

The informational role of prices

A review essay

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1. Introduction

The last three or four years have seen an explosion in the literature on asset markets with asymmetric information and especially on trading mechanisms, an area called the ‘microstructure of financial markets’.¹ There are a number of reasons for this development. First, following the crash of 1987 and, more generally, given the increasing complexity of the trading environment, many policy issues related to the organization of financial markets have become important. Examples of such issues include the interaction between different exchanges where the same or very closely related securities are traded, the role of designated market makers, the desirable degree of competition among market makers, the type of information which should be communicated during the trading process to various participants (e.g., what information about the trading process should become public and when, how should communication between market makers and different exchanges be structured), and so on. A number of reports issued after the stock market crash have emphasized the need to study the details of the trading process.²

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¹An illustration of this is the fact that over 60 papers have been submitted to a special session on ‘market microstructure’ organized by the Western Finance Association and the *Review of Financial Studies* in June 1990.

²These include that of Brady’s ‘Task Force on Market Mechanisms’, the Miller commission appointed by the Futures Exchange, and others. See Barrow et al. (1989).

Since the interaction between asymmetrically informed traders is central to many of the questions in this area, it has become important to work with models in which traders are asymmetrically informed.

A second reason for the increasing interest in asset markets with asymmetric information and in market microstructure is that empirical research has uncovered a number of phenomena that call for theoretical explanations beyond what can be obtained by traditional models (in which informational asymmetries are not present). These studies were based both on aggregate stock market data and on extensive transactions data sets which have become available recently. Examples of the empirical findings include the January effect (returns, especially on small firms, tend to be significantly higher in January than in other months), the weekend or Monday effect (stock returns tend to be negative over the weekend), various patterns in trading volume, variances, and expected returns over the trading day and week, differences in variability of returns depending on whether the exchange is open or closed, and so on.³ Theoretical and empirical research on asset markets with asymmetric information have thus begun to feed and stimulate each other.

The literature on asset markets with asymmetric information began with the development of rational expectations equilibrium models in the late seventies and early eighties. Sanford Grossman was among the pioneers of this subject, and he remains a leading contributor. The most influential of his papers are collected in *The Informational Role of Prices* (MIT Press, Cambridge, MA, 1989). In this essay, I will review Grossman's work and its place in the larger literature. The essay is divided into two major sections. In section 2 I discuss the equilibrium concept that Grossman developed, the competitive rational expectations equilibrium with asymmetric information. I describe briefly the four early papers of Grossman on this topic which are included in the volume. (Readers familiar with these papers can skip this subsection without loss of continuity.) Next some recent extensions and applications of these models, including two chapters of the current volume, will be discussed. Section 2 closes with a discussion of some of the problems with the foundations of rational expectations equilibrium that have been studied.

Because of the conceptual problems raised at the end of section 2, because rational expectations models are often analytically intractable, and because of the inherent interest in how market microstructure affects market performance, the subject has developed from the rational expectations equilibrium notion to alternative models of trading in markets with asymmetric information. These alternatives are the subject of section 3. Some of the basic models which have been extensively used in the recent literature will be discussed as

³See, for example, French and Roll (1987), Gibbons and Hess (1981), Harris (1986), and Keim (1989).

well as some of their applications. It should be noted that although much of the competitive rational expectations literature described in section 2 precedes the recent 'microstructure' literature discussed in section 3, the division of the essay according to the type of model used is somewhat arbitrary, since different types of models can be and have been used to analyze similar problems on asset markets with asymmetric information.

The final three chapters of *The Informational Role of Prices* contain other papers by Grossman that I will not discuss in detail in this essay. Chapter 7 [Grossman and Hart (1981)] is a seminal paper in the modern literature on takeover mechanisms. The main idea is that unless there is some change that the takeover will provide an improvement in the firm's profit, the takeover cannot be successful in a rational expectations equilibrium.⁴ Chapters 8 and 9 [Grossman (1981b), and Grossman, Hart, and Maskin (1983)] include two important papers on the informational role of contracts, in the context of signaling quality levels and labor markets. These chapters differ from the others in that information is not revealed by prices but rather by another endogenous element of the model, namely by contracts.

2. Rational expectations equilibrium with asymmetric information

2.1. Grossman's early contributions

Grossman's volume includes four seminal papers [Grossman (1977, 1978, 1981a) and Grossman and Stiglitz (1980)] on the notion of a competitive rational expectations equilibrium with asymmetric information. It is the informational role of prices in such an equilibrium that is referred to in the title of the volume. The main feature of the type of rational expectations equilibrium discussed in these papers is that agents use *current* equilibrium prices to learn some of the information possessed by others. Equilibrium prices therefore perform a dual task. First, as in a standard Walrasian equilibrium, they describe the terms of trade at which exchange takes place to clear the markets. In addition, they serve as information signals which can change agents' preferences directly through changing their beliefs. This is an example of the general idea that unifies all the papers in this volume, namely that with information asymmetry 'the very activity of trading conveys information that affects the outcome of the activity' (p. 1).

Rational expectations equilibrium prices can be so effective as information signals that they wipe out any informational asymmetry which may have existed initially among agents. This occurs when the price effectively reveals all the information available in the economy. The same price would then

⁴To overcome the free-rider problem discussed in Grossman and Hart (1980) this paper assumes that the raider can dilute the value of the firm after a successful takeover.

obtain in the (Walrasian) equilibrium of the 'artificial economy' in which agents share all the information they have before the market opens. Grossman (1977, 1978, 1981a) provides three financial market models where this occurs. In Grossman (1981a) it is shown that in a complete market Arrow–Debreu economy there always exists a fully revealing rational expectations equilibrium price. Grossman (1977) focuses on the informational role of futures markets, showing first an example in which there is a one-dimensional information signal which the spot price fully reveals, and one in which the spot price together with the futures price jointly reveal a two-dimensional signal. Grossman (1978) reproduces a version of the Sharpe–Lintner Capital Asset Pricing Model in an economy in which initially agents have diverse information and the equilibrium price vector aggregates all private information and provides a sufficient statistics. [This is a generalization of the well-known model of Grossman (1976) to many assets and a more general information structure.]

Fully revealing equilibria have some appealing properties. The 'invisible hand' somehow transmits to each agent all the relevant information in the economy. However, if we believe that information asymmetries actually exist in financial markets, that they prevail at the trading stage and beyond, and that they motivate some if not much of the trading, then fully revealing models are not descriptive of these markets. Moreover, serious conceptual problems arise with this notion. One problem, on which Grossman has focused, is that if prices are fully revealing then there are no incentives for agents to spend resources on acquiring information. This paradox is discussed in detail in Grossman and Stiglitz (1980), who show that if the information acquisition is endogenous and information is cheap but not free, then there may exist no overall equilibrium. Specifically, if no information is collected (and therefore none is revealed by the price) agents have private incentives to collect it, but if some agents collect the costly information, each one of them, taking the actions of others as given, prefers not to collect it but rather to obtain it freely from the price. This impossibility result is important since it examines the theoretical and conceptual underpinnings of the frequently used notion of *efficient financial markets*. It shows that under some conditions it is logically impossible for financial markets to be efficient in the 'strong' sense that they reflect all the information available in the market.⁵

⁵A related problem with fully revealing prices is discussed in Grossman (1978). If the homogeneous beliefs which are implied by fully revealing equilibria lead to very thin trading and if it is costly to operate markets, then some markets will close down. In that case the price system could no longer be fully revealing, since there would be fewer pieces than are necessary for full revelation. As pointed out by Beja (1977), there is also a serious implementation problem associated with fully revealing prices – if no trader is using their private information, how can any trading process actually bring this information into the price? See section 2.3 for a discussion of related issues.

Grossman and Stiglitz (1980) proceed to develop a model in which the price is not fully revealing. The noise in this model, as in much of the subsequent literature, comes from the stipulation of random supply for the risky asset, which can be motivated by assuming that certain agents trade for liquidity reasons. The existence of this unpredictable element in the price masks some of the private information and prevents full revelation. As a result, we can also see trading among speculators who hold, in equilibrium, different beliefs, and costly information acquisition is consistent with equilibrium.

2.2. Recent extensions and applications

In the few years following their publications, extensions and modifications of the models suggested by Grossman (1976, 1978) and Grossman and Stiglitz (1980) have been developed and applied to study a number of topics. Following is a discussion of a few of the recent extensions and applications, including two from the current volume.⁶

Grossman (1988) discusses the effect of program trading and dynamic hedging strategies on stock and futures markets. The success of portfolio insurance and other dynamic trading strategies, Grossman observes, shows that many investors are interested in purchasing long-term put options, which would insure them against losses below a certain level and lower their risk exposure when prices decline. If such options are not available directly, it may be possible to create them 'synthetically', by using a particular dynamic hedging strategy in which stocks are replaced with bonds when stock prices decline. A problem arises if investors do not know the exact demand for such dynamic strategies. In this case a market in the relevant options, which would otherwise be considered redundant, has an informational role to play. That is, the prices of these securities can provide information about their demand, while agents will not be able to separate this from payoff-relevant information in interpreting the price of the underlying stock.

In the introduction to the current volume Grossman notes that in the presence of informational asymmetries, dynamic hedging strategies have two effects on asset prices, both of which have implications for understanding the possibility of a financial panic such as the crash of 1987. First, they increase the sensitivity of the price to information when the price is low – relatively minor news can cause large shifts in the price. Secondly, since a large unidentified order might be the result of very negative information, the price becomes more sensitive to liquidity demands as well. A panic might start

⁶Some applications of rational expectations models are discussed in Admati (1989). More recent papers which will not be discussed below include Admati and Pfleiderer (1990, 1991), Dennert (1990), Leland (1990), Amershi and Ramamurtie (1990), Kraus and Smith (1990), and Lundholm (1990).

when a large uninformed order causes other uninformed traders to sell as well, suspecting that negative information may have been observed by informed traders.⁷

The rational expectations models described so far are static – trading takes place only once. This has limited their applicability. Intertemporal asset pricing models with asymmetric information in which prices are not fully revealing are very complex analytically, and thus developments in this area have been difficult to come by. Nevertheless, some progress has been made. Grundy and McNichols (1990) develop some simple models with two trading periods in order to examine the effect of public announcements on trading volume. Among other things they show that nontrivial amount of trading can take place in a financial market even when no new information comes in, if traders are able to use both past and current prices to update their beliefs. This bears both on the notion of ‘technical analysis’, namely the use of past prices to make prediction about future payoffs, and on the crash of 1987, which did not seem to follow a major informational event. The idea that technical analysis might be a part of a multi-period rational expectations equilibrium is examined further in Brown and Jennings (1990). In another development Wang (1990) analyzes a continuous-time noisy rational expectations model. This paper shows that asymmetric information among investors might be important in understanding notions such as excess volatility or the ‘equity premium puzzle’.⁸

2.3. *Foundational research on the rational expectations model*

As with the Walrasian competitive equilibrium, the competitive rational expectations equilibrium is a reduced-form description of market interactions, which does not specify an explicit game among traders or a price formation mechanism. An important issue is the extent to which this equilibrium can be supported by an explicit trading and price formation mechanism. A related and fundamental problem concerns competitive behavior with asymmetric information. Possibly the strongest assumption in the rational expectations equilibrium models mentioned above is that agents are price

⁷In a related paper, Gennotte and Leland (1990) describe how lack of knowledge of hedging demand characteristics can lead to discontinuous shifts in the equilibrium price in a two-period noisy rational expectations model. Admati and Pfleiderer (1991) use a similar framework to examine the implications of ‘sunshine trading’, i.e., the notion that certain liquidity traders would preannounce their demands publicly prior to trading. Roell (1990) addresses a related issue in the context of a version of Kyle’s (1989) model (which is discussed below).

⁸The excess volatility theory says that stock prices ‘move too much’ to be justified by changes in dividends and has been hotly debated; see Kleidon (1986) for a review of this literature. The equity premium puzzle refers to the difficulty in explaining the excess return on stocks by a model with a representative agent with ‘reasonable’ preferences. See Mehra and Prescott (1985), for example.

takers, i.e., each of them behaves as if his actions do not have any effect on the realization or the informational content of the price. This assumption is stronger and possibly more problematic here than it is in a standard Walrasian equilibrium, because the price in a rational expectations equilibrium serves both to clear the market and to provide information to agents. The question is under what condition is an informed agent 'small' enough, at least to a good approximation, to ignore the effects of his actions on the price.

A number of approaches have been taken to study these problems. The implementation literature has been concerned with the possible existence of a game (among a finite number of agents) which can *implement* the rational expectations equilibrium allocations in a class of economies. It turns out that a necessary condition for the existence of such a game is that information is not 'exclusive', a version of which says that the information of each individual agent is collectively known to the other agents [see Postelwaite and Schmeidler (1986), for example]. This is not surprising since, with a finite number of agents, an agent who has exclusive information can manipulate the allocation strategically. This provides a partial answer to the question on price taking behavior; an informed agent with exclusive information who is one of a finite number of traders cannot be considered small in this sense; he would not behave as a price taker.

A limitation of the implementation literature is that the set of possible games is usually very large. As a result, even if an allocation is implementable, the mechanism that implements it might be very complicated and/or unrealistic. It thus becomes important to study specific and realistic trading processes. Moreover, since the Walrasian competitive equilibrium notion can be justified if the number of agents is very large, and since financial markets are composed of a large number of traders, it is important to study the equilibria of economies as the number of agents grows.⁹

One price formation mechanism which could lead to the behavior postulated in the rational expectations model has agents submitting their demand functions to an auctioneer who then chooses a market clearing price. Kyle (1989) examines this type of model with a finite number of traders. In this model each trader takes into account the effect of his demand on the market clearing price (but not on the pricing function). Among other things Kyle shows that with imperfect information the equilibrium price is less informative than it would be if traders behave competitively. The model does not collapse even if traders are risk-neutral, in which case it is indeed inappropriate to model them as perfectly competitive (since their demands would be unbounded unless the asset is priced at its expected payoff given their

⁹Palfrey and Srivastava (1986) examine conditions under which agents become informationally small as the economy grows.

information). On the question of whether the model converges to the perfectly competitive equilibrium as the number of agents grows, Kyle obtains an ambiguous result; it depends on the way in which the limit is taken. Gale and Hellwig (1988) examine a similar issue in a model in which there is one strategic informed trader who is the only one holding shares of the risky asset (thereby providing a motive for trade). Their analysis suggests that in most cases theoretical support can be given to the notion that prices provide signals and convey information, but that the assumption of perfect competition is problematic under asymmetric information. In their model the informed monopolist does not behave as a price taker even if he is small in terms of his resources relative to the rest of the market.¹⁰

Another foundational issue is that of learning. Underlying the rational expectations model is the assumption that agents know the correct joint distribution of equilibrium prices and payoff-relevant variables. How do agents come to know this distribution? Grossman (1981) invokes learning to argue that the Walrasian equilibrium concept (in which agents do not learn from current prices) is inappropriate: such an equilibrium is unstable since, if it is repeated over time, agents will learn how to use the price as a signal of the information held by others. The rational expectations equilibrium is immune from this criticism; it is self-fulfilling. Yet the issue of how agents can actually learn the distribution of endogenous variables in a rational expectations equilibrium remains. It is a particularly difficult issue, since while agents are learning, the economy is not stationary even if the underlying variables are. Some references include Bray (1982), Bray and Kreps (1985), and Marcet and Sargent (1989).

Finally, and related to the issue of learning, a number of studies have attempted to evaluate the rational expectations equilibrium notion in an experimental context. This literature started with Plott and Sunder (1982), who showed that in a simple trading environment subjects arrived to the rational expectations equilibrium allocations within few trading rounds. Subsequent research has examined different and somewhat more complex environments, and has provided conditions under which rational expectations equilibrium would emerge. See, for example, Plott and Sunder (1988) and Forsythe and Lundholm (1990).

3. Alternative trading mechanisms and the market microstructure literature

For most of the issues to which rational expectations models have been applied the precise details of the trading mechanism, or even the assumption

¹⁰A related paper is Bhattacharya and Spiegel (1990), which characterizes the equilibria of a parametric version of a model with a single strategic informed trader. See also Laffont and Maskin (1990).

of perfect competition, do not seem very important to the results. This is not the case for issues related to the organization of financial market and to the trading mechanism itself. Moreover, rational expectations models are analytically very complex and are particularly difficult to apply in studying dynamic issues. Various aspects of the trading mechanism might also be important in understanding the empirical properties of asset prices, particularly on a transaction-by-transaction level. As a result, a number of alternative models of the trading environment have been developed.

Actual trading mechanisms in financial markets are complex and varied. In most US markets, for example, traders can submit various types of orders, the simplest of which are market orders specifying a quantity to be bought or sold at the 'market price' and limit orders specifying a price and a quantity. Also, most financial markets are characterized by the existence of market makers or specialists, who are typically involved in both facilitating trade among other traders and in trading on their own account. In a sense, market makers are simply a particular type of trader, who have the ability to quote prices as part of their strategies. At the same time, their role as intermediaries and price setters, as well as the information they obtain while coordinating exchange (particularly information about the orders of other traders), might call for a special treatment.¹¹ Markets also differ by whether trading is conducted as an auction where orders are batched and traded at the same price (as, for example, in the opening trade at the NYSE) or through specialists trading sequentially. Different markets may also be characterized by different degrees of competition between market makers.¹²

The basic auction model of Kyle (1985) has been particularly popular in recent literature, in large part due to its simplicity relative to, for example, the rational expectations models. Kyle postulates a set of liquidity/noise traders and one informed trader, all of whom submit market orders (i.e., orders specifying a quantity to be bought or sold at the 'market price') to a market maker. The orders are executed in a batch – all orders arriving in a given time period trade at the same price. The market maker, who trades from his own account to clear the market, sets the price on the basis of the net order flow so that he earns zero expected profits. (This is justified by assuming that there are multiple risk-neutral market makers competing for

¹¹The earlier market microstructure literature has focused on the role and the objectives of market makers and specialists and on the details of the trading mechanism. Information issues were not typically modeled. See, for example, Garman (1976), Amihud and Mendelson (1980), and Cohen, Maier, Schwartz, and Whitcomb (1986).

¹²In fact, the degree of competition among specialists seems to vary across exchanges. A specialist in the NYSE, for example, resembles a regulated monopolist, except that he faces competition both indirectly from other specialists in related securities and from floor traders who can submit limit orders. In the American Stock Exchange, by contrast, entry into market making is easier and so there seems to be more intense competition among market makers.

the same total order flow.) The price is sensitive to (indeed, increasing in) the order flow because the order flow includes the order of the informed trader, which is based on payoff-relevant private information. In choosing his order size, the informed trader takes into account the effect his order will have on the price, although he takes the pricing function as given. Note that, since traders cannot submit price-contingent orders, they cannot learn from the current price. However, if information is long-lived (so that the informed trader gets to trade over a number of trading periods before it becomes public), past prices or order flows are obviously informative.

The basic auction model described above lends itself to numerous extensions and variations. For example, Kyle (1985) analyzes the case where the insider's information is long-lived. The single-period auction model has also been extended to include multiple informed traders and imperfect or diverse information among informed [see Kyle (1984) and Admati and Pfleiderer (1988a)]. Since the strategy space for traders involves only the choice of quantity, this is akin to a Cournot model of trading. Other extensions include models with multiple assets [Caballe and Krishnan (1989)], risk-averse traders [Subrahmanayam (1991b)], multiple informed traders with long-lived information [Holden and Subrahmanyam (1990)], and infinite number of traders [Vives (1989)].

Applications of Kyle's basic model include Admati and Pfleiderer (1988a), who discuss a model with short-lived private information in which some liquidity traders have discretion as to the timing of their trade. They show that in equilibrium there will be concentration of trading both by informed and uninformed traders, leading to patterns in volume and price variability. Versions of Kyle's model have also been applied to study, for example, markets for information [Admati and Pfleiderer (1988b)], interday trading patterns with long-lived information [Foster and Viswanathan (1990)], the interaction between different exchanges where the same asset is traded [Chowdhry and Nanda (1991)], the effect of insider trading on price informativeness [Fishman and Hagerty (1990)], security 'baskets' [Bushan (1990) and Subrahmanyam (1991a)], and international cross-listing [Freedman (1990)].

Another simple model of trading with asymmetric information is proposed in Glosten and Milgrom (1985).¹³ In this model prices are posted by a specialist and orders are processed sequentially. Unlike Kyle's model, the order size is restricted to one (normalized) unit. (This feature greatly simplifies the model, but makes it difficult to model the arrival process of traders.) The specialist posts bid and ask prices, with the interpretation that he is willing to buy one unit at the bid or sell one unit at the ask. An arriving trader chooses whether to buy, sell, or not trade. The arrival process of

¹³Informal accounts of the idea that the bid-ask spread is at least partly due to adverse selection can be found in Bagehot (1970) and Copeland and Galai (1983).

traders, which is given exogenously, is such that at most one trader is present at any point in time. Knowing the statistical properties of the arrival process, the specialist sets the bid and ask prices to earn zero expected profits. (Again, the zero profit assumption can be justified by assuming that more than one risk-neutral market maker are present at each point and they compete for each arriving order.) Note that the ask price is equal to the conditional expected payoff of the asset given that the arriving trader chooses to buy, while the bid price is equal to the conditional expectation given that the arriving trader chooses to sell. If there is a positive probability that the arriving trader is informed, then the ask price will be strictly higher than the bid price, since the event that the trader chose to buy indicates possible good news for the asset, while the opposite is true if the trader chose to sell. Moreover, it is possible (for example, if the arriving trader is definitely better informed than the market maker) that there are no possible bid and ask prices for which the specialist earns zero expected profits. In this case the adverse selection problem faced by the specialist is too severe and the market breaks down. As prices are updated over time, information is gradually incorporated into them. This is similar to the result obtained in Kyle's model with long-lived information.

A number of authors have employed specific parameterizations of Glosten and Milgrom's (1985) general model to investigate specific issues. For example, Diamond and Verrecchia (1987) analyze the effect of short sales restrictions on the price process and the adjustment of price to information, and Jacklin, Kleidon, and Pfleiderer (1990) argue that underestimation of portfolio insurance prior to October 1987 could have led to a price process such as that observed in the crash. [This formalizes the idea discussed by Grossman (1988) in a dynamic context.]

Glosten and Milgrom (1985) note that in their model if the market breaks down in the sense that there are no prices for which the specialist can break even, then this condition will persist until the informational asymmetry between the specialist and the informed trader is mitigated, e.g., through the release of some public information. This is because, once the market is closed, there can be no learning from the trading process, and so the adverse selection problem will persist. The authors conjecture that this result might not hold in a model in which the specialist is not competitive but rather is a monopolist. The competitive model assumes that the specialist must break even on each and every transaction. The monopolist, by contrast, might be able to average over different time periods, possibly losing in some transactions but more than making it up in others. In a sense, the monopolist specialist will be paying for information by executing trades early, then making profits in later periods when the level of informational asymmetry is lower. Glosten (1987) illustrates a similar idea by allowing the specialist to post a schedule of prices, with different prices corresponding to different

order sizes. He shows that, while the condition that the specialist earns zero expected profits on each transaction implies that for some parameters the market will be closed (since no zero profit quotes exist), a monopolist specialist will always keep the market open. If the adverse selection problem is severe, the monopolist will lose on very large orders (which occur infrequently) but gain on orders of relatively small size, leading to overall positive profits.¹⁴

A number of recent papers analyze models in which, unlike Kyle (1985) and Glosten and Milgrom (1985), the market makers do not set each price conditional on the precise number of trades that will take place at this price. For example, in Easley and O'Hara (1987) prices are posted and all orders arriving within a given time period are executed at the same price. Admati and Pfleiderer (1989) show that in this type of model the price process may exhibit patterns in expected price changes. Rock (1990) presents another trading model which addresses similar issues and which makes a distinction between market orders and limit orders.

4. Concluding remarks

This essay has described both the early and recent literature on rational expectations models and the literature in which alternative trading models have been developed and applied. We have seen an evolution away from the reduced form model that Grossman used in his pioneering work on the subject, but at the same time continued development of ideas and continued probing of the agenda that was set by his earlier work. As the essay indicates, interest in these ideas is very high; the literature is growing extremely quickly. I believe that this will continue for a while longer, since there are still many interesting problems and challenges related to the organization of financial markets. This research has the potential of both providing a descriptive understanding of existing market institutions and exploring the implications of various alternative organizations. For anyone interested in this subject, Grossman's volume is indispensable.

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¹⁴Manhaven (1990) discusses a dynamic model which captures the intuition suggested by Glosten and Milgrom (1985). The issue of whether prices set by a monopolist specialist will be sensitive to the order flow is addressed by Madrigal and Scheinkman (1990). Gammill (1989) discusses a model in which the issue competition and the information available to market makers when setting prices play an important role. Finally, Dennert (1989) models explicitly competition between market makers.

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