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ABSTRACT

This work compares a dealer market and a limit-order book. Dealers commonly observe order flow and collect information from multiple market orders. They may be better informed than other traders, although they do not earn rents from this information. Dealers earn rents as suppliers of liquidity, and their decisions to enter or exit the market are independent of the degree of adverse selection. Introduction of a limit-order book lowers the execution-price risk faced by speculators and leads them to trade more aggressively on their information. Introduction of the book also lowers dealer profits, but increases the informational efficiency of prices.

> The falling stock market was stopped only by the 4 p.m. close. The Dow Jones Industrial Average had fallen 508 points, or 23 percent, on volume of 604 million shares. . . . The record volume on the New York Stock Exchange had overwhelmed the data processing and communications systems of the exchange. . . . Because timely information was scarce, investors did not know if their limit orders had been executed and therefore did not know to set new limits.
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> *The Presidential Task Force on Market Mechanisms*, January 8, 1988, p. 111–121

THE DISTINCTION BETWEEN DEALERS on a financial exchange and outsiders is important. Members of exchanges—a class that includes both brokers and dealers—have privileges, that include the opportunity to be present on the floor, to trade with other members, and to observe the order flow from outsiders. Indirect evidence that order flow to an exchange is informative and valuable includes the fact that exchange members are willing to pay for their memberships; seats on the Chicago Board of Trade (CBOT) and Chicago Mercantile Exchange (CME), for example, were sold recently for more than one-half million dollars. More direct and convincing evidence is the schedules of prices for immediate versus delayed information from an exchange floor. Exchange fees and vendor administrative fees for electronic data feeds carry-

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ing immediate past prices from the CME floor total over $350 per month, whereas these fees are zero for quotes and prices delayed ten minutes.[1]

As further evidence, consider the quotation above, which characterizes the New York Stock Exchange (NYSE) on Black Monday, October 19, 1987. Because of excessive demands on the limited capacity of the exchange membership and electronic hardware to transmit information from the exchange floor, outsiders were poorly informed of conditions on the floor. It was difficult to predict the prices at which market orders were to be executed, as well as the likelihood of the execution of limit orders. Although the volume of trade and volatility of prices were exceptional on Black Monday, many similar characteristics are found at other times on the NYSE floor and in other markets, such as Nasdaq. For example, dealer spreads and the size of the market—i.e., the number of shares offered for purchase or sale at the inside quotes—vary through time. In addition, small market orders may be executed within the spread, whereas large orders may be executed as packages of smaller trades over several hours or days. When market size is small, dealer spreads are wide or alternatively when price volatility is high, specialist quotes and immediate past prices convey little information regarding the price at which an order might be executed. At times such as these, execution-price risk is high.

One purpose of this article is to characterize the opportunity of dealers on exchanges and in financial markets generally to aggregate information from order flow. We first examine a dealer market in which liquidity traders and risk-averse, heterogeneously informed speculators submit market orders to a community of competitive and risk-averse dealers. An equilibrium price is set so that the net dealer demand is equal to the net market orders. Dealers have the opportunity to trade after observing the order flow, whereas speculators do not. It follows that speculators bear execution-price risk, and dealer's rights to trade are valuable.

The adverse-selection problem of dealers—i.e., dealers risk losing to informed investors—is well studied in extant literature.[2] By comparison, the advantage of a dealer relative to an outsider that follows from the dealer's observation of multiple market orders is studied here. The idea that order-flow information is valuable to dealers is suggested by the work of Manaster and Mann (1995). They characterize locals in futures pits as profiting from price trends as well as from the spread, but do not describe the source of the profits. Do dealers profit from order flow because they learn about asset fundamentals, because they act as liquidity suppliers, or both? Our work suggests the following answer to this question.

Dealers learn about fundamentals from observing order flow, and the accuracy of a market price as a signal of future cash flows increases with the precision of the information in the order flow. However, dealers operating in a

[1] The cost of on-line information from the exchange floors typically includes other fees as well, such as those covering the hardware carrying the data. We thank Marilee Radecki of the CME for her explanations of the fee structure.

[2] See Glosten and Milgrom (1985) and Kyle (1985).

competitive market with commonly observed order flow do not earn rents from this information. Realized dealer profits decline with the size of informed trade relative to liquidity trade, but the profit expected prior to order arrival is independent of the expected volume of informed trade. In fact, the ex ante dealer welfare is determined as if only liquidity trade existed and as if there were no adverse selection. This last interpretation suggests, for example, that dealer decisions to enter or exit a competitive market are independent of the adverse-selection component of the spread. Dealers also act as suppliers of liquidity and earn rents from this activity. For example, a dealer increases inventory in anticipation of a positive future price trend that follows outsider selling, and the expected return, which is conditional on order flow, increases with the size of the optimal inventory.

A related issue is the association between the supply of dealers and informational efficiency. Efficiency in a dealer market is determined in part by the level of execution-price risk, which in turn is a function of the supply of dealer services. When the supply is low, for example, execution prices are less predictable, outsiders are less aggressive in trading on their private information, and informational efficiency is lower than when supply is high. We also recognize as a practical matter that sufficiently permanent or long-run increases in order flow may be accompanied by increases in the supply of dealer services. As an example, consider the migration of locals on a futures exchange from pit to pit. For this reason, much of our analysis allows an endogenous supply of dealers. This provides a simple characterization of those who choose to be dealers and those who trade off the exchange. It also provides a tangential benefit of generalizing the Walrasian model of Grossman and Miller (1988) to a setting with informed trade and market orders.

Our work also compares the outcomes of trade in the dealer market to those in a Walrasian market. In the latter, speculators trade using demand-price schedules instead of using market orders. Because a demand schedule may be approximated to any degree of accuracy by a large number of small limit orders, we interpret the Walrasian market as an ideal open limit-order book in which speculators may submit without cost an unlimited number of limit orders. This particular interpretation leads to conclusions that are similar in spirit to those of Glosten (1994), so a brief comparison may be helpful.

Glosten concludes that an open limit-order book survives in competition with any one of a number of alternative market structures, i.e., it is the low-cost provider of liquidity in the eyes of a market-order submitter. Whereas Glosten allows only risk-neutral traders to submit limit orders to the book and ignores execution-price risk, our limit-order submitters are risk averse and we allow a random execution price. Furthermore, he compares the limit-order book to a large number of alternative market structures, whereas our conclusions are focused on the specific alternative of a dealer market. For example, we conclude that dealerships are valuable because outsiders are constrained in the number or type of orders they may submit as well as by the costs of order submission or execution. Broadly construed, these results suggest that the introduction of a limit-order book to a dealer market such as the floor of a

Chicago-style futures exchanges or the Nasdaq system will diminish the value of dealers' right to trade.

Another purpose of our work is to compare the informational efficiency of prices across the dealer and limit-order markets. We find that prices are more informative of future cash flows and less volatile in the limit-order market. This particular comparison is supported by the empirical evidence of Dhillon et al. (1995), who measured variances and autocorrelations of daily price changes in gold futures on the Tokyo Commodities Exchange (TOCOM) before and after March 31, 1991. TOCOM held several Walrasian auctions per day during the early period, and operated as a dealer market in the later period. Estimated TOCOM variances were significantly lower in the early than in the later period, and TOCOM variances in the early period were lower than contemporaneous variances on the Commodities Exchange of New York (which is a dealer market). We believe, therefore, that although dealer markets offer continuity of trade and may generate greater volume of trade, prices in batch auctions vary less with noise and are more informative signals of value. Furthermore, our results suggest that introduction of a limit-order book to a dealer market will increase the information content of prices.

The formal structure of the dealer model is proposed in Section I of the article. The analysis of Section II focuses on price as a function of exogenous measures of informed investors and dealers; the supply of dealer services is held fixed in this section. We refer to the equilibrium with market-order submission as the "dealer market." Characterization of the equilibrium supply of dealer services in the presence of informed trade appears in Section III. The Walrasian paradigm—which we refer to as the "limit-order market"—is introduced and informational efficiency of prices is compared across limit-order and dealer markets in Section IV. The analysis of Section III assumes that risk aversions are homogeneous, so Section V reconsiders the equilibrium supply of dealer services under heterogeneous risk aversions. Section VI concludes the article.

I. The Dealer Market

This section introduces a model that merges two existing paradigms of financial markets: (i) the rational expectations equilibrium (REE) exemplified by the works of Admati (1985), Diamond and Verrechia (1981), Grossman and Stiglitz (1980), Hellwig (1980), and, more recently, Wang (1993); and (ii) the dealer market introduced by Kyle (1985) and analyzed by numerous other authors, including Holden and Subrahmanyam (1992) and Vives (1995). Like the single-period case in Kyle, the trading period of this model represents a brief interval during which dealers observe market order flow for a single risky asset on an exchange floor. Unlike Kyle, but like the REE, many heterogeneously informed speculators exist. As a result, the order flow and the asset price aggregate speculators' private information.

In a REE, there is no distinction between dealers on an exchange and speculators off an exchange. Instead, there is a Walrasian structure. Demand schedules from speculators and market orders from liquidity traders are submitted simultaneously to an auctioneer who then chooses an equilibrium price such that the aggregate excess demand is zero. A speculator does not know the equilibrium price at the time demand schedules are submitted. However, because a schedule associates a unique allocation with any price, each speculator can choose a private allocation conditional on the equilibrium price to be realized. Although it is a tradition in the literature to use "rational expectations equilibrium" as a reference to the Walrasian structure of Diamond-Verrechia, Hellwig, and other authors, this is misleading to the extent that expectations are also rational in Kyle's model, in the microstructure literature generally, and in the dealer market of this article. Our choice is to refer to the Walrasian structure as a limit-order market.

At least one attempt, Gennotte and Leland (1990), has been made to incorporate a distinct class of dealers into a limit-order market paradigm. In their model, a fixed number of dealers and speculators submit demand schedules simultaneously, but dealers have the advantage of observing a signal of the liquidity order flow. In this way, dealers are better able to infer fundamental information regarding the risky cash flow from the equilibrium price, which is a linear function of the cash flow and the liquidity trade. Our model is in the spirit of Gennotte and Leland in that dealers observe order-flow information. However, dealers in our model do not observe any private information about the value of the asset, and we allow an endogenous supply of dealer services.

There are two dates {0, 1}, and a continuum of individuals indexed by points along the interval $[0, N]$. Individuals $j \in [0, I]$, $0 \leq I < N$, are speculators outside the exchange, while the remainder, $j \in [I, N]$, are dealers, i.e., members of the exchange who trade on the floor, where an asset with random time 1 cash flow $\tilde{q}$ is traded. Let $M \equiv N - I$. All individuals have endowments of n^j units of a riskless numeraire asset, and have preferences $-\exp(-\alpha W)$ in time 1 wealth W, with constant absolute risk aversion α.

At time 0, the speculators pay C_S to receive signals $\tilde{s}^j = \tilde{q} + \tilde{e}^j$ of the cash flow $\tilde{q}$, with errors $\tilde{e}^j$. They submit market orders to the floor, with the objective of maximizing the expected utility of time 1 wealth conditional on their signal and prior information; thus:

$$\mathrm{EU}^j \equiv \underset{x^j}{\text{Maximize}}\ \mathrm{E}[-\exp(-\alpha(n^j + x^j(\tilde{q} - \tilde{p}) - C_s))|\tilde{s}_j]. \tag{1}$$

The time 0 spot price per unit of the riskless asset, $\tilde{p}$, is not known when x^j is chosen, so speculators must estimate its joint distribution with $\tilde{q}$. Let $\tilde{x}$ be the random value of the speculators' market orders per capita speculator:

$$\tilde{x} \equiv \int_{j=0}^{\mathrm{I}} \tilde{x}^j \, \mathrm{d}j/\mathrm{I}.$$

At time 0, liquidity traders, who have price insensitive demands, also submit market orders to the floor; the exogenous net flow from them is $\tilde{\phi}$. Together, speculators and liquidity traders are referred to as outsiders.

To become a dealer, each prospective exchange member pays an amount C_M. Once on the floor, the dealers commonly observe the net orders

$$\tilde{F} \equiv (\tilde{\phi} + I\tilde{x})/M, \tag{2}$$

which is in units of the asset per capita dealer. The dealers' demands may be thought of as determined in a Walrasian equilibrium after the arrival of market orders; an auctioneer accepts demand schedules from the dealers on the floor, then picks a price that clears the market, and finally allocates units of the asset according to the schedules. Dealers are atomistic, so the competitive allocation of the order flow from the problem

$$\mathrm{EU}^M \equiv \underset{y}{\text{maximize}}\ \mathrm{E}[-\exp(-\alpha(n^j + y(\tilde{q} - \tilde{p}) - C_{\mathrm{M}}))|\tilde{F}, \tilde{p}], \tag{3}$$

where the price and order flow are taken as given, is the solution to the auctioneer's allocation problem for each dealer. The price must be chosen so that the market clears, i.e.,

$$\tilde{y} + \tilde{F} = 0. \tag{4}$$

In our analysis, dealers are not privately informed, although a generalization allows them to purchase signals, say, $\tilde{s}^j$, of the asset cash flow. In this case, one solves equation (3) conditioning on $\tilde{s}^j$ in addition to the order-flow information and the market clearing is solved as in Hellwig (1980), with dealers submitting linear demand schedules, which are functions of their individual signals, to the auctioneer.

In Section II of the article, I and M are exogenously fixed. The equilibrium in the dealer market is a price $\tilde{p}$ (as a function of the exogenous variables in the economy) such that the market clears with probability one, where the orders of the speculators satisfy equation (1) and allocations of the dealers satisfy equation (3). Expectations are rational in the sense that conjectures of the speculators regarding the joint distribution of $\tilde{q}$, $\tilde{\phi}$, and $\tilde{p}$ are correct.

Prior to the time 0 signals and trading opportunities, individuals choose whether to participate in the market and, if so, whether to participate as dealers or speculators. The equilibrium consists of a market clearing price $\tilde{p}$, a measure of speculators I, and a measure of dealers M. In this equilibrium the unconditional expected utilities satisfy

$$\mathrm{E}[\mathrm{EU}^j] \leq \mathrm{E}[\mathrm{EU}^M], \tag{5}$$

which, as an equality, determines the measure of speculators relative to the measure of dealers. For some exogenous parameter values— e.g., when the cost of information is high relative to its value in trade—an equilibrium exists in which all participants act as dealers. In this case $I = 0$, (5) is a strict inequality, and the risky-asset price is informative of prior beliefs only, because there is no speculative activity. For other parameter values, (5) is an equality, $I > 0$, and the price varies with the average of speculators' signals. Finally, the measure of dealers M is determined by a comparison of an exogenous reservation level of utility $U < 0$ and the maximum utility available from dealing:

$$U = \mathrm{E}[\mathrm{EU}^M]. \tag{6}$$

Because wealth is irrelevant for the participants' investment decisions, and because only the difference in the costs $C_{\mathrm{M}} - C_{\mathrm{S}}$ is relevant to the choice between speculating and dealing, given exponential utility, n^j and C_{S} are set to zero without loss of generality. With this normalization, U is the reservation level adjusted by the cost of private information; $U = U \exp(-\alpha C_{\mathrm{S}})$ where U is the unadjusted reservation level. If U is smaller than the minimum utility achievable from either role, which can be obtained by entering and then not trading, an infinite number of individuals will enter. For this reason,

$$U \geq \max[-\exp(\alpha C_{\mathrm{M}}),\ -1]$$

is assumed. Given this normalization, a level of $C_{\mathrm{M}} = 0$ does not imply that the cost of either speculating or dealing is zero, but only that the costs are equal.

Throughout the article, the random variables $\{\tilde{q},\ \tilde{\phi},\ \{\tilde{e}^j,\ j \in [0,\ N]\}\}$ are normally and independently distributed with means $\{0, 0, \{0\}\}$ and variances $\{V, S, \{v\}\}$. Linear equilibria are examined in each of the scenarios; the endogenously determined price in the dealer market is a linear function of the order flow per capita dealer, $\tilde{p} = \lambda\tilde{F}$. The inverse of λ measures the market depth. Because price and order flow are proportional, they are equally informative of the cash flow. The results are not changed qualitatively, however, if the mean values of $\tilde{q}$ and the noise $\tilde{\phi}$ are positive. One finds that a linear price is obtained, but with a nonzero intercept.

To understand how linear equilibria are calculated, first conjecture that a speculator's order size from (1) is $\tilde{x}^j = \beta\tilde{s}^j$, where β is the speculator's aggressiveness in trading on the signal. If the law of large numbers applies, so that

$$\int_{j=0}^{I} \tilde{e}^j \, \mathrm{d}j = 0,$$

then $I\tilde{x} = I\beta\tilde{q}$ and the order flow per capita dealer is $\tilde{F} = (I\beta\tilde{q} + \tilde{\phi})/M$.[3] Given this order flow, one shows that a price

$$\tilde{p} = \lambda(I\beta\tilde{q} + \tilde{\phi})/M \tag{7}$$

[3] See Laffont (1985) for discussions of the application of the law of large numbers to a continuum of random variables. See also Admati (1985) and Vives (1995) for applications in contexts similar to ours.

together with a demand $\tilde{y}$ that is linear in $\tilde{F}$ jointly solve the dealers' problem (3) and clear the market (4). This demonstrates the validity of the linear price given the linear order $\beta\tilde{s}^j$. Given the linear price (7), one finds a solution to (1) that is of the form $\tilde{x}^j = \beta\tilde{s}^j$, with β endogenously determined. This verifies the conjecture and completes the proof.

II. Equilibrium Prices In The Dealer Market

Given that the measures of dealers and speculators are fixed in this section, it is possible to demonstrate the existence of an equilibrium with heterogeneous levels of risk aversion. So we allow $\alpha = \alpha_s$ for speculators and $\alpha = \alpha_m$ for dealers.

PROPOSITION 1: *In the economy with fixed measures I and M of speculators and dealers, respectively, a linear equilibrium described above exists, with $\beta \geq 0$ solved as the positive root of a cubic equation:*

$$f_1(\beta;\ V,\ v,\ \alpha_s,\ \alpha_m,\ I/M,\ S/M^2) = 0. \tag{8}$$

The root of equation (8) and the equilibrium β are unique when $\alpha_s = \alpha_m$. The equilibrium market depth is $1/\lambda$, where

$$\lambda = \alpha_m V B_n + B_q \qquad B_n \equiv \frac{S}{S + I^2\beta^2 V} \qquad B_q \equiv \frac{MI\beta V}{S + I^2\beta^2 V}. \tag{9}$$

All proofs are in the Appendix. The endogenous values λ and β are invariant to changes in $\sqrt{S}$, provided M and I are changed proportionally. For this reason, the results in the remainder of this section can be interpreted as if N = 1 but without loss of generality.

The depth inverse in equation (9) is the sum of two parts. The first of these captures the *inventory component* and the second the *information component* of the market depth. When dealers are risk-neutral, the inventory component is zero and $\lambda = B_q$, which is the ordinary least squares (OLS) regression coefficient of the future cash flow $\tilde{q}$ on the order flow $\tilde{F}$. The spot price $\tilde{p}$ is the expected value of the cash flow conditional on the order flow, as it is in Kyle (1985). Furthermore, with $\alpha_m = 0$, this model is equivalent to a single round of trade in Vives's (1995) work with risk-neutral dealers. Alternatively, when dealers are risk averse and either the measure of speculators is zero ($I = 0$) or the volatility of liquidity orders is large ($S \to \infty$), the order flow is uninformative, i.e., $\beta = 0$. In these cases, the market depth is $1/(\alpha_m V)$, which is the depth under pure risk sharing, and this measure declines with the risk aversion of the dealers and the unconditional volatility of the future cash flow.

B_n is the OLS regression coefficient of the net liquidity orders $\tilde{\phi}$ regressed on the order flow $\tilde{F}$ and its value determines the extent to which the dealers' risk aversion matters. Unlike the speculators, dealers face no execution-price risk, and their inventory risk is determined solely by the conditional (on $\tilde{F}$) volatility of the future cash flow $\tilde{q}$. If order flow is completely uninformative ($\beta = 0$ or $I =$

0), then the conditional and unconditional volatilities are equal to V, and B_n is equal to one. Alternatively, if the order flow is very informative and the future cash flow is precisely known by the dealers, then their inventory risk is small and B_n is near zero. Note that as far as a dealer's inventory risk is concerned, liquidity orders are important here only to the extent that they hide the information in the order flow. However, a second effect exists in a multi-period setting, where $\tilde{q}$ is an endogenous end-of-period price that varies with the noise. The inventory risk increases with the volatility of noise. Within the formalism of this model, one might think of this effect as a positive relation between V and S.

The existence of orders from speculators has two effects on market depth (cf. Grossman 1986). On the one hand, they tend to decrease the depth because dealers have to protect themselves from being taken advantage of by the informed. On the other hand, inventory risk decreases and the depth increases as dealers become better informed about future cash flows. Without informed trades, there is no adverse selection, but dealers' inventory risk is at its maximum. With very risk-tolerant speculators, dealers face severe adverse selection, but their holding cost is minimal. In the extreme case of this model where speculators are risk neutral ($\alpha_s = 0$) and trade aggressively, the depth is $1/(\alpha_m V)$,[4] which is identical to the depth under pure risk sharing ($I = 0$). Even though the depth is identical in the two cases, informational efficiency is very different. Current price is completely uninformative of the future cash flow in the second case ($I = 0$) and very informative in the first ($\alpha_s = 0$).

In one of the settings studied by Subrahmanyam (1991), there exist risk-neutral dealers and a finite number of identically informed and risk-averse investors. That setting is a special case of this model, except that here investors exist as points on a continuum. (Because of risk neutrality, the number of dealers is indeterminate in either case.) Corollary 1 (a corollary to Proposition 1 found in the Appendix) establishes an equivalence between this model and the limit of Subrahmanyam's model as the number of investors increases to infinity. This result provides an example in which the impact of any investor's trade on the aggregate order flow and the endogenous price is nearly irrelevant in a large market, so that price behavior in the large but finite market may be approximated by the ideal of the continuum.

III. The Supply Of Dealer Services

The purpose of this section is to generalize the dealer market by allowing an endogenous supply of dealer services. We view the questions "Who goes to the floor?" and, in regard to those on the floor, "Who scalps, who day trades, and who brokers?" with considerable interest. However, the equilibrium of dealer services is most easily analyzed under the assumption that the risk tolerances of all participants are equal, i.e., $\alpha_m = \alpha_s = \alpha$. (A discussion of the case with heterogeneous risk aversions appears in Section V.) Prior to trade, identical

[4] This is shown in the Appendix.

individuals choose between dealing, speculating, and an exogenous alternative offering the level of utility U; the difference in cost between dealing and speculating is C_M. An equilibrium is a measure of dealers M, a measure of speculators I, and a price $\tilde{p}$ such that conditions (4)–(6) hold.

PROPOSITION 2: *In the economy with endogenous market participation and quantity of dealer services, an equilibrium with a linear price function exists and is unique. The price function satisfies Proposition 1. The measure of dealers is*

$$M = \alpha(SV/U_2)^{1/2}, \tag{10}$$

and the measure of speculators may be either zero or positive. When the measure of speculators is positive ($I > 0$), *the ratio* I/M *is given by the unique positive root of the quadratic*

$$A_2(I/M)^2 + 2A_1 I/M + A_0 = 0, \tag{11}$$

where

$$A_2 \equiv U_1(U_1 + 1)^2 Q/U_2 > 0,$$

$$A_1 \equiv U_1(U_1 + 1) > 0,$$

$$A_0 \equiv U_1(U_2 + 1)(1/Q - 1) + U_1 U_2 - 1,$$

$$Q \equiv \frac{V}{V + v} = 1 - \frac{\mathrm{Var}[\tilde{q}|\tilde{s}^j]}{\mathrm{Var}[\tilde{q}]}$$

$$U_1 \equiv 1/U^2 - 1$$

$$U_2 \equiv \exp(2\alpha C_M)/U^2 - 1.$$

The measure of speculators is positive if and only if $A_0 < 0$, *or alternatively,*

$$(1/U^2 - 1)\exp(2\alpha C_M) < Q. \tag{12}$$

In an equilibrium with $I > 0$, *a cost-adjusted equality of variances conditional on speculators' and dealers' information sets,*

$$\mathrm{Var}[\tilde{q} - \tilde{p}|\tilde{s}^j]\exp(2\alpha C_M) = \mathrm{Var}[\tilde{q} - \tilde{p}|\tilde{F}], \tag{13}$$

is equivalent to the equality of utilities $\mathrm{E}[EU^j] = \mathrm{E}[\mathrm{EU}^{\mathrm{M}}]$.

A dealer's primary business on an exchange floor precludes time spent searching for and analyzing information that outsiders obtain directly. The information in the dealer's order flow is imperfect to the extent that orders from those trading for reasons that are (at least partially) unrelated to information, i.e., liquidity traders or hedgers, cannot be distinguished from orders of informed traders. Bagehot (1971), Kyle (1985), and Glosten–Milgrom (1985) note that, for these reasons, dealers are possibly less informed than others. On the other hand, the flow of orders over any period of time might be used to aggregate the information of multiple speculators, so it is possible that a dealer is better informed than outsiders.

In the present setting an equality of information sets (13) exists, whenever speculators are present and the costs of dealing and speculating are equal ($C_M = 0$). Participants are indifferent between the two roles, the speculator and the dealer, if the information in the order flow regarding the price difference $\tilde{q} - \tilde{p}$ is equivalent to that obtained by any speculator.[5] When the cost of dealing is greater than the cost of private information ($C_M > 0$), a dealer is better informed than a speculator in equilibrium, and the difference provides sufficient revenue from trade to cover the cost of dealing. Alternatively, when private information is more costly ($C_M < 0$), a speculator is better informed in equilibrium than a dealer. A similar equilibrium arises when speculators have heterogeneous costs of signals, except that the gain of the marginal speculator is equivalent to that of any dealer; any participant with a cost lower than the margin speculates and obtains rents from doing so.

The existence of dealers is a necessary condition for the equilibrium of Proposition 2. Without their services, market clearing is not possible. The same cannot be said for speculators, however. From equation (12), the measure of speculators is zero if U is large (i.e., close to zero), C_M is large, or Q is low. Because market depth is a critical determinant of the cost of trade, speculators do not trade when the incentives for dealing and therefore the supply of dealer services are poor. Lucrative alternatives to dealing on the exchange floor (large U) or high seat prices or cost of capital (large C_M) lead to poor depth. Similarly, the quality of fundamental information is a critical determinant of speculators' willingness to gather information. Quality is nicely represented in equation (12) by Q, which is confined to the unit interval and is decreasing with the precision of private information. As a measure of relative quality, Q is the proportional reduction in the prior variance conditional on the signal $\tilde{s}^j$ being observed. From equation (12), $I = 0$ if Q is low. In summary, speculators do not trade when their information is poor and their expected profits are insufficient to cover their costs, which include both the effort of gathering information and the execution-price risk.

An alternative interpretation is available if we consider speculators here as trading on fundamental information—e.g., signals regarding future dividends—and if we consider dealers as technical analysts trading on order-flow information. Note that when the quality of fundamental information is poor, or the cost of fundamental information is high, then equation (12) does not hold and there are no speculators in the market. All rational traders are technical analysts.

A nonzero measure of speculators as a proportion of the measure of dealers—i.e., I/M—is given by the unique positive root of equation (11). It is a function

[5] Grossman and Stiglitz (1980) derive a similar equivalence in a limit-order market with costly information. They show that a cost-adjusted equality of information sets obtains if and only if the utilities of informed and uninformed traders are equal in equilibrium.

only of the reservation utility levels, via the values U_1 and U_2, and the quality of information Q. From equation (10), the measure of dealers M is proportional to and increasing with the quantity $\alpha(SV)^{1/2}$, and it follows from equation (11) that I is as well.[6] Further examination of equations (10) and (11) provides the following separation results:

COROLLARY 2: *In the dealer market with endogenous participation, the relative measure of speculators I/M is independent of the level of liquidity trading. Given a constant quality of information Q, I/M is also independent of the cash flow volatility V. Similarly, given a constant V, the supply of dealer services M is independent of the quality Q of speculators' information, and is independent of the measure of speculators once V, U_1, and U_2 are fixed.*

Certainly the depth of the market $1/\lambda$ and therefore the cost of trade for the liquidity traders depend upon the degree of information in the order flow. As in Kyle (1985), the equilibrium depth is set here so that the dealers' prospective losses to speculators are covered by the gains from the liquidity traders. The equilibrium supply of dealers, however, is determined as if there are no speculators and only liquidity traders exist in the market.

Given a reservation level $U = -1$, equation (10) is identical to equation (19) of Grossman and Miller (1988) (GM), with one exception. Because there is no informed trade in GM, they find that $M + 1$ (and not M) is equal to $\alpha(SV/U_2)^{1/2}$. An explanation lies in the difference of order flow characteristics of the alternative models. Here, outsiders submit market orders and cannot condition their trades on the order imbalance; only dealers can "make a market." In contrast, the outsiders of GM submit demand schedules to the floor and, given their rational expectations, choose schedules that recognize variations in price due to the liquidity trades. In this case, the dealers have no informational advantage relative to the speculators, and each speculator provides dealer services as well as any dealer. The size of the speculators is 1 in GM, so $M + 1$ is the effective measure of dealers in their model.

An alternative way to view the results of Proposition 2 is to fix the measure of dealers M and then calculate the equilibrium level of C_M. With this revision, C_M is the value of a dealer's seat on an exchange (relative to the cost of speculative information).

Corollary 3: *For a fixed M, the equilibrium value of a dealer's right to trade is*

$$C_M = \frac{\ln(-U)}{\alpha} + \frac{\ln(1 + \alpha^2 SV/M^2)}{2\alpha}. \tag{14}$$

C_M is decreasing with the number of dealers and independent of the quality of speculators' information. C_M is also increasing with the volatility of liquidity trade; this result is consistent with the evidence of Schwert (1977) and Chiang et al. (1987). Whereas Schwert examines NYSE and American Stock Exchange

[6] U_2 is a function of risk aversion a. Variation in risk aversion can be offset by variation in the relative cost C_M, so that U_2, U_1, and all exogenous parameters remain constant.

(AMEX) data and Chiang et al. study commodity exchange data, each of these studies demonstrates that changes in exchange seat prices are positively related to unexpected changes in the volume of trade. Perhaps a more interesting prediction of Corollary 3 is that C_{M} is increasing with V, i.e., exchange seats fluctuate positively through time as a function of price volatility when the number of seats and the level of order flow are held constant. This suggests that dealers in financial markets follow volatility, shifting their willingness to make markets toward those securities with the greatest price volatility. To our knowledge, the relation between seat prices and price volatility remains untested.

The equilibrium levels of the measure of dealers M and their unconditional expected utility $\mathrm{E}[\mathrm{EU}^{\mathrm{M}}]$ are each independent of the quality of information, but this does not imply that dealers ignore the information in the order flow $\tilde{F}$. When choosing their trades and inventory, dealers use the conditional distribution of the cash flow $\tilde{q}$. If an individual dealer irrationally chose to use the unconditional distribution instead, he or she would trade less aggressively and would obtain a level of utility lower than the reservation level U. At the same time, $\tilde{F}$ is a signal of $\tilde{q}$ that is observed without cost by all dealers, the market in which dealers operate is perfectly competitive, and entry to the floor is unrestricted aside from payment of C_{M}. As a result, dealers receive no economic rent despite the fact that they condition their decisions on observation of the order flow $\tilde{F}$. Their equilibrium utility level is equal to their reservation level U.

IV. Market Efficiency And Market Structure

Many definitions of the efficiency of a financial market can be found in the literature, although a common feature of many of these alternatives is that they capture or measure the information content of current prices regarding future cash flows.[7] One measure of efficiency in this model is the difference of one and the ratio of conditional (on $\tilde{p}$) to unconditional variances of the cash flow $\tilde{q}$:

$$\mathscr{E} \equiv 1 - \frac{\mathrm{Var}[\tilde{q}|\tilde{p}]}{\mathrm{Var}[\tilde{q}]} = 1 - B_{\mathrm{n}} = \frac{I^2\beta^2V}{S + I^2\beta^2V}. \tag{15}$$

The measure $\mathscr{E}$ takes values on the interval [0, 1], and the extreme values represent complete informational inefficiency or efficiency. It is zero (one) when $\tilde{p}$ is completely uninformative (perfectly informative) of the cash flow $\tilde{q}$. We will show that the dealer market is less efficient than a limit-order market with an equal number of participants.

To understand the comparison, consider the model of Section I, but allow speculators to submit demand schedules instead of market orders. Let R be the total measure of participants and J be the measure of them receiving signals

[7] See Brown and Jennings (1989) for a discussion of various definitions of market efficiency.

$\tilde{s}^j$. This is equivalent to a specific case of Hellwig's (1980) model, where a finite proportion $(R - J)/R$ of the agents are uninformed and the remaining proportion J/R receive signals $\tilde{s}^j$ of equal precisions. Let each of these individuals, as well as all participants in Proposition 1, have risk aversion α. Each of the informed in Hellwig's model solves

$$\mathrm{EU}^r \equiv \underset{x^j}{\text{Maximize}}\ \mathrm{E}[-\exp(-\alpha x^j(\tilde{q} - \tilde{p}_r))|\tilde{s}^j, \tilde{p}_r], \tag{16}$$

while each uninformed trader solves the same problem, except that traders' information set includes the equilibrium price $\tilde{p}_r$ but no private information. Note again that the dealers observe only the price in the dealer market, so the uninformed traders play their role in the limit-order market. The market clearing condition is identical to expression (4).

In practice, a market order to a financial exchange specifies a fixed quantity of an asset to be bought or sold at the best possible price, while a limit order specifies a limit price; a limit buy order, for example, is executed if the purchase can be fulfilled at a price less than or equal to the limit price. A single limit order is not equivalent to a demand schedule, but multiple orders with different limits can be used to approximate the schedule. In the ideal case, where submission and execution of orders is costless and there are no discrete ticks between prices, an outsider can simultaneously submit an infinite number of infinitesimal limit orders to create a continuous demand schedule. Therefore, Hellwig's model is reasonably interpreted as an open limit-order book in the sense of Glosten (1994).

Informed traders using limit orders face less execution-price risk and therefore trade more aggressively on their information than when only market orders are available. For this reason, one expects the price in a market where limit orders are allowed or encouraged, as a substitute or a complement for market orders, to be more informative than prices in a dealer market. In addition, one expects informational efficiency to increase with the number of limit orders one can submit for a given cost.

PROPOSITION 3: *Informational efficiency in the limit-order market is given by*

$$\mathscr{E}_r \equiv 1 - \frac{\mathrm{Var}[\tilde{q}|\tilde{p}_r]}{\mathrm{Var}[\tilde{q}]} = \frac{(J/av)^2V}{(J/av)^2V + S}.$$

Given equal numbers of participants $(R = N)$ *and equal numbers of informed* $(J = I)$, *the limit-order market is more efficient than the dealer market, i.e.,* $\mathscr{E}_r > \mathscr{E}$.

Because speculators in the dealer market do not condition their demands on the price $\tilde{p}$, they are unable to make a market for the liquidity traders and hedgers. The volatility of the spot price equation (7) is determined, in part, by the willingness of the dealers on the floor to bear the risk of the orders $\tilde{\phi}$, which they take into their inventory in equilibrium. In comparison, all traders share

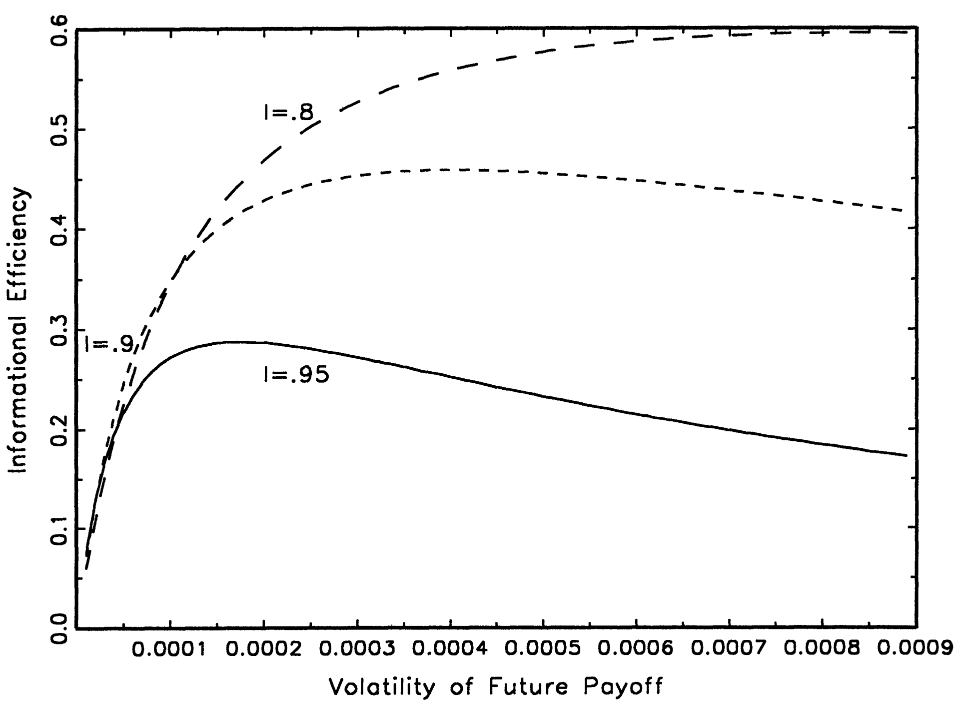

Figure 1. Informational efficiency. Informational efficiency (see equation (15)) is shown as a function of the unconditional variance of future payoff V. The values of parameters other than V are $\alpha_s = \alpha_m = 1$, $S = 4$, $v = 0.005$, and $N = 1$, while the alternative lines represent proportions of speculators I = 80 percent, 90 percent, and 95 percent, respectively.

this risk in the limit-order market, and for this reason the depth and the informational efficiency are larger than in the dealer market.

Levels of efficiency $\mathscr{E}$ in the dealer market as a function of V are displayed in Figure 1 using three alternative measures of speculators. The precision of speculators' signals and the execution-price risk rise with V, ceteris paribus. The aggressiveness of speculator trade and $\mathscr{E}$ are positively (negatively) related to the first (second) effect. On net, $\mathscr{E}$ rises with V for low initial values; only in this range does the first effect outweigh the second. Furthermore, across the three cases shown, $\mathscr{E}$ declines with the measure of speculators for high levels of volatility, while the opposite relation holds at low levels of the volatility.

Figure 2 provides a comparison of efficiency across the limit-order and the dealer market structures. The *efficiency ratio* is defined by $\mathscr{E}/\mathscr{E}_r$, i.e., efficiency in the dealer market divided by that in the limit-order market. The calculation of the ratio takes the exogenous parameters as equal across the two mechanisms—for example, the uppermost curve represents the case that the measure of the informed is $I = 0.80$ in each of the two mechanisms—and the only difference is the type of orders submitted by the informed.

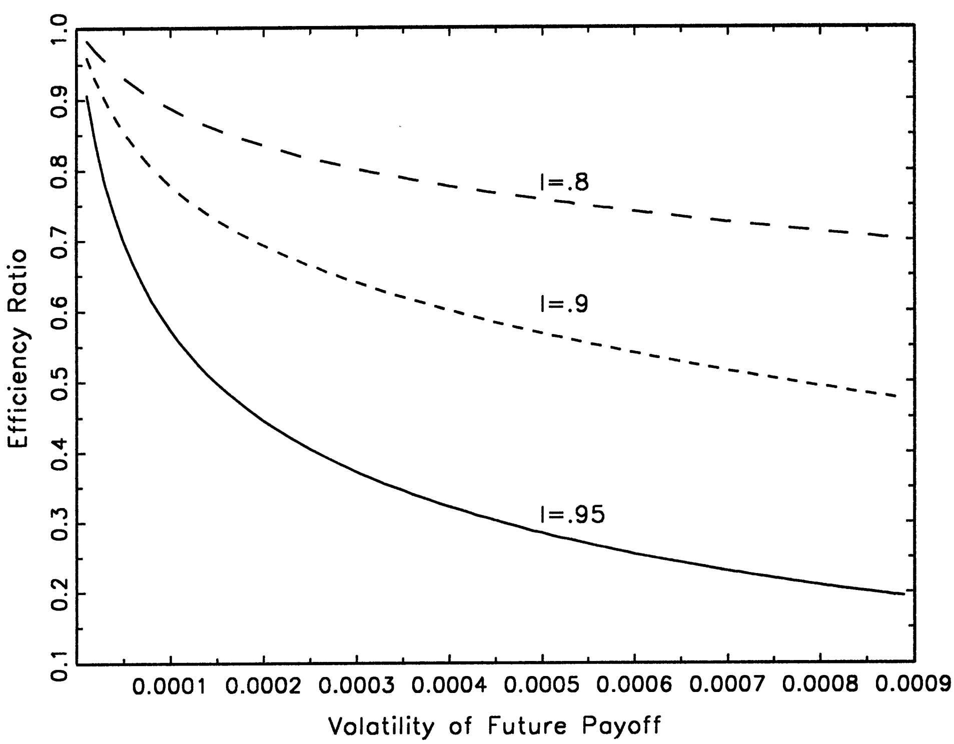

Figure 2. Efficiency ratios—no entry. The efficiency ratio, i.e., the informational efficiency (see equation (15)) in the dealer market divided by that in the limit-order market is shown as a function of the unconditional variance of future payoff V. The cases shown are identical to those of Figure 1. The values of parameters other than V are $\alpha = 1$, $S = 4$, $v = 0.005$, and $N = 1$, while the alternative lines represent proportions of speculators $I = 80$ percent, 90 percent, and 95 percent, respectively.

The efficiency of the dealer market relative to the limit-order market declines with the cash flow volatility V. One part of an explanation is the fact that private information becomes more precise in either market (because v is held constant as V changes in this comparative static analysis), which increases the information in the order flow. A countervailing effect in the dealer market is an increase in execution-price risk, so that speculators trade less aggressively as cash flow volatility increases; in the limit-order market there is no execution-price risk. Figure 1 demonstrates that for high levels of volatility, the execution-risk effect dominates and $\mathscr{E}$ declines with V in the dealer market. A similar demonstration for the limit-order market would show that $\mathscr{E}_r$ increases monotonically with volatility. Together, these effects imply that the relative efficiency $\mathscr{E}/\mathscr{E}_r$ declines with V in Figure 2.

The ratios $\mathscr{E}/\mathscr{E}_r$ also decline as the measure of dealers declines relative to size of the informed trade in the dealer market; recall that uninformed traders submitting demand schedules in the limit-order market are the counterpart of the dealers. Again, execution-price risk is one determining factor. A decline in dealer services increases the sensitivity of the current price to the order flow, increases the execution-price risk, decreases the aggressiveness of speculative trade, and therefore decreases $\mathscr{E}$. In particular, $\mathscr{E}$ declines despite the fact that the total measure of informed traders *increases* as the measure of dealers declines. In comparison, $\mathscr{E}_r$ is increasing with I across the curves in Figure 2 (from top to bottom).

A. Efficiency and the Supply of Dealer Services

A.1. Informational Efficiency

One expects that a change in the supply of dealer services over sufficiently long periods of time—e.g., an increase in the number of locals in a futures pit, the capital of a specialist on a stock exchange or the volume of limit orders—will ameliorate volatility-induced changes in the level of inventory risk and the information content of prices. This idea is investigated in this section by a comparison of informational efficiency across the dealer and limit-order markets in which the measure of participants is endogenous.

In Section III, U is the utility of an individual who does not participate in the dealer market adjusted for the cost of information C_s. Conditions for participation in the dealer market are equations (5) and (6), and the equilibrium measures of dealers and speculators are calculated in equations (10) and (11) respectively. Recognizing that our comparison here is across market structures, the cost of fundamental information in the limit-order market is set equal to that in the dealer market. This implies that U is also the information-adjusted reservation utility of a limit-order market participant. It is possible to assume differential costs in the limit-order market for those with and without information, but this is not done here to maintain simplicity; all participants are informed ($R = J$), and the condition for the number of participants R is

$$\mathrm{E}[\mathrm{EU}^r] = U, \tag{17}$$

where EU^r is defined in equation (16). This equality leads to the following result.

PROPOSITION 4: *In the limit-order market with informed participants only ($R = J$), the number of participants R is determined by the equality*

$$\frac{(1 - Q)SV(Q(R/\alpha)^2 + SV(1 - Q))}{(R/\alpha)^2(Q^2(R/\alpha)^2 + SV(1 - Q))} = U_1. \tag{18}$$

An explicit solution for R^2 is obtained as the root of a quadratic equation (18). Like the solution for the measure of dealers M in equation (10), (18) demonstrates that R is proportional to $\alpha(SV)^{1/2}$. A simple solution analogous to equation (10) is available only when the signal quality is either zero or infinite. If $Q = 0$ and if $C_M = 0$ (which implies $U_1 = U_2$), then $R = M$. Alternatively, $R \to 0$ *as* $Q \to 1$.

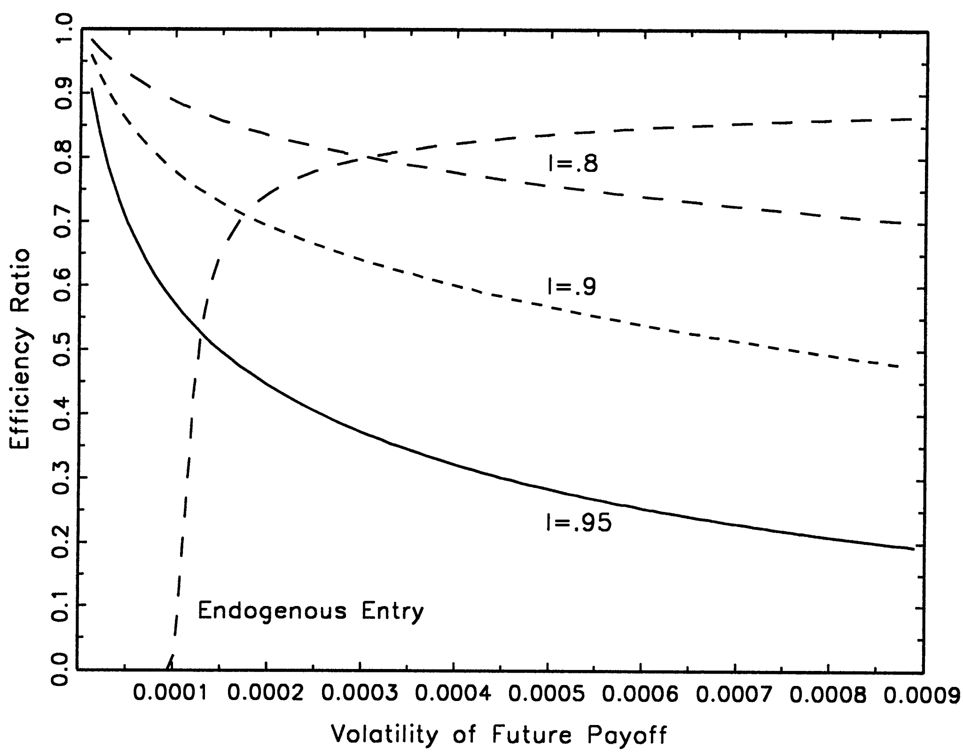

Figure 3. Efficiency ratios—endogenous entry. The efficiency ratio, i.e., the informational efficiency (see equation (15)) in the dealer market divided by that in the limit-order market is shown as a function of the unconditional variance of future payoff V. The cases shown are identical to those of Figure 2, with the addition of the case of endogenous entry. The alternative lines represent cases where the proportions of speculators are I = 80 percent, 90 percent, and 95 percent, and the case where I varies with V.

In Figure 3, the efficiency ratio with endogenous entry is overlaid on the ratios of Figure 2. Recall that in this comparative analysis, V varies while the other parameters, including v, are held constant. For this reason, both the unconditional volatility of the cash flow and the measure of information quality Q increase from left to right in the figure. Because the figure shows $\mathscr{E}/\mathscr{E}_r < 1$, it is obvious that the efficiency of the dealer market is below that of the limit-order market, even in the case with endogenous entry. A major difference across the cases, however, is that the relative efficiency increases with V, whereas if I and M are held constant the relative efficiency declines. This difference is explained by the relative levels of execution-price risk. With no entry into the dealer market, dealer inventory risk (per unit of the asset held) increases with V, so dealers cut back their willingness to hold the asset. In equilibrium, the expected absolute return given any level of liquidity trade increases, implying that execution-price risk increases. Speculators submitting market-order cut back their aggressiveness, β, and the information in the price declines. At the same time, deviations in price are profitable opportunities for the dealers (because they condition their demands on $\tilde{p}$), and ex ante expected utility from participation as a dealer increases with V. Given the opportunity to enter, the measure of dealers increases with V. The net result is that with entry the execution-price risk declines, while β and $\mathscr{E}/\mathscr{E}_r$ both increase as the volatility of $\tilde{q}$ increases.

A.2. Transaction Costs

Outsiders with immediate needs to trade are likely to use market orders, as opposed to limit orders, which may not be executed. Market orders $\tilde{\phi}$ in this article represent the price-insensitive demand of these outsiders. Up to this point, efficiency is defined by equation (15), which captures the informational efficiency of market prices. An alternative notion is the measure of the cost of the liquidity trading used by Admati and Pfleiderer (1991) and by Pagano and Röell (1996). One expects uninformed, market-order traders to "get a fair deal," i.e., to trade at prices close to fundamental values in a relatively efficient market. If they lose in trade to speculators and dealers so that their transaction costs are high, then one is tempted to say that the market is inefficient. In this section, the liquidity costs are compared across dealer and limit-order markets.

The profit per unit of trade is $\tilde{q} - \tilde{p}$, so the expected losses of liquidity traders in the dealer and limit-order markets are

$$L \equiv -\mathrm{E}[\tilde{\phi}(\tilde{q} - \tilde{p})] = \lambda S/M,$$

$$L_r \equiv -\mathrm{E}[\tilde{\phi}(\tilde{q} - \tilde{p}_r)] = b_3 S, \tag{19}$$

respectively, where b_3 is given in the proof of Proposition 3. Figure 4 portrays these losses as a function of the quality of information; only the signal-error volatility v is varied in this analysis. The height of the solid curve is L in the dealer market, where the measure of dealers is equation (10) and is independent of the quality of information, and the measure of speculators satisfies equation (11). The losses in the dealer market without speculation ($I = 0$) but with a measure of dealers satisfying equation (10) are shown by the horizontal line. Because dealers' allocations are the outcome of a Walrasian competition, the horizontal line also represents losses in the limit-order market with only uninformed participants. The dashed curve shows the losses L_r in the limit-order market with the measure of informed participants satisfying equation (17).

Because Grossman (1986) argues that informed trade can reduce the inventory risk of a dealer, one is tempted to conjecture that the existence of speculators improves the terms of trade in a dealer market. But this conjecture does not hold here. The fact that the solid curve is everywhere above the line shows that the existence of speculation adds to the liquidity costs. An alternative conjecture, which does hold for some parameter values, is that the losses decline with an increase in the quality of speculators' information. Note that L

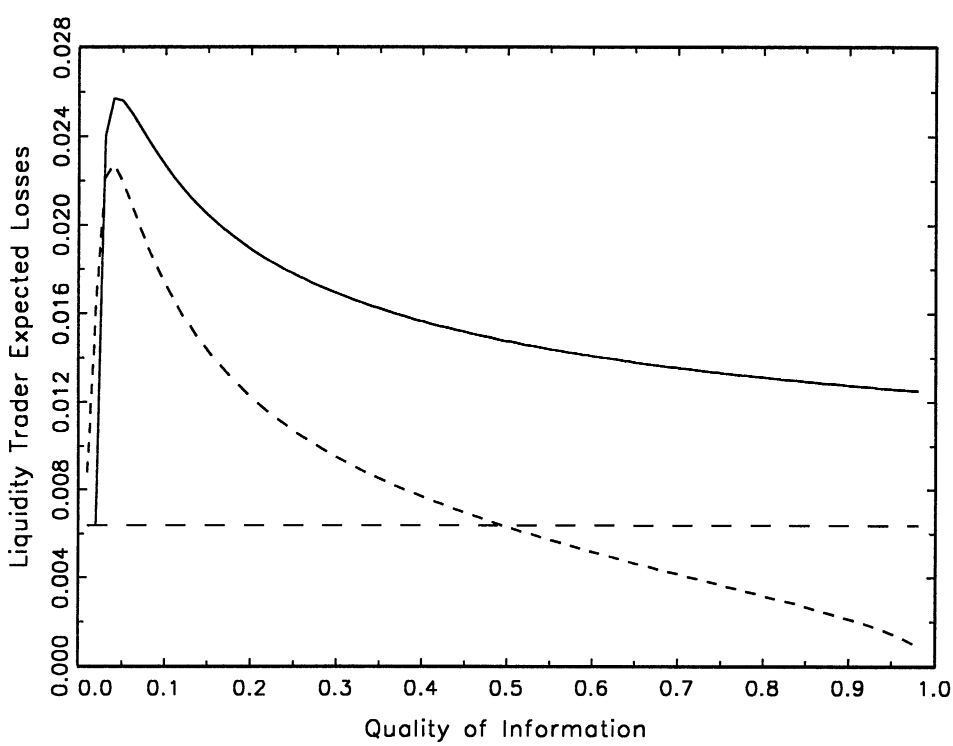

Figure 4. Transaction costs. The expected losses of liquidity traders as determined by the quality of information Q (defined in Proposition 2). The solid curve represents the dealer market (see L in equation (19)) with endogenous participation, while the horizontal line is the case with pure risk sharing, i.e., $I = 0$, and with M equal to the measure of dealers in the endogenous case. On the dashed curve are losses in the limit-order market (see L_r in equation (19)) with endogenous participation and private information; condition (17) of the text determines the number of participants. The values of the parameters other than v (which is varied) are $\alpha = 1$, $S = 4$, $V = 0.0005$, $U = 0.99$, and $C_m = 0$.

increases with Q given low initial values, but declines from high initial values.[8] In addition, Figure 4 demonstrates that *Grossman's conjecture may hold in the limit-order market* and that, unlike the conclusion of Proposition 3 regarding relative informational efficiency, the liquidity costs of the dealer market are sometimes lower than those of the limit-order market. Specifically, L_r is below the horizontal line for large Q, and is above L for small Q.

One conclusion is that the inference drawn from a comparison of liquidity traders' costs across market structures depends on the quality of private information. For example, when the quality is low, some speculators choose not to trade in the dealer market due to the execution-price risk, but choose to trade in the otherwise equivalent limit-order market. A smaller number of

[8] Figure 3 of Subrahmanyam (1991) demonstrates this same phenomenon, given risk-neutral dealers and a large, finite number of speculators.

informed traders in the dealer market implies a lower degree of adverse selection and a lower liquidity cost. This is despite the fact that the informational efficiency in the limit-order market is higher.

This particular conclusion drawn from Figure 4 differs slightly from that of Pagano and Röell, who also examine liquidity costs and market structures. Liquidity costs are lower in their transparent auction market—which has a trading structure identical to our limit-order market—than in their dealer market. One explanation is the respective natures of the informed trade. Speculators here are small and competitive, so some leave when Q is low, while a single informed trader appears in their analysis. A second difference is the existence of execution-price risk in our dealer market that does not exist in theirs.

V. Heterogeneous Risk Aversion and the Supply of Dealer Services

Aside from Section II, it is assumed throughout the prior analysis that participants are equally risk averse. Here we present a formal analysis of the equilibrium of dealer services in the case of heterogeneous risk aversion and with a fixed measure of participants $N = 1$. This provides a partial answer to the question, "Who chooses to deal, and who speculates?"

With normally distributed prices and exponential utility, the quantities traded by speculators and dealers are proportional to risk tolerance. This suggests that the aggressiveness parameter β can be redefined relative to the earlier analysis, so speculators' demands are now written $\tilde{x}^j = \beta\tilde{s}^j/\alpha_j$, where β is homogeneous across speculators. Similarly, in earlier sections I and M are the measures of participants acting as speculators and dealers respectively, but here I and M are the aggregate risk tolerances of these subsets of participants, viz.,

$$I \equiv \int_{j\in\Omega} \frac{1}{\alpha^j}\,\mathrm{d}j, \tag{20}$$

and

$$M \equiv \int_{j\in\Psi} \frac{1}{\alpha^j}\,\mathrm{d}j = \int_0^1 \frac{1}{\alpha^j}\,\mathrm{d}j - I \equiv T - I,$$

where Ω and Ψ are the subsets of [0, 1] that represent the participants in speculator and dealer roles, respectively, and T is the aggregate risk tolerance of all participants. Finally, we assume that the following condition holds:

$$\int_{j\in\Omega} \frac{\tilde{e}^j}{\alpha^j}\,\mathrm{d}j = 0.[9]$$

[9] See footnote 3.

An equilibrium is defined by a price such that the market clears, and by an allocation of the participants across the two roles. With our reinterpretation of I, M, and β, it is shown that Proposition 1 describes the equilibrium price when risk aversion is heterogeneous across participants. The equilibrium allocation is determined by the condition that no participant is better off switching roles. As in Proposition 2, it is possible that all participants deal and none speculate. For example, if execution-price risk is large, no participant speculates, $M = T$ and $I = 0$. The more interesting case is when $I > 0$, so this condition is assumed in the following proposition:

PROPOSITION 5: *With heterogeneous risk aversions and with the number of participants fixed ($N = 1$), the equilibrium β and λ are given by Proposition 1 with unitary risk aversions, i.e., with $\alpha_s = \alpha_m = 1$. The aggregate risk tolerance of speculators is $I = T - M$, and the aggregate risk tolerance of dealers is defined by a positive root M of a polynomial equation (defined in the proof). In equilibrium: (a) if $C_{\mathrm{M}} = 0$, all participants are indifferent between speculating and dealing, (b) if $C_{\mathrm{M}} > 0$, the risk tolerance of any dealer is greater than that of any speculator, and (c) if $C_{\mathrm{M}} < 0$, the risk tolerance of any dealer is less than that of any speculator.*

Consider first the case that $C_{\mathrm{M}} = 0$. In this setting, the aggregate risk aversions of both speculators and dealers are determined in equilibrium, but not the measures of these two groups of participants, which are $\int_{j\in\Omega} \mathrm{d}j$ and $\int_{j\in\Psi} \mathrm{d}j$, respectively. Because it is possible to vary these measures while leaving I and M fixed, an equilibrium in which the least risk-averse participants are dealers coexists with one in which the most risk-averse deal. In the former equilibrium, the measure of dealers is relatively small and every dealer trades aggressively, whereas in the latter a relatively large supply of dealers exists and each bears a small amount of risk. The total risk-bearing capacities of the dealer community in the two equilibria are identical, resulting in the same market depth and efficiency $\mathscr{E}$.

Alternatively, the equilibrium measure of dealers is unique when a cost differential exists between speculating and dealing. This measure can be characterized as if there is a central planner allocating participants to roles such that (i) the total cost of dealing and speculating, i.e.,

$$(C_M + C_s)\int_{j\in\Psi} \mathrm{d}j + C_s\int_{j\in\Psi} \mathrm{d}j,$$

is minimized; (ii) participants' rationality constraints are satisfied; and (iii) the aggregate risk tolerance of dealers satisfies the equilibrium condition of Proposition 5.[10] For example, consider the case in which $C_{\mathrm{M}} > 0$, and let α_k be the

[10] In this representation of total cost, C_{M} is the difference in costs between dealing and speculating per participant, C_{S} is the cost of speculating per participant, and we allow the possibility that $C_{\mathrm{S}} > 0$. The integrals are the measures of dealers and speculators.

risk aversion of a marginal participant k who is indifferent between dealing and speculating. The risk aversion of this participant and the aggregate risk tolerances of speculators and dealers are simultaneously determined by the equilibrium conditions. Because their risk-adjusted expected profit per unit of trade is larger, risk-tolerant participants (i.e., $\alpha_j < \alpha_k$) choose to deal in equilibrium, whereas the relatively risk-averse ($\alpha_j > \alpha_k$) choose to speculate. Therefore, the measure of dealers required to achieve the equilibrium level of aggregate risk tolerance M is less than it would be if the least risk tolerant chose to deal instead. The converse holds for the case in which speculating is more costly. In either case, risk-tolerant participants take the role that requires the larger cost, allowing the measure of participants in the high-cost role to be minimized while holding M and I fixed.

These results offer a partial understanding of the character of the membership of exchanges. For concreteness, consider a Chicago-style pit exchange, where locals act as dealers. Although an increase in the number of locals increases aggregate risk tolerance on the floor and lowers inventory costs, which benefits customers off the floor, other costs of trade on the exchange grow with the number of locals. Obviously, the cost of the physical facility grows with their number. A less obvious concern is fragmentation of the market within a pit; because it is difficult, if not impossible, to communicate from one side to the other, simultaneous execution prices will differ across an excessively large pit.[11] Interestingly, the cost of increased market fragmentation due to the addition of locals in a pit—that cost being primarily a reduction in the willingness of outsiders to trade and in their volume of trade—is borne collectively, and not fully by the entrants. Therefore an exchange organizer has an incentive to limit membership to the exchange. Sufficiently stringent limits lead to high seat prices, which in turn (recognizing Proposition 5) attract a community of locals who are more risk tolerant than the average speculator.

VI. Concluding Remarks

This article examines the supply of dealer services and the informational efficiency of prices in a dealer market. The formal analysis brings together two important strands of literature, the limit-order models of Diamond-Verrechia (1981) and Hellwig (1980) and the dealer model of Kyle (1985). A comparison is made of efficiency in limit-order and dealer markets. Conditions are described such that exchange members who observe market-order flow are more or less informed than the average trader off the floor, and we show how an informational advantage contributes to the value of exchange seats and leads to an equilibrium of dealer services. This leads to a characterization of individuals who choose to deal in a competitive market.

[11] There is no fragmentation of order flow in our dealer market. All dealers commonly observe the aggregate orders. One considers fragmentation by introducing a random division of the order flow $\tilde{\phi}$ across dealers.

The analysis has assumed that the costs of information are equal across speculators and that the precisions of their signals are identical, but an equilibrium with heterogeneous costs and precisions is easily analyzed. The primary change is that the equality of information sets (13) becomes the defining characteristic of the marginal speculator. Participants with low costs or high signal precisions choose to speculate; for them, equation (13) holds as an inequality.

An analysis of multiple markets—i.e., pits on a single exchange—promises to be an interesting extension of this model; in the analysis of this article, only one market exists. One expects to find, for example, that an increase in the trading volume or price volatility in one pit attracts locals from the other pits, and that the liquidities of markets in different contracts or assets on a single exchange are jointly determined. Furthermore, exchange members' welfare and exchange seat prices will be shown to be a function of the *covariation* of the volumes of trade across the pits at an exchange, in addition to the variation of volumes in the individual pits. An immediate implication is that when a large proportion of wealth of members of a futures exchange is the value of their seats, the membership will find it in their interest to establish a set of contracts with well-diversified volumes of trade.

Dual trading, which is the opportunity for an exchange member to act as either a broker or a dealer, might also be examined in an extension of this work. One advantage of dual trading is the flexibility it allows the members of the exchange (as a whole) to meet the variation in the relative demands for these alternative services. For example, on an exchange in which dual trading is allowed, but in which members must declare at the beginning of the day the role they will take for the entire day,[12] intraday variations in the demands for the brokerage and dealer services will lead to nonoptimal numbers of locals and brokers. One expects to find in this case a large intraday variation in market depth and the costs to liquidity traders, relative to the case in which members may choose freely to deal or broker. This is an alternative to Röell's (1990) argument in favor of dual trading.

Appendix

Proof of Proposition 1: Given the conjecture that $\tilde{p} = \lambda(I\beta\tilde{q} + \tilde{\phi})/M$, and that $\tilde{p}$ is in the information set of dealers, one solves the demands in expressions (1) and (3),

$$x^j = \frac{\mathrm{E}[\tilde{q} - \tilde{p}|\tilde{s}^j]}{\alpha_j \operatorname{Var}[\tilde{q} - \tilde{p}|\tilde{s}^j]} = \frac{(1 - \lambda I\beta/M)V}{[\lambda^2 S(V + v)/M^2 + (1 - \lambda I\beta/M)^2 Vv]} \frac{\tilde{s}^j}{\alpha_j}, \tag{A1}$$

$$y^k = \frac{\mathrm{E}[\tilde{q} - \tilde{p}|\tilde{p}]}{\alpha_k \operatorname{Var}[\tilde{q} - \tilde{p}|\tilde{p}]} = \frac{[I\beta V - \lambda(I^2\beta^2 V + S)/M]}{SV} \frac{(I\beta\tilde{q} + \tilde{\phi})}{\alpha_k}, \tag{A2}$$

[12] The CME has imposed this rule in some of its pits.

where $\alpha_j = \alpha_s$ and $\alpha_k = \alpha_m$. Note that in Proposition 1 all speculators (dealers) have identical risk aversion α_s (α_m), although we allow individual specific risk aversions in equations (A1) and (A2) in anticipation of results to be shown later. Note also that with $\alpha_k = \alpha_m$, the demands in (A2) are homogeneous across dealers. Given the market clearing condition in equation (4) and the demand in (A2),

$$\alpha_m SV = \lambda(I^2\beta^2 V + S) - IM\beta V. \tag{A3}$$

The right-hand side of equation (A1) is equal to $\beta\tilde{s}^j$, so

$$(1 - \lambda I\beta/M)V = \alpha_s\beta[(\lambda/M)^2 S(v + V) + (1 - \lambda I\beta/M)^2 Vv]. \tag{A4}$$

Expression (9) follows from (A3). The fact that $1/\lambda = 1/\alpha_m V$ when $\alpha_s = 0$ follows from equations (A3) and (A4).

Define the cubic polynomial

$$f_1(\beta) \equiv k_3\beta^3 + k_2\beta^2 + k_1\beta + k_0 \tag{A5}$$

where

$$k_3 \equiv VI^2[\alpha_s(V + v)M^2 + \alpha_m IVM + \alpha_s\alpha_m^2 vSV] > 0,$$

$$k_2 \equiv VIM[2\alpha_s\alpha_m SV - IM],$$

$$k_1 \equiv S[\alpha_s vM^2 + \alpha_m VIM + \alpha_s\alpha_m^2 SV(V + v)] > 0,$$

and $$k_0 \equiv -SM^2 < 0.$$

Substituting for λ from (A3) in (A4), one finds the equilibrium β of Proposition 1 is the root of $f_1(\beta)$. The facts that $k_4 > 0$ and $k_0 < 0$ guarantee the existence of a positive root. Let J be the determinant of $f_1(\beta)$. When $\alpha_s = \alpha_m$,

$$J = 27(k_3k_0)^2 - 18k_3k_2k_1k_0 + 4k_2^3k_0 + 4k_1^3k_3 - (k_2k_1)^2 > 0,$$

which proves the uniqueness of the real root.

COROLLARY 1: *Consider the equilibrium of Proposition 1, but let the speculators be perfectly informed ($v = 0$), let speculators and dealers have homogeneous risk aversions α, and let the number of speculators I_s be finite. Let the standard deviation of liquidity trading be proportional to the number of speculators, i.e., $\sqrt{S} = I_S\sqrt{s}$, where $\sqrt{s}$ is the factor of proportionality. And let the number dealers be $M = 1$. As the finite number of speculators increases to infinity, the equilibrium converges to that of Proposition 1 with $v = 0$, $M = 1$, and risk aversions α.*

Proof of Corollary 1: In the equilibrium with a finite number of speculators I_s, and assuming $v = 0$, each speculator solves the problem (1) of the text where the price is proportional to the order flow

$$\tilde{p} = \lambda \tilde{F}$$

and order flow is given by (2). Because $v = 0$, the cash flow $\tilde{q}$ is known exactly by each speculator when they submit their market orders, but order flow (and therefore the equilibrium price) is uncertain due to the liquidity trade. The only uncertainty faced by the speculators is execution price risk. The aggregate order flow from speculators per capita is a finite average:

$$\tilde{x} = \sum_{i=1}^{I_s} x_i / I_s .$$

Therefore speculators solving equation (1) recognize the impact of there own order size on the equilibrium price, and the essence of the proof of Corollary 1 is to demonstrate that the impact of any speculator's order is zero in the limit as the number of speculators goes to infinity.

Analogous to equation (A1), the first order condition for any speculator provides

$$x^j = \frac{\mathrm{E}[\tilde{q} - \tilde{p} | \tilde{q}] + (\partial E[\tilde{p} | \tilde{q}] / \partial x^j)}{\alpha \ \mathrm{Var}[\tilde{q} - \tilde{p} | \tilde{q}]} = \frac{(1 - \lambda(I_s + 1)\beta)}{S\lambda^2} \frac{\tilde{q}}{\alpha},$$

where the second equality follows from the assumption that each speculator's demand is given by the linear form $x = \beta q$. Summing this across speculators provide the following expression for β:

$$\beta = [\lambda(I_s + 1) + \alpha I_s^2 \lambda^2 s]^{-1} \tag{A6}$$

(which is equivalent to Subrahmanyan's equation (5)). The market clearing condition is equation (4) of the text where the dealers' demands are given by (A2) with $M = 1$, $\alpha_k = \alpha$ and $S = I_s s$. The coefficient on the liquidity trade in equation (A2), therefore, must be equal to 1, so that

$$s I_s^2 V \alpha - I_s \beta V + \lambda (I_s^2 \beta^2 V + s I_s^2) = 0.$$

Substituting for β from equation (A6) provides:

$$\alpha^2 \lambda^3 I_s^3 s^2 + 2\alpha I_s^2 \lambda^2 s + \lambda I - \alpha + [(2s\lambda^2 I_s^2(\alpha\lambda I_s s + 1) + s I_s \lambda^2 - 1)/I_s^2 \lambda] = 0, \tag{A7}$$

(which is equivalent to Subrahmanyam's equation (8)). Our goal now is to show for large I_s that equations (A6) and (A7) are nearly equivalent to equations drawn directly from the model of Proposition 1.

A root λ of equation (A7) is approximately proportional to $1/I_s$ for large I. To see this, note that the fifth term (which is in square brackets) declines to zero as I increases provided that λ/I_s remains bounded as I_s increases. Therefore, for large I_s, a solution of (A7) λI_s is approximated by a root of the first four terms, which implies that λ is proportion to I_s, and equation (A6) is solved as

$$\beta \approx [\lambda I_s + \alpha\lambda^2 S]^{-1}. \tag{A8}$$

Now set $v = 0, M = 1, I = I_s$ and assume homogenous risk aversions α in the proof of Proposition 1. By (i) isolating β^2 in equation (A3), (ii) substituting for β^3 and then β^2 in (A4), and then isolating β, and finally (iii) substituting for β in (A3), one derives a polynomial in λI for the large dealer market. This polynomial is the first four terms of equation (A7), and one derives (A8) as the solution for beta.

Proof of Proposition 2: One calculates the unconditional expected utilities of speculators and dealers (appearing in equations (5) and (6)) using the following result: If $Q(X) \equiv -X'AX$, and X is distributed normally $N(\mu, \Omega)$, where A is a symmetric constant matrix, then

$$\begin{aligned}&\mathrm{E}[\exp(\mathrm{Q}(\mathrm{X}))]\\&\quad = |\Omega^{-1}|^{1/2}|2A + \Omega^{-1}|^{-1/2} \exp[-\mu' A\mu + 2\mu' A(2A + \Omega^{-1})^{-1} A\mu].\end{aligned} \tag{A9}$$

Using equation (3), the first equality of (A2) and the fact that order flow F and spot price p are equally informative, an expression for the unconditional expected utility of a dealer is

$$\mathrm{E}[\mathrm{EU^M}] = -\mathrm{E}\left[\exp\left(-\frac{1}{2}\frac{\mathrm{E}[\tilde{q} - \tilde{p}|\tilde{p}]^2}{\mathrm{Var}(\tilde{q} - \tilde{p}|\tilde{p})} + \alpha_k C_{\mathrm{M}}\right)\right],$$

where $\alpha_k = \alpha_m$. (Again, as in Proposition 1 and in anticipation of later results, we write the risk aversions as if they are heterogeneous across participants.) Recognizing that the conditional expectation $\mathrm{E}[\tilde{q} - \tilde{p}|\tilde{p}]$ is normally distributed and that the conditional variance is constant, using equation (A9), this becomes

$$\begin{aligned}\mathrm{E}[\mathrm{EU^M}] &= -\exp(\alpha_k C_{\mathrm{M}})\left[1 + \frac{\mathrm{Cov}^2(\tilde{q} - \tilde{p}, \tilde{p})}{\mathrm{Var}(\tilde{p})\mathrm{Var}(\tilde{q} - \tilde{p}|\tilde{p})}\right]^{-1/2}\\ &= -\exp(\alpha_k \mathrm{C_M})\left[\frac{\mathrm{Var}(\tilde{q} - \tilde{p}|\tilde{p})}{\mathrm{Var}(\tilde{q} - \tilde{p})}\right]^{1/2}.\end{aligned}$$

A similar expression, with $\tilde{s}^j$ substituted for p as the conditioning information, can be obtained for the unconditional expected utility of the speculator from equation (1). Together, the expressions imply the equivalence of the equality of expected utilities and the equality of conditional variances in equation (13) when $\alpha_k = \alpha_m = \alpha$. Using the expression (7) for the equilibrium price, and the definition of $\tilde{s}^j$ one calculates

$$\mathrm{E}[\mathrm{EU}^j] = -[1 + \alpha_j \beta V(1 - \lambda\beta I/M)]^{-1/2} \tag{A10}$$

and

$$\mathrm{E}[\mathrm{EU}^M] = -\exp(\alpha_k C_{\mathrm{M}})[1 + \alpha_k^2 SV/M^2]^{-1/2}, \tag{A11}$$

where β is the root of (A6).

Consider the expression (6). Using (A11) with $\alpha_k = \alpha_m$,

$$\alpha_m^2 SV/M^2 = U_2. \tag{A12}$$

Expression (10) for the measure of dealers M is obtained directly from (A12). Similarly consider the expression (5) as an equality. Using equations (A10) and (6) with $\alpha_j = \alpha_s$,

$$\alpha_s \beta V(1 - \lambda\beta I/M) = U_1. \tag{A13}$$

One solves for M and λ uniquely using equations (A13) and (A4). With these substitutions, (A12) and (A5) become simultaneous equations in β and I. Repeated substitution for β^2 from (A12) into (A5) provides a linear expression in β. Substitution of this expression into equation (A12), and then substitution of the product $(I/M)M$ for I provides the quadratic (11).

When equation (12) holds, $A_0 < 0$ and (11) has a unique root $I > 0$, which is the equilibrium level of speculation. In this case, equation (5) obtains as an equality. When equation (12) does not hold, all coefficients of (11) are positive and the quadratic either has no real roots or only negative roots. In this case, equation (5) obtains as a strict inequality and the equilibrium level of speculation I is zero.

Proof of Corollary 2: Examine equations (10) and (11) for these results.

Proof of Corollary 3: The corollary follows immediately from equation (10).

Proof of Proposition 3: Let risk aversions of all participants be α. Consider J informed and $R - J$ uninformed traders in the REE. Their demands respectively solve equation (16) with and without $\tilde{s}^j$ as conditioning information. These are

$$x_{\mathrm{I}}^j(s^j, p_r) = \frac{\mathrm{E}[\tilde{q} - \tilde{p}_r | \tilde{s}^j, \tilde{p}_r]}{\alpha \operatorname{Var}[\tilde{q} - \tilde{p}_r | \tilde{s}^j, \tilde{p}_r]},$$

$$x_u(p_r) = \frac{\mathrm{E}[\tilde{q} - \tilde{p}_r | \tilde{p}_r]}{\alpha \operatorname{Var}[\tilde{q} - \tilde{p}_r | \tilde{p}_r]}.$$

Given the conjecture of a linear price function,

$$\tilde{p}_r = b_2\tilde{q} + b_3\tilde{\phi}, \tag{A14}$$

that satisfies the market clearing condition $(R - J)\tilde{x}_U + J\tilde{x}_I + \tilde{\phi} = 0$, where

$$J\tilde{x}_1 \equiv \int_{j=0}^{J} \tilde{x}_1^j \,\mathrm{d}j,$$

and $\tilde{x}_U$ is similarly defined, one solves for the coefficients (b_2, b_3). These are

$$b_2 = (JR + \alpha^2 vS)JV/G, \tag{A15}$$

$$b_3 = \alpha v b_2/J, \tag{A16}$$

where

$$G \equiv J^2RV + \alpha^2 vSJV + (\alpha v)^2 RS.$$

Consider the efficiency measures $\mathscr{E}_r$ and $\mathscr{E}$ for prices in the dealer market and the REE, respectively. Let the numbers of informed be equal, i.e., $J = I$. One calculates

$$\mathscr{E} = \frac{(I\beta)^2V}{(I\beta)^2V + S} \quad \text{and} \quad \mathscr{E}_r = \frac{(I/\alpha v)^2V}{(I/\alpha v)^2V + S}, \tag{A17}$$

where β is the root of $f_1(\cdot)$ defined by (A5). $\mathscr{E}_r > \mathscr{E}$ if and only if $1/(\alpha v) > \beta$. Consider that

$$f_1(1/(\alpha v)) = (\alpha^2 vS + IM)(I(M + I)V + \alpha^2 vS(v + V))V/(\alpha^2 v^3) > 0.$$

Because f_1 has a unique positive root, and because $k_3 > 0$, $1/\alpha v = \beta$ if $R = N$ and $J = I$.

Proof of Proposition 4: Let risk aversions of all participants be α. Using arguments similar to those in the proof of Proposition 2 and using also the demands of informed individuals in the REE (found in the proof of Proposition 3), one derives the unconditional expected utility for informed REE participants. This is

$$\mathrm{E}[\mathrm{EU}^r]$$

$$= -\left[1 + \frac{\mathrm{cov}[\tilde{q} - \tilde{p}_r, (\tilde{p}_r, \tilde{s}_j)]\mathrm{var}[(\tilde{p}_r, \tilde{s}_j)]^{-1}\,\mathrm{cov}[\tilde{q} - \tilde{p}_r, (\tilde{p}_r, \tilde{s}_j)]^{\mathrm{T}}}{\mathrm{Var}(\tilde{q} - \tilde{p}_r|\tilde{p}_r, \tilde{s}_j)}\right]^{-1/2}$$

$$= -\left[\frac{\mathrm{Var}(\tilde{q} - \tilde{p}_r|\tilde{p}_r, \tilde{s}_j)}{\mathrm{Var}(\tilde{q} - \tilde{p}_r)}\right]^{1/2}$$

where

$$\mathrm{cov}[\tilde{q} - \tilde{p}_r, (\tilde{p}_r, \tilde{s}_j)] = [(1 - b_2)b_2V - b_3^2S,\ (1 - b_2)V],$$

$$\mathrm{var}[(\tilde{p}_r, \tilde{s}_j)] = \begin{bmatrix} b_2^2V + b_3^2S & b_2\mathrm{V} \\ b_2V & V + v \end{bmatrix}.$$

Using the solutions for the price coefficients from (A15) and (A16), and recognizing that $R = J$,

$$\mathrm{E[EU}^r] = -\left[1 + \frac{(1 - Q)SV(Q(R/\alpha)^2 + (1 - Q)SV)}{(R/\alpha)^2(Q^2(R/\alpha)^2 + (1 - Q)SV)}\right]^{-1/2}.$$

Setting this equal to U provides equation (18).

Proof of Proposition 5: First consider the equilibrium price given fixed I, M, and T. With heterogeneous risk aversions, speculators' and dealers' demands are given by equations (A1) and (A2), which also are heterogeneous, but are proportional to risk tolerance. Following the arguments of Proposition 1, the equilibrium values of β and λ are shown to satisfy equations (A3) and (A4), except with the risk-aversion coefficients α_m and α_s each set equal to unity. It follows that the unique equilibrium β and λ satisfy equations (A6) and (9), respectively (again with $\alpha_m = \alpha_s = 1$).

Now consider the determination of equilibrium levels of I and M with T fixed. By definition, I satisfies $I = T - M$. The equilibrium level of M must satisfy the condition that no dealer finds greater utility speculating and, similarly, no speculator gains by becoming a dealer. For any individual k, we use the arguments in the proof of Proposition 2 to derive the unconditional expected utilities, given that the individual participates as a dealer or as a speculator. These are, respectively,

$$\mathrm{E[EU}^M] = -\exp(\alpha_k C_\mathrm{M})[1 + SV/M^2]^{-1/2}, \tag{A18}$$

and

$$\mathrm{E[EU}^j] = -[1 + \beta V(1 - \lambda\beta I/M)]^{-1/2} \tag{A19}$$

Setting (A18) equal to (A19) provides an equation that simultaneously determines M and a marginal participant k^*, for whom dealing and speculating provide equal levels of utility. When $C_\mathrm{M} = 0$, equations (A18) and (A19) are each independent of the individual's risk-aversion coefficient, so all individuals are indifferent between the roles of speculating and dealing, and the equilibrium M satisfies

$$SV/M^2 = \beta V(1 - \lambda\beta I/M). \tag{A20}$$

Alternatively, when $C_\mathrm{M} > 0$ ($C_\mathrm{M} < 0$), the right side of equation (A18) is decreasing (increasing) in risk aversion. A marginal participant k^* is one for whom (A18) and (A19) are equal. When ($C_{\mathrm{M}} > 0$), all individuals with $\alpha_k < \alpha_{k^*}$ choose to be dealers (because for them equation (A19) is greater than (A18)) and all participants with $\alpha_k > \alpha_{k^*}$ are speculators. Similarly, when $C_{\mathrm{M}} < 0$, all individuals with $\alpha_k < \alpha_{k^*}$ ($\alpha_k > \alpha_{k^*}$) are speculators (dealers). To determine k^* and M simultaneously, we order participants $j \in [0, N]$. If $C_{\mathrm{M}} > 0$, then order all participants j and k so that $\alpha_j < \alpha_k$ if and only if $j > k$, and similarly for $C_{\mathrm{M}} < 0$. Then M defined by

$$M(k^*) \equiv \int_{k^*}^{N} \frac{1}{\alpha_j}\, \mathrm{d}j$$

is monotonically decreasing in k^*. A k^* determined as the root of equation (A20) determines M as well.

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