market maker takes the opposite side of every transaction, $\Delta I_t = I_t - I_{t-1} = -x_{t-1}$. Substituting this expression into Eq. (13) yields a model that can be estimated without inventory data, i.e., using data on trades and quotes alone. Usually the trade initiation variable is inferred indirectly by the 'tick test' or from the relation of the trade price to prevailing quotes as in Lee and Ready (1991). Additional data on the quote generating process is needed to distinguish the inventory effect $\phi$ from other spread elements such as order processing cost and information asymmetry. In a hybrid market, where some trades are between public investors without dealer intervention, $\Delta I_t$ need not equal $-x_{t-1}$ and we cannot estimate a structural model of the sort given by Eq. (13) without actual market maker inventory data. In this case, a reduced form approach (Hasbrouck, 1988) can yield estimates of the relative importance of the two effects. Intuitively, the information effect has a permanent effect on prices (trade causes a revision in consensus beliefs) while the inventory effect is transitory.

### *3.3.4. Empirical tests of microstructure models*

Ho and Macris (1984) test a model of dealer pricing using transactions data recorded in an AMEX options specialist's trading book. These data contain the dealer's inventory position and also classify transactions were classified as being purchases or sales, so that econometric estimation is straightforward. They find the percentage spread is positively related to asset risk and inventory effects are significant. The specialist's quotes are influenced by his inventory position; both the bid and ask prices fall (rise) when inventory is positive (negative). Ho and Macris do not test their model against an information effects model, possibly because of observational equivalence.

Glosten and Harris (1988) decompose the bid–ask spread into two parts, the part due to informational asymmetries, and the remainder, which can be attributed to inventory carrying costs, market maker risk aversion, and monopoly rents. Unlike Ho and Macris, their data did not indicate if a transaction was a purchase or a sale. Glosten and Harris (1988) develop a maximum likelihood technique to overcome the estimation problem caused by unsigned transaction volume data and the discrete nature of prices. They find that the adverse selection component of the bid–ask spread is not economically significant for small trades, but increases with trade size. Neal and Wheatley (1998) provide empirical evidence on the Glosten–Harris model, illustrating some of the difficulties in estimating the various components of the spread.

Hasbrouck (1988) uses a vector autoregressive (reduced form) approach to model NYSE intraday data on volume and quoted prices, and examines both series for Granger–Sims causality. Hasbrouck finds that the intraday transactions volume and quote revision exhibit strong dependencies in both directions, evidence consistent with both the inventory control and asymmetric information models. Hasbrouck then estimates the impact of trade innovations on quote revisions. The trade innovations, from which autocorrelation due to inventory effects has been extracted, continue to have a positive impact on quote revisions, suggesting the information effect dominates inventory control effects. This finding may be due to inventory effects being spread over a longer period than information effects. Hasbrouck (1991a, b) uses a similar vector autoregressive approach to examine the information content of stock trades, finding significant information effects. See also Barclay et al. (1990) and Jones et al. (1994).

Madhavan and Smidt (1991) use actual specialist inventory data to disentangle the two effects and estimate the extent to which asymmetric information is indeed a factor in security pricing. Intuitively, the market maker's conditional mean estimate at time $t$, $\mu_t$ is a weighted average of the signal conveyed by order flow, denoted by $\beta(q_t)$, and the previous period's conditional mean, $\mu_{t-1}$, so that $\mu_t = \alpha\beta(q_t) + (1-\alpha)\mu_{t-1}$. Using past prices as a proxy for mean beliefs, Madhavan and Smidt (1991) recover the weight placed by a Bayesian dealer on order flow as a signal of future value and distinguish this from inventory effects. Their results suggest that asymmetric information is an important element of intraday price dynamics. By contrast, evidence for intraday inventory effects are weak, a finding also reached by Hasbrouck and Sofianos (1993) using different data and methodology. See, however, Manaster and Mann (1996) whose study of futures trading suggests stronger inventory effects, possibly because of competition or other factors.

Madhavan and Smidt (1993) argue that the weak intraday inventory effects may arise from the confusion of inventory and information. They develop a dynamic programming model that incorporates both inventory control and asymmetric information effects combined with level shifts in target inventory. The basic idea is that a market maker acts as a dealer and as an active investor. As a dealer, the market maker quotes prices that induce mean reversion towards inventory targets; as an active investor, the market maker periodically adjusts the target inventory levels towards which inventories revert. Specifically, they allow $I^*$ to move periodically, which appears reasonable over long periods of time. They estimate the model with daily specialist inventory data using intervention analysis to correct for (unknown) level shifts in target inventory.

Specialist inventories exhibit mean reversion, as predicted by inventory models, but the adjustment process is slow, with a half-life of over 49 days. This implies weak inventory effects on price. After controlling for shifts in target inventories, the half-life falls to 7.3 days, suggesting that shifts in target inventory explain the weak intraday results. They find strong evidence of information effects; quote revisions are negatively related to specialist trades and positively related to the information conveyed by order imbalances. Madhavan and Sofianos (1997) suggest an explanation for the failure of previous research to detect strong effects of inventory on prices. They suggest that dealers selectively participate in trades to unload excess inventory instead of actively manipulating prices to solicit the desired direction of order flow. Such a strategy might explain how dealers can control inventory without altering prices. Confirmation is provided by Lyons (1995) who finds strong direct effects of inventory on price. Lyons shows that dealers selectively engage in trades at other dealers' prices in order to reduce excess inventory.

### 3.4. Summary

The studies surveyed above have considerably enhanced our understanding of the black box through which prices are determined. We have developed a considerable understanding of the role of dealers in price formation since the seminal work of Working and Demsetz. Identification of the factors that cause price movements – inventory and asymmetric information – is the key to building realistic models to analyze high frequency data. An example of such a model, taking into account discreteness and clustering, is Hasbrouck (1999). In turn, such models could be used to examine the sources of observed patterns in spreads, volumes, and volatility over the trading day and across trading days. They could also be used to explain short-run return phenomena (Gourieroux et al., 1999) as well as explain periodic fluctuations in market liquidity, a source of considerable concern for traders and investors.

One area that needs further investigation is the nature of price discovery in a multi-asset or multi-market setting. The models discussed above are largely models of a single market, although there are now multi-market models such as Chowdhry and Nanda (1991). Clearly, inventories could be controlled not just through price but also through trades in derivative securities (options or futures) or by balancing positions in other assets. This is an important area for future research.

## 4. Market structure and design

### 4.1. Overview

The initial focus of the literature on the role of market makers in price formation is logical given their central position in the trading process. However, reality is a great deal more complicated and the literature quickly recognized that market structure influences price formation. In this section, I survey the large and growing literature on market structure and the implications of structure for metrics of market quality such as spreads, liquidity, and volatility. Much of this literature is heavily influenced by on-going debates about floor versus electronic markets and auction versus dealer systems. We begin accordingly with a taxonomy of market types, and then move on to a discussion of the major debates in market structure.

### 4.2. Market architecture

#### 4.2.1. A conceptual framework

It is useful to begin with a taxonomy of market structures which will help guide our subsequent discussion. *Market architecture* refers to the set of rules governing the trading process, determined by choices regarding

- Market Type
  (1) *Degree of continuity*: Periodic systems allow trading only at specific points in time while continuous systems allow trading at any point in time while the market is open.
  (2) *Reliance on market makers*: Auction or *order-driven* markets feature trade between public investors without dealer intermediation while in a dealer (or *quote-driven*) market, a market maker takes the opposite side of every transaction; and
  (3) *Degree of automation*: Floor versus screen-based electronic systems. The technology of order submission is rarely as important as the actual protocols governing trading.
- *Price discovery*: The extent to which the market provides independent price discovery or uses prices determined in another market as the basis for transactions.
- *Order forms* permitted (i.e., market, limit, stop, upstairs crosses, baskets).
- *Protocols* (i.e., rules regarding program trading, choice of minimum tick, trade-by-trade price continuity requirements, rules to halt trading, circuit breakers, and adoption of special rules for opens, re-opens, and closes).
- *Transparency*, i.e., the quantity and quality of information provided to market participants during the trading process. Non-transparent markets provide little in the way of indicated prices or quotes, while highly transparent markets often provide a great deal of relevant information before (quotes, depths, etc.) and after (actual prices, volumes, etc.) trade occurs. Markets also differ in the *extent* of dissemination (brokers, customers, or public) and the *speed* of dissemination (real time or delayed feed), degree of anonymity (hidden orders, counterparty disclosure), and in whether off exchange or after hours trading is permitted.

#### 4.2.2. Real-world systems

Trading systems exhibit considerable heterogeneity in these dimensions, as shown in Fig. 1. For example, automated limit order book systems of the type used by the Toronto Stock Exchange and Paris Bourse offer continuous trading with high degrees of transparency (i.e., public display of current and away limit orders) without reliance on dealers. Foreign exchange and corporate junk bond markets rely heavily on dealers to provide continuity but offer very little transparency while other dealer markets (Nasdaq, London Stock Exchange)

| | Nasdaq-NMS | NYSE Open | NYSE Intraday | Paris Bourse | POSIT | CBOT | FX Market |
|---|---|---|---|---|---|---|---|
| **Market Type** | | | | | | | |
| Continuous | × | | × | × | | × | × |
| Floor-based | | × | × | | | × | |
| Dealer Presence | × | × | × | | | × | |
| Multilateral | | × | | | × | | |
| **Transparency** | | | | | | | |
| Pre-trade Quotes | × | | × | × | | × | |
| Post-trade Reports | × | × | × | × | × | × | |

Fig. 1. Variation in real-world trading systems.

offer moderate degrees of transparency. Non-continuous markets include the Arizona Stock Exchange and the NYSE open, which differ considerably in transparency and dealer participation. Some exchanges also require fairly strict trade-to-trade price continuity requirements while others, like the Chicago Board of Trade (CBOT), allow prices to move freely.[5] Most organized markets also have formal procedures to halt trading in the event of large price movements.[6] Crossing systems such as POSIT do not currently offer independent price discovery, but rather cross orders at the midpoint of the quotes in the primary market.

Do such differences affect price formation and the costs of trading? We turn now to this issue, focusing on some of the key issues in market design. Specifically, we focus on two questions: (1) the network externality puzzle, and (2) the dealer puzzle.

### *4.3. Current issues in market design*

#### *4.3.1. The network externality puzzle*

The diversity of systems above has spurred considerable theoretical research. Early in the literature, the presence of strong network externalities was recognized. In terms of our model, suppose the same security is traded in two markets simultaneously with prices $p_{1t}$ and $p_{2t}$, respectively. Suppose that order

[5] For example, the Tokyo Stock Exchange (TSE) has strict rules on trade-by-trade price movements (Lehmann and Modest, 1994) while no such requirements are imposed (or are practicable) in foreign exchange trading.

[6] Such 'circuit breakers' might not, however, result in smoother prices. Subrahmanyam (1994, 1997) examines this topic and discusses the possibility that circuit breakers exert a gravitational pull that might result in more frequent closures while Goldstein and Kavajecz (2000) provide empirical evidence on this issue.

processing costs are a decreasing function of trading volume, $V$, so we write $s(V)$. This is reasonable because higher volumes imply a shorter holding period for market makers and hence lower inventory control costs.

Initially, suppose volumes are split equally between the two markets, but suppose that volume migrates to the market with lower costs. Formally, for market $i$ the change in volume is assumed to be $\Delta V_{it} = f(s_{it} - s_{jt})$, where $f$ is a decreasing function. If the initial volume allocation is perturbed slightly, the higher volume market will enjoy reduced costs, attracting further volume, until in the long run there will consolidation into a single market. The inclusion of information into this model only serves to confirm this prediction. With asymmetric information, rational informed traders will split their orders between the two markets, providing incentives for liquidity traders to consolidate their trading geographically (see Garbade and Silber, 1979; Cohen et al., 1982, Mendelson, 1987; Pagano (1989a, b) or intertemporally as in Admati and Pfleiderer (1988). Intuitively, if two markets are combined into one, the fraction of informed trading volume will drop, resulting in narrower spreads. Even if we just assume symmetric, but diverse, information signals, pooling orders will provide informationally more efficient prices than decentralized trading across fragmented markets. Indeed, even when multiple markets coexist, the primary market often is the source of all price discovery (as shown by Hasbrouck, 1995) with the satellite markets merely matching quotes. This issue is closely related to differences in transparency across markets and we discuss this in more detail in the following section, focusing instead on fragmentation arising through off-exchange trading.

The network externality puzzle refers to the fact that despite strong arguments for consolidation, many markets are fragmented and remain so for long periods of time. Indeed, the sources and impact of market fragmentation is the subject of considerable controversy. See, for example, Biais (1993), Chowdhry and Nanda (1991), Madhavan (1995), and Hendershott and Mendelson (2000), among others. We discuss two aspects of this below, namely the failure of a single market to consolidate trading in time and the failure of diverse markets to consolidate in space (or cyberspace) by sharing information on prices, quotes, and order flows.

*4.3.1.1. Periodic versus continuous trading.* Theory suggests that multilateral trading systems (such as single-price call auctions) are efficient mechanisms to aggregate diverse information. Consequently, there is interest in how call auctions operate and whether such systems can be used more widely to trade securities. Excellent analyses of single-price markets include Mendelson (1982) and Ho et al. (1985). The information aggregation argument suggests call auctions are especially valuable when uncertainty over fundamentals is large and market failure is a possibility. Casual empiricism appears to support this aspect of the argument. Indeed, many *continuous* markets use single-price auction mechanisms when uncertainty is large such as at the open, close, or to re-open following a trading halt.

Yet, trading is often organized using continuous, bilateral systems instead of a periodic, multilateral system. For reasons not well understood, there is a surprising demand for continuous trading, even if this necessitates reliance on dealers to provide liquidity. This question is analogous to the question of why geographically separate markets that operate in the same time zone do not integrate despite strong network economies of scale.

*4.3.1.2. Off-exchange and upstairs trading.* While consolidated markets pool information, it is not necessarily clear that they will be more efficient than fragmented markets if some traders can develop reputations based on their trading histories. One example of such rational fragmentation is off-market trading.

In many equity markets, including the United States, there are two economically distinct trading mechanisms for large-block transactions. First, a block can be sent directly to the 'downstairs' or primary markets. These markets in turn comprise the continuous intraday markets, such as the NYSE floor, and batch auction markets, such as openings. Second, a block trade may be directed to the 'upstairs' market where a block broker facilitates the trading process by locating counter-parties to the trade and then formally crossing the trade in accordance with the regulations of the primary market. The upstairs market operates as a search-brokerage mechanism where prices are determined through negotiation. By contrast, downstairs markets are characterized by their ability to provide immediate execution at quoted prices.

Upstairs trading captures the willingness of traders to seek execution outside the primary market, and hence is of interest in debates regarding consolidation and fragmentation. One argument cited for the growth of upstairs markets in the U.S. is that the downstairs markets – in particular the NYSE – offer too much information about a trader's identity and motivations for trade. Madhavan (1995) argues that large traders are afraid of being front-run or having their strategies leaked, and prefer to use upstairs markets to accomplish large-block trades in one single step. Similar intuition underlies the results of Seppi (1990), who develops an intertemporal model where an investor has the choice between trading upstairs or downstairs. Seppi shows that a liquidity trader may trade a block upstairs rather than place a sequence of small transactions in the primary market. Similarly, Grossman (1992) argues that upstairs markets aggregate information about investor's latent demands. Keim and Madhavan (1996) model the upstairs market as a mechanism to aggregate traders and dampen the price impacts associated with a block trade by risk sharing. Models emphasizing asymmetric information provide some rationale for the success of off-market competitors in attracting order flow from primary markets. Easley et al. (1996a) show that established markets could experience competition in the form of cream-skimming of orders likely to originate from uninformed traders. Similarly, broker-dealers might internalize their order flow, passing on the unmatched orders to the primary market.[7]

#### *4.3.2. The dealer puzzle*

Within the class of continuous markets, trading can be accomplished using designated dealers or as a limit order market without intermediaries. In active securities, pure limit order book markets of the type discussed below are clearly feasible. Yet, most markets, including very active ones such as the foreign exchange market, rely upon market makers to act as intermediaries. This issue, which I refer to as the dealer puzzle, really concerns two parts: First, what are the functions of market makers that make their presence valuable? Second, why can"t public auction markets provide the same functions? We consider these questions in this section.

*4.3.2.1. Dealer markets.* We have already discussed some of the key functions of dealers, namely price discovery, the provision of liquidity and continuity, and price stabilization.

The models of market making in Section 3 above presuppose some degree of market power by dealers. But many markets (Nasdaq, London Stock Exchange) feature competition between market makers. Such competition may affect security prices in different ways. Models of competition among market makers have been developed by Ho and Stoll (1983) and others. Given a fixed number of market participants, inter-dealer trading reduces spreads by allowing dealers to move closer to desired inventory levels.[8] Each dealer determines an upper and lower bound on inventories given attitudes towards risk etc. Price competition among dealers determines which dealer will be ‘hit’ by the next order. Informal evidence, backed by theoretical studies, suggests a dealer typically will be competitive on only one side of the market. If, for example, a dealer is long, he or she will rarely (see Silber, 1984) purchase another security but instead will quote a competitive ask price to lower inventory levels. A general result is that actual market spreads will be much narrower than quoted spreads. This has important implications for empirical work using quoted spreads.[9] We turn now to the operation of pure auction markets, and ask whether such markets can achieve the same outcomes.

*4.3.2.2. Limit order markets.* Pure auction markets can be structured as batch (single-price) auctions or more commonly as automated limit order book

[7] See Battalio (1997).

[8] Reiss and Werner (1995) provide empirical evidence on interdealer trading on the London Stock Exchange.

[9] See Hansch et al. (1998).

markets.[10] Studies by Rock (1988), Angel (1991), Kavejecz (1996), Harris and Hasbrouck (1996), Seppi (1997), Biais et al. (1995, 1999) and Foucault (1999), among others, help advance our knowledge of liquidity provision by studying the limit order book. With a limit order, an investor associates a price with every order such that the order will execute only if the investor receives that price or better. A limit buy order for example, may specific the purchase of $q$ shares if and only if $p_t < L$, where $L$ is the limit price. Clearly, all orders can be viewed as limit orders. Thus, a market order is simply a limit order where $L$ is the current ask price or higher. In markets where dealers are also present, limit orders directly compete with them and serve as a check on their market power. On the NYSE, for example, the specialist can only trade after all limit orders at the best bid or offer have been filled.

While the literature on limit orders is still evolving, a basic trade off has been identified. To see this, suppose the ask price is $p^{\text{ask}}$, with a depth of, say, $q^{\text{a}}$ units, and suppose an investor places a limit order to sell $q^L$ shares at the next highest available price, $p^{\text{ask}} + \delta$, where $\delta$ is the minimum tick or price increment, historically one-eighth but now one sixteenth. If the limit order is hit, it must be because the size of the incoming market order $Q > q^{\text{a}}$. Conditional upon the initiator being uninformed, the limit order trader's expected profit is

$$(p^{\text{ask}} + \delta - \mathrm{E}[v|\Theta = u])\min[q^{\mathrm{L}}, Q - q^{\text{ask}}]. \tag{14}$$

This term is positive since the ask price exceeds the unconditional expectation of the security. Conversely, if the trader were informed, the limit order trader makes a profit equal to

$$-(\mathrm{E}[v|Q; \Theta = i] - p^{\text{ask}} - \delta)\min[q^L, Q - q^{\text{ask}}]. \tag{15}$$

Note that this term is negative because an informed trader will buy only if $v > p^{\text{ask}} + \delta$.

Overall expected profit is a weighted average of the profits in Eqs. (14) and (15), where the weight on is the probability the trade was initiated by an uninformed agent and the weight on is the probability the trader was informed. Under *ex post* rationality, the relevant probabilities are the conditional probability of seeing such a trader type given the order size and the state of the book. In equilibrium, competition among limit order traders will fill in the book. At higher prices, the probability the limit order was triggered by an uninformed trade is lower but the profits from executing against such a trader are higher. Foucault (1999) presents a game theoretic model that describes such an equilibrium, where traders can chose between submitting market and limit orders.

If there are exogenous shocks that cause changes in values, a limit order provider is offering free options to the market that can be hit if circumstances

[10] Black (1971) is an early proponent of a fully automated market structure.

change. Consequently, the limit order trader needs to expend resources to monitor the market, a function that may be costly. It is perhaps for this reason that dealers of some form or the other arise so often in auction markets.

*4.3.2.3. Decimalization and discreteness.* The model above provides some insights into the consequences of changing the minimum tick. This is an issue of considerable importance that is often referred to as 'decimalization'. Strictly speaking, decimalization refers to the quoting of stock prices in decimals as opposed to fractions such as eighths or sixteenths. Proponents of decimalization note that it would allow investors to compare prices more quickly, thereby facilitating competition, and would also promote the integration of US and foreign markets. By contrast, the minimum tick is a separate issue that concerns the smallest increment for which stock prices can be quoted. For example, one can envisage a system with decimal pricing but with a minimum tick of 5 cents. From an economic perspective, what is relevant is the minimum tick, not the units of measurement of stock prices.

If $\delta$ is reduced, the profits from supplying liquidity (assuming a constant book) go down in Eq. (14) while the losses go up from Eq. (15). It follows that there will be a reduction in liquidity at prices away from the best bid or offer. However, the quoted spread itself may fall through competition. Thus, a reduction in the minimum tick may reduce overall market liquidity. See Harris (1991, 1998) for a discussion of this and related points and Werner (1998) for an analysis of the impact of a reduction in the minimum tick. A related strand of the literature focuses on the effect of discreteness – induced by the minimum tick – for spreads and price efficiency. For example, Hausman et al. (1992) use an ordered probit approach to estimate a microstructure model that incorporates discreteness. More recently, Hasbrouck (1999) proposes and tests a model that explicitly embodies price rounding arising from discreteness. On the theoretical side, Kandel and Marx (1999a) and Dutta and Madhavan (1997) show that price discreteness can be an important factor in facilitating tacit collusion by dealers, allowing them to earn excess rents for their liquidity provision services.

### *4.4. Empirical evidence on market structure and design*

#### *4.4.1. Continuous and intermittent trading*

Smidt (1979) discusses how differences between periodic and continuous systems might affect returns. Amihud and Mendelson (1987) compare and contrast return variances from open-to-open and close-to-close for NYSE stocks. Since both periods span 24 hours, any differences are likely to reflect differences in the trading system, the NYSE opening price being determined in a single-price auction while the closing price is determined in a continuous double-auction. Their evidence seems to support the view that differences between continuous and batch systems are exhibited in observable variables such as price efficiency and return volatility. Similarly, Amihud and Mendelson (1991a); Stoll and Whaley (1990), and Forster and George (1996) also conclude that differences in market structure affect returns. Amihud et al. (1997) document large increases in asset values for stocks moving to continuous trading on the Tel aviv stock exchange.

*4.4.1.1. Intermarket comparisons: empirical evidence.* Intermarket comparisons are very difficult because real world market structures are more complex than simple models would suggest. The NYSE, for example, has elements of both auction and dealer markets. Further, there are serious empirical issues concerning the definition and measurement of market quality. For example, the usual measure of trading costs (or illiquidity), namely the quoted bid–ask spread is problematic because quoted spreads capture only a small portion of a trader's actual execution costs. See Lee (1993), Chan and Lakonishok (1993, 1995), Huang and Stoll (1996), and Keim and Madhavan (1997).

While the early literature argued that competition among market makers on the Nasdaq system would result in lower spreads than a specialist system of the type used by the NYSE, the opposite seems to be the case, even after controlling for such factors as firm age, firm size, risk, and the price level. One explanation is provided by Christie and Schultz (1994) and Christie et al. (1994), who suggest that dealers on Nasdaq may have implicitly colluded to set spreads wider than those justified by competition.[11] Theoretical studies by Kandel and Marx (1997) and Dutta and Madhavan (1997) provide some justification for this view in terms of the institutions of the Nasdaq market.[12] Specifically, institutions such as order flow preferencing (i.e., directing order flow to preferred brokers) and soft-dollar payments limit the ability and willingness of dealers to compete with one another on the basis of price, resulting in supra-normal spreads despite the ease of entry into market making. More recently, Chen and Ritter (1999) suggest that underwriters implicitly collude to set underwriting spreads, citing evidence that the great majority of underwriting spreads are exactly 7%. Chen and Ritter's article, like that of Christie and Schultz (1994), has triggered an investigation by regulatory authorities.

*4.4.2. Empirical evidence on off-exchange trading*

A key issue in market structure concerns traders' incentives to seek off-exchange venues to accomplish their trades. Thus, it is important to document the extent to which there is empirical support for theoretical models of upstairs intermediation.

[11] See also Barclay (1997) for another perspective. Gehrig and Jackson (1998) provide a model of monopolistic competition between market makers.

[12] Kandel and Marx (1999b) link avoidance of odd-eighths to the presence of so-called 'SOES bandits', traders who hit market maker quotes immediately following news announcements.

Keim and Madhavan (1996) use data for 5625 equity trades in 1985–1992. Unlike previous studies (Kraus and Stoll, 1972; Holthausen et al., 1987), all trades are known to be upstairs transactions and are identified as either buyer- or seller-initiated. The upstairs market affects the pricing of large equity transactions in several important respects. They find that price movements up to four weeks prior to the trade date are significantly positively related to trade size, consistent with information leakage as the block is 'shopped' upstairs. Further, the estimated price impacts are substantially larger than found in previous studies. What is surprising here is that traders chose to trade upstairs over the primary market despite the high costs and information leakage. Presumably the costs of trading downstairs would be even higher. However, without data on comparable downstairs trades, it is not possible to make any firm conclusions about traders' choices between venues.

Madhavan and Cheng (1997) use NYSE audit-trail data to estimate the costs of trading in *both* upstairs and downstairs markets. They use statistical techniques to infer what costs would have been had a trader chosen the alternative venue. Madhavan and Cheng (1997) find that the economic benefits of upstairs intermediation are small for the average-sized block trade. They also find evidence to support the hypothesis advanced by Seppi (1990) that upstairs markets are preferred by traders who can credibly signal that their trades are not information-motivated.

As described above, the upstairs market has been viewed in the literature primarily from the initiator's viewpoint. Upstairs intermediation can reduce trading costs by mitigating adverse selection costs (Seppi, 1990), locating trade counter-parties (Grossman, 1992), and risk sharing (Keim and Madhavan, 1996). However, every block trade involves willing participants on both sides of the transaction. Thus, one way to interpret the results reported is that the primary benefit offered by the existence of an upstairs market may not be to the initiator but rather to the counter-parties to the transaction. Liquidity providers, especially institutional traders, are reluctant to submit large limit orders and thus offer free options to the market. Upstairs markets allow these traders to selectively participate in trades screened by block brokers who avoid trades that may originate from traders with private information. Thus, the upstairs market's major role may be to enable transactions that would not otherwise occur in the downstairs market. If so, then these traders would perhaps be more willing to trade in downstairs markets if they offered less information about their identities.

#### 4.4.3. *Experimental studies*

Tests of theories concerning market structure face a serious problem: the absence of high quality data that allows researchers to pose 'what if' questions. Traders adjust their strategies in response to market protocols and information. This makes it difficult to assess the impact of market protocols. Further, empirical studies are limited in that there are not large samples of events to study. Compounding the problem, changes in structure are often in response to perceived problems. An example is the Toronto Stock Exchange's change in display rules in response to the migration of order flow to U.S. markets. Complicating matters, such changes are often accompanied by design alterations in other dimensions as well.

Laboratory or experimental studies offer a very promising way to test subtle theoretical predictions of regarding market design. In a laboratory or experimental study, human subjects trade in artificial markets. Irrespective of method, researchers seek to examine the effects of various changes in protocols (e.g., changes in pre- and post-trade reporting) on measures of market quality. Variables most often studied include the bid–ask spread, market depth or liquidity, and volatility. Some experimental studies also study quality variables that might not otherwise be possible to observe. These include trader profits segmented by information quality or trader type, the accuracy of the beliefs of market participants over time, and the rate of convergence of prices to full-information values.

Schnitzlein (1996), Bloomfield (1996), Bloomfield and O'Hara (1999a, b) among others present evidence on experimental markets that offer useful insights into the possible impacts of changes in disclosure rules. Researchers have studied the speed at which prices converge to full-information values, bid–ask spreads, and other attributes of liquidity across different regimes. The ability to frame controlled experiments allows researchers to also gather data on traders' estimates of value over time, their beliefs regarding the dispersion of 'true' prices, and the trading profits of various classes of traders. Some interesting findings have already emerged. It turns out to be quite easy to generate price bubbles, even if market participants are aware of bounds on fundamental value. Interestingly, prices in auction markets need not always converge to full information values; agents may learn incorrectly and price settle at the 'wrong' value.

This new literature uses more realistic trading regimes and incorporates institutional features found in actual markets. The advantage of this approach is that some of the more subtle predictions of theoretical models can be examined in a controlled setting. The disadvantage, however, is that in some cases the laboratory settings are still too simple or stylized to really provide deep insights into the economic behavior of agents. A further problem is that the results are often sensitive to subtle differences in the experiments or the instructions given to participants. The literature is still evolving but offers many promising avenues for future research.

### *4.5. Summary*

Issues of market structure are central to the subject of market microstructure. While a great deal has been learned, it is fair to say that there is not a uniform view on what structures offer the greatest liquidity and least trading costs. This is hardly surprising given the considerable complexity of real-world market structures. Ultimate decisions on market structure are likely to be decided by the marketplace on the basis of factors that have less to do with information than most economists believe. The factor I would single out is a practical one, namely the need for automation and electronic trading to handle the increasingly high volumes of trading. While this factor will inevitably lead towards the increased use of electronic trading systems, this does not mean that investigations of market structure are irrelevant. The point to keep in mind, however, is that what ultimately matters is not the medium of communication between the investor and the market but the protocols that translate that order into a realized transaction. For instance, it is possible to replace the NYSE floor with a virtual, fully electronic market, while keeping the institutions of the specialist, brokers, etc. Formerly verbal communications between market participants would be replaced with communication by email. Whether this is desirable – or practical – is not the point. Rather, I just want to emphasize the importance of studying protocols rather than focusing on the technological aspects of trading.

There is considerable room for new research in this subfield. Indeed, in terms of the stylized model of Section 2, the studies surveyed above can be viewed as analyzing the influence of structure on the magnitude of the friction variable $s$. What is presently lacking is a deep understanding of how structure affects return dynamics, in particular, the *speed* of price discovery. This is especially true in terms of empirical research where the focus has largely been on static cost considerations. We turn now to issues of information and disclosure, an area closely related to the structural issues discussed above.

## 5. Information and disclosure

### *5.1. Overview*

Many informational issues regarding market microstructure concern information and disclosure. Market transparency is defined (see, e.g., O'Hara, 1995) as the ability of market participants to observe information about the trading process. Information, in this context, can refer to knowledge about prices, quotes, or volumes, the sources of order flow, and the identities of market participants. It is useful to think of dividing transparency into pre- and post-trade dimensions. Pre-trade transparency refers to the wide dissemination of current bid and ask quotations, depths, and possibly also information about limit orders away from the best prices, as well as other pertinent trade related information such as the existence of large order imbalances. Post-trade transparency refers to the *public* and *timely* transmission of information on past trades, including execution time, volume, price, and possibly information about buyer and seller identifications. Consequently, transparency has many dimensions. This section begins with a more detailed look at the current issues in transparency, and then turns to a discussion of the theoretical and empirical evidence.

### *5.2. Current issues concerning market transparency*

Issues of transparency have been central to some recent policy debates. For example, the issue of delayed reporting of large trades has been highly controversial and continues to be an issue as stock exchanges with different reporting rules form trading linkages.[13] A closely related issue concerns the effects of differences in trade disclosure across markets. These differences, some argue, may induce order flow migration, thereby affecting liquidity and the cost of trading.

Transparency is a major factor in debates over floor versus electronic systems. Floor systems such as the New York Stock Exchange (NYSE) generally do not display customer limit orders unless they represent the best quote. By contrast, electronic limit order book systems such as the Toronto Stock Exchange Computer Assisted Trading System (CATS) and the Paris Bourse *Cotation Assistee en Continu* (CAC) system disseminate not only the current quotes but also information on limit orders away from the best quotes.[14] In general, the trend around the world has been towards greater transparency.

The practical importance of market transparency has given rise to a large theoretical and empirical literature. Specifically, several authors have examined the effect of disclosing information about the *identity* of traders or their *motives* for trading. These issues arise in many different contexts including:

- post-trade transparency and reporting;
- pre-disclosure of intentions to trade such as sunshine trading or the revelation of order imbalances at the open or during a trading halt;
- dual-capacity trading, where brokers can also act as dealers;
- front-running, where brokers trade ahead of customer orders;
- upstairs and off-exchange trading;
- the role of hidden limit orders in automated trading systems;
- counterparty trade disclosure; and
- the choice of floor-based or automated trading systems.

We first review the theoretical research in this area, and then consider the empirical evidence.

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[13] Naik et al. (1994); Gemmill (1994), and Board and Sutcliffe (1995) provide analyses of the effects of delayed trade reporting on the London Stock Exchange. See also Franks and Schaefer (1991).

[14] See Harris (1998) and Porter and Weaver (1998a).

## 5.3. Theoretical studies

### 5.3.1. Anonymity and trader identity

As noted above, the prototypical market microstructure model contains two classes of agents: informed traders who possess private information about future asset values and uninformed traders who are liquidity motivated. These traders trade anonymously and market makers (or representative liquidity providers) adjust prices based on the net order imbalance (i.e., the difference between buy and sell share volume) observed. While this type of simple model is useful to characterize the evolution of asset prices over time, it fails to capture the fact that in many real-world situations floor traders, brokers, and dealers often have considerable information about the source of their order flow. On the New York Stock Exchange (NYSE), for example, it is not uncommon for specialists to ask a broker to reveal the identity of the trader behind an order if it does not come in through the exchange's anonymous SuperDot system.

### 5.3.2. Non-anonymous trading

Several recent papers study the effects of disclosure of information about the sources and motivation of trades. Forster and George (1992) model the effect of anonymity in securities markets. They relax the usual assumption that traders are anonymous to allow market makers to have some idea about the future direction and magnitude of trade. This is very reasonable in many markets, especially those with trading floors. They show that information regarding traders' motivations can significantly affect asset prices. In particular, when dealers have some idea about the *direction* of liquidity trades (e.g., whether small retail orders are net buyers or sellers), this lowers trading costs for liquidity traders. Intuitively, the cost of trading (both in the form of bid–ask spreads and the market impact of the trade) reflect adverse selection costs that arise because some traders may possess private information.

When trading is not fully anonymous, i.e., when uninformed trading can be partly anticipated, the premium these traders pay is lowered, producing the result. Interestingly, Forster and George (1992) show that transparency concerning the *magnitude* of trading (e.g., through disclosure of order imbalances, etc.) can have ambiguous effects, depending on the extent to which liquidity providers are competitive.

### 5.3.3. Brokers and disclosure of identity

In a totally automated trading system, where the components of order flow cannot be distinguished, transparency is not an issue. However, most floor-based trading systems offer some degree of transparency regarding the composition of order flow. For example, on the New York Stock Exchange (NYSE), the identity of the broker submitting an order may provide valuable information about the source and motivation for the trade. Benveniste et al. (1992) develop a model where dealers can partly distinguish informed and uninformed order flow.[15] The exact mechanism by which this distinction (which cannot be perfect without causing market failure) is accomplished could be through a variety of sources. For example, if trader identity is disclosed to counter-parties, some traders may be able to form reputations based on their past trading for either being informed or uninformed.

They show that the ability of brokers to achieve this separation can reduce bid–ask spreads relative to a purely anonymous market for both informed and uninformed traders. If liquidity traders are price sensitive, they and trade more if their trading costs (the bid–ask spread in the model, but more generally all trading costs including market impact) are lowered. With counter-party disclosure, spreads for those agents identified as more likely to be uninformed are reduced, as in Forster and George (1992). This may induce larger volumes of uninformed trading, allowing overall spreads to be lower than would otherwise prevail in a fully anonymous market.[16]

#### *5.3.4. Voluntary disclosure*

*5.3.4.1. Sunshine trading.* Another issue concerns the disclosure of information about pending orders. Admati and Pfleiderer (1991) provide a model of *sunshine trading* where some liquidity traders can *preannounce* the size of their orders while others cannot. They show that those investors who are able to preannounce their trades enjoy lower trading costs because the market correctly infers that these trades are not information motivated. However, the costs for liquidity traders who are unable to preannounce their trades rises. Intuitively, preannouncement identifies the trade as informationless, but increases the adverse selection costs for other traders.[17]

These results are similar to those obtained in a different context by Madhavan (1996), who shows that greater transparency in the form of disclosure of retail order flows can exacerbate the price volatility. The rationale is that disclosing information about 'noise' in the market system increases the effects of asymmetric information, thereby reducing liquidity. Essentially, noise is necessary for markets to operate, and disclosure robs the market of this lubrication. Market

[15] Sofianos and Werner (1997) discuss the functions performed by brokers on the NYSE floor.

[16] Disclosure is also an issue in models of dual-trading because brokers may be able to identify certain customer trades as liquidity-motivated. Röell (1990) and Fishman and Longstaff (1992) model dual-capacity trading. In these models, broker-dealers can trade based on their private information regarding the order flow directed to them by their own customers.

[17] Fishman and Hagerty (1991) show that corporate insiders who are forced to disclose their trades can profitably manipulate prices. In their model, only insiders know whether their trades are liquidity- or information-motivated, so that disclosure can mislead other traders.

quality can also suffer with lower liquidity and higher implicit transaction costs. However, transparency can reduce price volatility and increase market liquidity. Transparency is more beneficial in a market with large numbers of traders that provide sufficient noise trading. Contrary to popular belief, the potentially adverse effects of transparency are likely to be greatest in thin markets.

These results have important policy implications concerning, for example, the choice between floor-based systems and fully automated, typically anonymous, trading systems.[18] Specifically, suppose traders obtain better information on the portion of the order flow that is price inelastic on an exchange floor than in an automated trading system. Floor-based systems may be more transparent because traders can observe the identities of the brokers submitting orders and make inferences regarding the motivations of the initiators of those orders. Unless it is explicitly designed to function in a non-anonymous fashion, such inferences are extremely difficult in a system with electronic order submission. If this is the case, traditional exchange floors may be preferred over automated systems for the active issues while the opposite may be true for inactive issues. Finally, the results provide insights into why some liquidity-based traders may avoid sunshine trades, even if they can benefit from reputation signaling.

*5.3.4.2. Voluntary agreements by dealers to disclose trading information.* There may, however, be other factors that may induce dealers to desire greater transparency in other forms. Chowdhry and Nanda (1991) provide a model where market makers voluntarily make information public to discourage insider trading while making the market more attractive to uninformed traders. Specifically, by revealing trades and providing information on trader identities, dealers can discourage or reduce trading by insiders or other informed traders. This allows dealers to charge lower bid–ask spreads because they face lower adverse selection costs, attracting more liquidity traders from markets that are more 'opaque'. The idea is that a market that can develop a reputation for being 'clean' may benefit from reduced adverse selection costs. In a multi-market context, this gives rise to the reverse of the 'race to the bottom', where markets compete for order flow by offering high levels of disclosure. These considerations may explain why some markets desire greater transparency.

#### *5.3.5. Large traders and disclosure*

*5.3.5.1. Transparency and off-exchange trading.* Madhavan (1995) examines the relation between fragmentation and market transparency. In this context, transparency refers to the disclosure of trading information to market participants

[18] Pagano and Röell (1996) provide a nice theoretical treatment of the differences in transparency across various market mechanisms and its impact on liquidity.

post-trade. This model provides a counter-point to that of Chowdhry and Nanda (1991), providing an argument for having less – rather than more – disclosure. Unlike Chowdhry and Nanda (1991), the trading universe here consists not only of informed and uninformed traders, but also of large liquidity traders or institutional traders. These traders are not motivated by information, but their trades are large and to minimize the price impact, they break up their trades over time. In this more complex model, the intuition of a 'race to the top' is shown not to hold.

Non-disclosure benefits large institutional traders whose orders are filled with multiple trades by reducing their expected execution costs, but imposes costs on short-term noise traders. The rationale is that these traders can breakup their trades over time without others front-running them and hence raising their trading costs. However, non-disclosure benefits dealers by reducing price competition. The implication of this analysis is that faced with a choice between a high disclosure market and a low disclosure market, an uninformed institutional trader will prefer to direct trades towards the more opaque market. Why? Essentially, a large trade can be successfully broken up without attracting too much attention and hence moving the price in the direction of the trade. This model suggests that one danger of too much transparency is that traders might migrate to other venues, including off-exchange or after-hours trading.

*5.3.5.2. The link between upstairs trading and primary market transparency.* Previous research shows that the upstairs and downstairs markets can coexist in equilibrium by serving different clienteles. Intuitively, traders who can credibly signal that they are liquidity motivated can trade large blocks in the upstairs markets with minimal price impacts. By contrast, traders who cannot credibly signal their motivations will trade anonymously downstairs, possibly facing large price impacts even for small trades. To interpret these findings, it is useful to ask examine the strategy of a large-liquidity trader. According to the models above, such traders prefer upstairs markets because they can obtain more favorable execution than by simply directing their trades to the downstairs market. More disclosure in the primary market may result in these traders obtaining more favorable pricing downstairs (as in Admati and Pfleiderer, 1991) but may also result in worse prices if others front-run their trades, knowing that such traders break up their trades (Keim and Madhavan, 1995) into many sub-trades. Thus, the effect of greater disclosure on the share of volume of the downstairs market is an empirical question.

### *5.4. Empirical research on transparency and disclosure*

#### *5.4.1. Pre-trade transparency*

Porter and Weaver (1998a) study the effect of an increase in transparency on the Toronto Stock Exchange (TSE) on April 12, 1990 when the TSE provided real-time public dissemination of the best bid and offer and associated depth (bid and ask size) as well as prices and sizes for up to four levels away from the inside market in both directions. Porter and Weaver (1998a) use a variety of measures to quantify liquidity and cost, including the *effective spread* defined as the absolute value of the difference between the transaction price and the mid-point of the prevailing bid and ask quotes. Both effective spreads and the percentage bid–ask spread widened after the introduction of the system, suggesting a *decrease in liquidity associated with transparency*, even after controlling for other factors that may affect spreads in this period, including volume, volatility, and price. The most likely explanation for this finding – consistent with theories discussed above – is that limit order traders are less willing to submit orders in a highly transparent system because these orders essentially represent free options to other traders.

### *5.4.2. Post-trade transparency*

Post-trade transparency refers to the public and timely dissemination of trading information. One aspect of this is information on counter-party identities, but the issues here can be as simple as whether or not to report prices and volume. Gemmill (1996) studies the effect of a change in post-trade transparency on the London Stock Exchange. On October 27, 1986, the LSE required that all trades be disclosed within 5 min. Some dealers argued that this put them in a difficult position if they had to unwind a large trade over some time. Essentially, the concern was that competitors would 'spoil' the trade by adjusting quotes immediately upon revelation of the trade. The LSE relaxed the immediate trade reporting rule in 1989 and then revised the rules again in 1991, offering an opportunity to study the effects of changes in disclosure on market quality. Specifically, from February 1989 to January 1991, the prices of large trades were subject to a 24 h delay. From January 1991 to January 1996, there was a 90 min delay for trades over 3 times normal market size.

Gemmill's finds that disclosure does not havelittle a dramatic effect on liquidity, as measured by the 'touch' (i.e., the best bid and offer in the market) and by price impact. This is surprising given the fact (noted in the paper) that market participants feel very strongly about trade disclosure. However, as Gemmill notes, this may reflect the fact that his measures (e.g., spreads, etc.) are affected by market-wide factors such as changes in volatility. These shifts in volatility are large in his sample period and it is difficult to isolate the impact of changes in disclosure rules.

Porter and Weaver (1998b) study the effects of late trade reporting on Nasdaq. They find that large numbers of trades are reported out-of-sequence relative to centralized exchanges such as the NYSE and AMEX. Porter and Weaver (1998b) conclude that there is little support for the hypothesis that late-trade reporting is random or is the result of factors (such as 'fast' markets, lost tickets, and computer problems) outside Nasdaq's control. Indeed, the trades most likely to be reported late are large block trades, especially those at away prices. This suggests that late-trade reporting is beneficial to Nasdaq dealers. This view is consistent with the arguments put forward by dealers on the London Stock Exchange.

#### *5.4.3. Experimental studies*

Bloomfield and O'Hara (1999a, b) compare and contrast markets with different sets of disclosure standards. Specifically, their experiments have human agents who act as dealers, some whom do not disclose trades, while others do. Bloomfield and O'Hara (1999b) allow disclosing and non-disclosing dealers to compete. They find that because the non-transparent dealers have informational advantages, they can set better prices, and capture more order flow and earn substantially higher profits than others. This is interesting since it suggests that the arguments that markets will naturally gravitate towards greater transparency are not true.

They then conduct an interesting second experiment where dealers are given a choice about whether they would prefer to disclose or not. The idea of this second experiment is to see whether transparent and non-transparent systems can co-exist. Their experimental evidence suggests that when dealers can choose their disclosure levels, most, but not all, prefer to not disclose their trades. However, the evidence suggests there may be some advantages to being the *sole* disclosing dealer. Thus, the experimental literature suggests more complex dynamics than either a straight race to the bottom or top.

### *5.5. Summary*

Transparency is a complicated subject, but recent research provides several revealing insights. First, there is broad agreement that transparency does matter; it affects the informativeness of the order flow and hence the process of price discovery. Greater transparency is generally associated with more informative prices. Second, complete transparency is not always 'beneficial' to the operation of the market. Indeed, many studies demonstrate that too much transparency can actually reduce liquidity because traders are unwilling to reveal their intentions to trade. Third, there is also general agreement that *some* disclosure – as opposed to *no* disclosure whatsoever – can improve liquidity and reduce trading costs. Finally, changes in transparency are likely to benefit one group of traders at the expense of others. The literature almost uniformly agrees that traders who trade on private information signals will prefer anonymous trading systems while liquidity traders, especially those who can credibly claim their trades are not information-motivated (e.g., passive index funds), prefer greater disclosure. Consequently, no single market structure is viewed as best by all parties.

## 6. Interface with other areas of finance

### 6.1. Overview

Some of the most interesting research in microstructure concerns the use of the models described above to other areas of finance. The recognition that microstructure matters – that it affects asset values and price efficiency – is relatively recent, but has important implications for other areas of finance. This section attempts to provide the reader with a quick introduction to the diverse research that relates to trading and markets being conducted today in three major areas: (1) asset pricing, (2) corporate finance, and (3) international finance.

### 6.2. Asset pricing

#### 6.2.1. Liquidity and expected returns

Previous research has modeled expected returns as functions of variables including proxies for size and default risk.[19] Amihud and Mendelson (1986) show that expected returns are an decreasing function of liquidity because investors must be compensated for the higher transaction costs that they bear in less liquid markets. Suppose for simplicity that agents in the economy are risk-neutral and that the risk-free rate is $r_f$. Consider a security paying a stochastic 'dividend' or interest coupon payment each period. Dividends are realized just after trading and are drawn from an independent and identically distributed distribution with mean $d$. Suppose, for simplicity, that each trader holds the security forever so that the immediate cost is all that is relevant.

In the absence of transaction costs, the expected present value of a security is simply $m^* = d/r_f$. With trading costs, Eq. (8) implies a purchase price of $p = m + (\lambda + s)$, where $m$ is the midquote. Under risk-neutrality, a purchaser with a $T$ period horizon must be compensated for the round-trip trading costs so

$$m = m^* - (1 + (1 + r_f)^{-T})(\lambda + s). \tag{16}$$

The presence of trading costs (asymmetric information, inventory costs, and other transaction costs) reduces the equilibrium *value* of the asset. It follows that the expected rate of return on the asset is higher than the risk free rate when $\lambda$ or $s$ are positive. This statement, while seemingly obvious, is important when we go to the data as discussed below.

#### 6.2.2. Liquidity as a factor in expected returns

There is growing support for the idea that expected returns must reflect a compensation for illiquidity. Amihud and Mendelson (1986) find there is

[19] Fama and French (1988, 1993) and Pontiff and Schall (1998) among others.

a significantly positive relation between returns and the bid–ask spread for NYSE/AMEX common stocks in the period 1961–1980, which is consistent with the model. Amihud and Mendelson (1991b) note that there is a difference in the bid–ask spread for treasury bills and treasury bonds, and that this affects bond yield to maturity. Amihud et al. (1997) document large changes in asset values for stocks moving to more liquid trading systems on the Tel Aviv Stock Exchange. These and other studies confirm the role of liquidity in asset pricing.

From a cross-sectional viewpoint, variation in expected returns across securities arises because of differences in trading costs. Of course, it matters how we compute returns. In the simple model above, suppose there are two assets: a security that is subject to trading costs and one that is not. If we correctly measure the return to the illiquid security based on the actual purchase price, it will equal the risk-free rate, which is the return provided by the fully liquid asset. However, as noted above, measuring the price impact of the trade (i.e., $\lambda$) is difficult, especially without transaction level data. Keim and Madhavan (1997) show that these costs can be substantially larger than the observed spread $s$. If we compute the return on the security ignoring transaction costs (i.e., using the midquote as the basis for value) we obtain return premium $r - r_f > 0$ that represents the compensation for illiquidity, $\lambda$. Thus, even if we correctly account for the spread, we are likely to observe that expected excess returns are positively related to the trading costs $(\lambda_i + s_i)$ across a sample of stocks after controlling for other factors affecting returns. This phenomenon may also explain in part the observed size effect because transaction costs are higher in less liquid assets where the omission of $\lambda$ in the computation of returns has the strongest effects. Cross-sectional models have been estimated by Brennan and Subrahmanyam (1996) among others, using the approach of Glosten and Harris (1988) and Hasbrouck (1991a) to estimate the liquidity parameter $\lambda$. See also Brennan et al. (1998).

A promising area for research in this area is the subject of commonality in liquidity and returns. So far, our analysis, like much of the microstructure literature has focused on a single stock. Consider a matrix generalization to $N$ stocks of the model in Eq. (13) of the form $\Delta \boldsymbol{p} = \boldsymbol{X}\boldsymbol{\Lambda} + \boldsymbol{U}$, where $\boldsymbol{X}$ is a matrix of order flows, current and lagged, as well as other predetermined variables affecting price movements, and $\boldsymbol{U}$ is the vector of error terms. Returns in stock $i$ may depend on current and lagged flows in stock $j$. Commonality in order flows is manifested in the fact that although $\boldsymbol{X}$ has full rank, only a few sources of independent variation explain most of the variation in the data.

Hasbrouck and Seppi (1999) use principal components analysis and canonical correlation analysis to characterize the extent to which common factors are present in returns and order flows. Principal components analysis can be viewed as a regression that tries to find a linear combination of the columns of the data matrix $\boldsymbol{X}$ that best describes the data, subject to the normalization restrictions imposed to remove indeterminacy. Hasbrouck and Seppi (1999) find that common factors are present in both returns and order flows. Common factors in order flows account for 50% of the commonality in returns. Related analyses are provided by Chordia et al. (1999). Whether such factors can help predict short-run returns (See Huang and Stoll, 1994), variation in intraday risk premia (Spiegel and Subrahmanyam, 1995), or the observed relation between price variability and volume (Karpoff, 1987; Foster and Viswanathan, 1995 among others) is still an open question.

#### 6.2.3. Behavioral explanations

Recent work in behavioral finance suggests interesting avenues for further research in terms of understanding return anomalies by incorporating aspects of trader behavior documented by psychological research. For example, it is well known that traders tend to overestimate the precision of their information. Such a bias may result in informed traders being overly aggressive in trading, with consequences for market efficiency. See, for example, Daniel et al. (1998) who study the relation between investor psychology and the degree to which prices over-react (or under-react) to new information. Other behavioral phenomena such as the tendency of agents to attribute luck to their own skill, the tendency to see patterns in pure noise, and aversion to realizing losses also affects trader behavior and hence return dynamics.

Another application is the study of trading motives. The microstructure literature relies heavily on the presence of uninformed, liquidity traders, known as noise traders. Black (1986) notes the importance of noise for there to be trading in equilibrium. Without uninformed or liquidity motivated traders, every trade is initiated by a party with private information, so dealers widen spreads to the point of no trade. But exactly who are these traders and why do they trade?

DeLong et al. (1991) examine the survival of noise traders in financial markets. Their results show that irrational noise traders are the source of price volatility and that other traders need to be compensated for the risk. Noise traders might normally incur losses in trading but if they move prices collectively, they might profit at the expense of other groups of traders. In short, their work suggests that we pay more attention to the role of noise traders and their motives for trading. Empirical evidence on the trading behavior and profits of small retail investors is contained in Barber and Odean (1999). Behavioral models may also be able to shed light on the determinants of trading volumes, an important topic in its own right.

### 6.3. Corporate finance

#### 6.3.1. Pricing of IPOs

Close economic ties between corporations and their sources of financing characterize many financial markets. Such arrangements are common in countries where corporations rely primarily on bank financing. Similarly, equity markets for smaller capitalization stocks are characterized by close relationships between new issuers and the underwriters who bring the stock public. In particular, underwriters sponsor new issues by arranging analyst coverage, promote the stock through marketing efforts, and provide liquidity by acting as broker-dealers in subsequent secondary market trading. Financial economists have only recently recognized the importance of such relationship markets. Yet, despite their prevalence, many basic questions concerning the operation of relationship markets remain unanswered.

An important issue is the role of underwriters in linking the primary and secondary stock markets for the firms they bring public. Underwriters of smaller stocks often dominate trading in the post-IPO market, giving them considerable ability to affect security prices. Ellis et al. (1999) examine the role of the underwriter in after-market trading. They find that for Nasdaq stocks, the lead underwriter is almost always the primary market maker in the after-market. Why is this arrangement so common? Is there a link between the degree of underpricing and the secondary market? How does this affect the IPO decision?

A simple extension of the basic model can show how the link between primary and secondary trading can have a crucial effect on the ability of small firms to raise capital in the primary market. Specifically, consider a model where an entrepreneur wishes to sell $Q$ shares of a privately owned corporation to the public. As before, uncertainty over true value is captured by $\sigma$, and the investment bank observes this variable during the process of taking the company public. The investment banker can locate, at cost, $Q$ potential IPO investors, each of whom will take one unit of the offering. The investment bank's IPO related payoff is $cp_0Q$, where $c$ is the commission rate. Both $c$ and $Q$ are fixed, and we assume IPO investors are risk-neutral and can only take one unit of the offering. They have a stochastic liquidation date distributed uniformly on the period $[t_1, T]$, with $T$ being the liquidation date. Using Eq. (16) above, the value of the asset to a potential IPO investor can be written as $p_0(s)$, where $p_0$ is a decreasing function of $s$, the cost of trading in the after-market. Initial investors care about future liquidity because there is a chance they will liquidate their holdings early.

Without market making by the lead underwriter, outside dealers provide liquidity. Since these dealers do not observe $\sigma$, they set a spread $S$ that will compensate themselves for the risk of insider trading should they underestimate risk. In other words, the spread is determined by the worst possible risk on cash flows. By contrast, if the underwriter also acts as the dealer in the after market, he can set lower spreads because of the information advantage acquired during the IPO process. Let $s^c$ denote the cost of supplying liquidity from the viewpoint of the underwriter, and let $s^*$ denote the actual spread chosen, where $s^c < s^* < S$.

The underwriter selects the spread with the objective of maximizing total revenues from commissions at the IPO stage plus future trading revenues. Specifically, the underwriter chooses $s$ to solve

$$\max_{\{s:\ s\in[s^c,\ S]\}} cp_0(s)Q + (s - s^c)\gamma Q. \tag{17}$$

Here, the first term is the IPO commission revenue while the second term captures the market making profits from the spread less costs times the expected volume of trade in the secondary market. Secondary market volume is assumed, for simplicity, to be proportional to the IPO size.

While the first term is decreasing in $s$, the second term is increasing, so that there exists a solution $s^* \in (s^c, S)$. Note that if the commission rate is sufficiently high, the underwriter undercuts the competitors and sets a lower spread. In turn, this increases the IPO price. Thus, the features of the relationship market are shown to have crucial effect on the ability of small firms to raise capital in the primary market. This model's predictions are consistent with stylized facts concerning both primary and secondary markets. Investment bankers who subsequently function as broker-dealers will have higher trading volume and will also offer to buy at higher prices, on average, than other competitive market makers. Several studies have documented that among firms qualified to list on both Nasdaq and the NYSE, smaller firms tend to list on Nasdaq. This result is puzzling because recent evidence suggests that both issue costs and bid–ask spreads tend to be higher on Nasdaq. This model, although simple, resolves this puzzle by showing that smaller firms might prefer a relationship market to a centralized market.

### *6.3.2. Stock splits*

Previous explanations for stock splits tend to focus on corporate finance explanations such as signaling. Angel (1997) notes the constancy of average stock prices over long periods of time within countries, despite variation across countries. However, the average stock price, relative to the minimum tick, is more constant. This suggests a possible microstructure based explanation for stock splits. Angel (1999) notes that a corporation can adjust its stock price relative to tick size through splits. Higher prices imply lower costs of capital and hence higher share values (Amihud and Mendelson, 1989), but at the same time, may discourage liquidity based trading by smaller retail investors. Thus, there might be an interior solution that maximizes share value.

Schultz (1999) examines whether splits increase the number of small shareholders who own the stock. He finds an increase in the number of small buy orders following Nasdaq and NYSE-AMEX splits in 1993–1994, along with an increase in trading costs. Schultz argues this finding can be explained by the fact that the minimum bid–ask spread is wider after the split, giving brokers an incentive to promote a stock. See also Easley et al. (1999) for a discussion of how trading is affected by stock splits.

### 6.4. International finance

#### 6.4.1. ADRs and multiple share classes

In the international area, an important aspect of the interaction with microstructure concerns internal capital market segmentation. Such barriers to investment are important because they may give rise to various documented 'anomalies' such as discounts on international closed-end funds. They also may give rise to arbitrage trading or other cross-border order flows and hence affect market efficiency. Finally, an analysis of segmentation may shed light on the positive abnormal stock returns (Karolyi, 1996) observed following liberalizations.

One interesting and puzzling aspect of international segmentation arises when domestic firms issue different equity tranches aimed at different investors. For example, countries as diverse as Mexico and Thailand have foreign ownership restrictions that mandate different shares for foreign and domestic investors. See, for example, Eun and Janakiramanan (1986), Bailey and Jagtiani (1994), Bekaert (1995), Stulz and Wasserfallen (1995), Foerster and Karolyi (1996), and Domowitz et al. (1997). The objective of such a partition of otherwise identical shares is to ensure that ownership of corporations rests in the hands of domestic nationals. Interestingly, the prices of these two equity tranches vary widely across firms and over time. A simple model suggests some insights into the nature of internal capital market segmentation.

Let $p_t^A$ denote the price of an $A$ share open domestic nationals only (converted from local currency into dollars) and let $p_t^B$ denote the (dollar equivalent) price of a $B$ share that is open only to foreign nationals, at time $t$, on the local market. The $B$ share premium is $\pi = (p_t^B/p_t^A) - 1$. What determines the premium? Supply and demand factors are important, but market liquidity may also be a crucial factor. In terms of our model above, liquidity in market $j = A, B$ is captured by the summary statistic $s_j + \lambda_j$. If both shares are otherwise equal but one share has higher transaction costs, that share will have a lower price if holding period returns are to be equal. Thus, share price premia or discounts can be explained in terms of relative trading costs. Elimination of market segmentation should reduce costs. Similarly, Stulz (1999) argues that globalization reduces the cost of equity capital because both the expected return that investors require to invest in equity to compensate them for risk and agency costs fall.

#### 6.4.2. Cross-border flows

These factors may also explain cross-border order flows. Foreign companies can list their shares abroad through the vehicle of depositary receipts (DR). Let $p_t^{\mathrm{DR}}$ denote the price of a depositary receipt (a claim against a $B$ share) in U.S. dollars. Arbitrage occurs if it is possible to buy in one market and sell in the other at a higher price net of transaction costs, i.e., if $|p_t^{\mathrm{DR}} - p_t^B| >$

$\lambda_{DR} + \lambda_B + s_{DR}| + s_B$. Even if this condition is satisfied, cross-border order flows may occur if the DR (foreign) market is cheaper for foreign nationals than trading in the local market, i.e., if $\lambda_{DR} + s_{DR} < \lambda_B + s_B$. In this case, order flow migration from the domestic ($B$ share) market to the foreign market (DR) may adversely impact the local market. To the extent that volume in the local market is valuable (an externality), such migration may affect even the liquidity of domestic issues that are not cross-listed abroad. These types of issues are vitally important to regulators and exchange officials and also to corporations whose cost of capital is directly affected by such decisions.

*6.4.3. The microstructure of foreign exchange markets*

Foreign exchange markets are by far the largest asset markets in terms of volume, and consequently there is considerable interest in how they operate and how prices are determined. Recent research (e.g., Lyons, 1995, 2000) uses microstructure models to explain some of the special aspects of foreign exchange trading, as described more fully below.

*6.4.3.1. Hot potato model.* An unusual feature of the foreign exchange market are the extremely large trading volumes, far larger than one would expect given the level of imports and exports. Lyons (1997) provides an elegant explanation for this phenomenon. The intuition of the model can be explained simply. Suppose an investor initiates a large block trade with a particular dealer. The trade causes this dealer's inventory to depart from the desired level. This is costly because of the risk of an adverse price movement. In a dealer market, the dealer can offset this added inventory risk by passing a portion of the block trade on to other dealers by hitting their quotes. The block is passed around to successive dealers through a 'hot potato' effect, so that the ultimate trading volume greatly exceeds the size of the initial trade. What is interesting about this explanation for the volume phenomenon is its reliance on two key aspects of market microstructure: (1) the dealer structure of the FX market, and (2) a lack of transparency in trade reporting. This is so particularly when dealers trade bilaterally over the telephone, still the most important method of dealing. The trade is then informative to them. The advent of electronic trading, e.g., EBS and Reuters D2000-2 systems, is changing the structure and availability of information to some extent. A violation of either of these assumptions would alter the nature of the equilibrium, dramatically reducing volumes.

*6.4.3.2. Exchange rate movements.* Another application comes in forecasting exchange rate movements. Economic theory suggests that exchange rates movements are determined by macroeconomic factors. Yet, macroeconomic exchange rate models do not fit the data well, with $R^2$ below 0.10 typically. Evans and Lyons (1999) propose a microstructure model of exchange rate dynamics based on portfolio shifts. Their theory augments the standard macroeconomic variables with signed order flow. They estimate their model for the Deutsche Mark/Dollar and Yen/Dollar exchange rates. In our notation, the model estimated takes the form

$$\Delta p_t = \beta_1 \Delta(i_t - i_t^*) + \beta_2 x_t + \varepsilon_t,$$

where $\Delta p_t$ is the daily change in the (log) spot rate, $\Delta(i_t - i_t^*)$ is the change in the overnight interest rate differential between the two countries, and $x_t$ is the signed order flow. As predicted, both $\beta_1$ and $\beta_2$ are positive and significant. The estimated $R^2$ improves substantially when signed order flow is included. Over 50% of the daily changes in the DM/$ rate and 30% Yen/$ rate are explained by the model. Applications include short-run exchange rate forecasting, targeting of central bank intervention, and prediction of trading costs for large transactions. See also Goodhart et al. (1996) for a study of quote dynamics in FX markets. While this approach is still in its early stages, it is suggestive of the potential value from combining microstructure and macro variables within a single model. Remaining problems, however, are the shortage of data on order flow, and the subsequent problem of what determines order flow itself, since the economic fundamentals used in exchange rate models cannot by themselves explain the incremental predictive power of order flow.

### 6.5. Summary

The interface of microstructure with other areas of finance is a growing subject. Besides the applications listed above, there are many other topics that merit study. A more complete understanding of the time-varying nature of liquidity and its relation to expected returns appears warranted given the growing evidence that liquidity is a 'factor' in explaining the cross-sectional variation in stock returns. Differences in liquidity over time may explain variation in the risk premium and hence may influence stock price levels. Much work remains in corporate finance. For example, the response of stock prices to new information is very rapid, a matter of minutes rather than hours. Yet, most event studies use daily returns as their unit of observation. Considerable evidence on the nature of corporate events might be gleaned from high-frequency data analysis. Using microstructure techniques to decompose the bid–ask spread (or price impacts) into transitory and information based components, a researcher might be able to make a more precise determination of the market perceptions regarding insider trading and asymmetric over time. Such a measure might be very useful in testing hypotheses about the reaction of stock prices to earnings and dividend announcements. Finally, to the extent that differences in the cost of trading drive cross-border order flows, microstructure models may have a lot to add to debates over the nature of international segmentation.

## 7. Conclusions

The last two decades have seen the emergence of a substantial literature in *market microstructure*, the area of finance that examines the process by which investors' latent demands are ultimately translated into transactions. This paper surveys the considerable theoretical, empirical and experimental literature on market microstructure with a special focus on informational issues relating to four major areas: (1) *price formation and price discovery*, including both static issues such as the determinants of trading costs and dynamic issues such the process by which prices come to impound information over time, (2) *market structure and design*, including the effect of trading protocols on various dimensions of market quality, (3) *market transparency*, i.e., the ability of market participants to observe information about the trading process, and (4) *interface of market microstructure with other areas of finance* including asset pricing, international finance, and corporate finance.

This review, although necessarily brief and selective, hopefully provides the reader with a sense of the richness of the literature and the considerable advances in our understanding of financial markets that has emerged. Indeed, one of the major achievements of the microstructure literature has succeeded illuminating the 'black box' by prices and quantities are determined in financial markets. We now understand the role of inventory and asymmetric information in determining the responsiveness of prices to order flows. The recognition that order flows can have long-lasting effects on prices has many implications that we are only now starting to investigate. For example, large price impacts may drive institutional traders to lower cost venues, creating a potential for alternative trading systems. Large price reactions to flows might also explain why proxies for liquidity appear to do so well in explaining the cross-sectional variation in returns.

Another major achievement of the literature is to highlight the importance of market design and trading protocols in the determination of agents' decisions to provide liquidity, and thereby attributes of market quality such as price efficiency, volatility, and trading costs. For example, a reduction in the minimum tick may induce investors to place market orders instead of limit orders because it is easier to undercut a limit price. The net impact of such a change might thus be a reduction in liquidity, even if quoted spreads narrow. Recent models also demonstrate the sensitivity and fragility of market equilibria to problems of adverse selection, illustrated by periodic breakdowns of liquidity. In this sense, the literature has demonstrated that microstructure does matter in both a practical and academic sense. Similar remarks apply to the effects of information disclosure and transparency, although there is less consensus on their effects on these dimensions of market quality. The application of microstructure theories to other areas of finance is a subject that is still evolving and very much in its infancy, but provides exciting avenues for future research.

What lessons can one draw from this survey? Several points emerge from a careful reading of the literature. First, markets and trading protocols are a great deal more complex than we had believed. Second, frictions do matter, and might serve to explain many observed empirical phenomena. The most important such manifestation lies in the possibility that markets may fail under certain protocols, or that there may be large deviations between 'fundamental value' and price. Third, and a consequence of the discussion above, we must guard against 'one size fits all' approaches to regulation and policy making. Greater transparency, for example, need not always enhance liquidity. Finally, although considerable advances have been made in our understanding of trading and markets, many puzzles remain. These include the question of why traders prefer continuous to intermittent trading systems or equivalently, why network externalities do not unify markets, the extent to which liquidity can explain variation in stock returns over time and across assets, and the reason for the wide diversity in trading mechanisms across assets.

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