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The Journal of Finance, Vol. 51, No. 2 (Jun., 1996), 579-611.

Stable URL:
http://links.jstor.org/sici?sici=0022-1082%28199606%2951%3A2%3C579%3ATALACO%3E2.0.CO%3B2-5

The Journal of Finance is currently published by American Finance Association.

THE JOURNAL OF FINANCE • VOL. LI, NO. 2 • JUNE 1996

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ABSTRACT

Trading systems differ in their degree of transparency, here defined as the extent to which market makers can observe the size and direction of the current order flow. We investigate whether greater transparency enhances market liquidity by reducing the opportunities for taking advantage of uninformed participants. We compare the price formation process in several stylized trading systems with different degrees of transparency: various types of auction markets and a stylized dealer market. We find that greater transparency generates lower trading costs for uninformed traders on average, although not necessarily for every size of trade.

IT IS A WIDELY HELD BELIEF among economists studying securities markets that greater transparency in the trading process enhances market liquidity by reducing the opportunities for taking advantage of less informed or nonprofessional participants. This has led, particularly in the United States, to a strong regulatory inclination to require as much trading information as possible to be made immediately available to all comers. To some extent, the purpose is to enable ordinary traders to check for themselves whether they have gotten a fair price, but the main idea is that making information visible to a large set of competing professionals improves price formation so greatly that ordinary traders obtain the best possible deal. In Europe, the speed of publication of trade data was a central issue in the drafting of the European Union's Investment Services Directive, implemented in January 1996, imposing a common regime on all securities firms operating in member countries. There was a difference of opinion on transparency between Britain, which favored slow publication of trade data, and most Continental regulators,

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who have pressed for immediate publication.[1] Within Britain itself, not everyone agrees with the current delayed trade publication regime imposed by the London Stock Exchange: a report by the Office of Fair Trading (1994) argues that delayed publication confers an unfair competitive advantage on large market makers.

Auction markets are inherently more transparent than dealer markets, in the sense that more information can be made directly available to all market participants. They provide greater pretrade transparency, i.e., greater visibility of the best price at which any incoming order can be executed. On electronic auction markets, brokers can scan the limit order book and see exactly at what price an order would execute (except for the presence of "hidden orders").[2] In contrast, dealer markets such as Nasdaq or London's Seaq display only very limited information, namely the "firm quotes" at which market makers must deal for up to the posted size. In practice, the quotes do not give more than a vague indication of the real transaction prices, which are arrived at by telephone negotiation. On the London Stock Exchange, such prices are typically better than quoted prices for medium and even large transactions.[3]

Post-trade transparency, i.e., the public visibility of recent trading history, also tends to be lower in dealer markets. This reflects both inherent technical factors and deliberate choices by exchange authorities. Technically, after a deal is negotiated over the telephone, it takes at least a few minutes to report it to the exchange and for the latter to publish it on screen. It is also hard to verify whether traders delay reporting of trades. Additionally, stock exchange authorities, under pressure from market makers, have tended to grant long publication delays to large transactions. The London Stock Exchange estimates that under current rules only 52 percent of trading by value is subject to publication.[4] In electronic auction markets, where all trade is centralized, real-time trade publication is feasible, and generally enforced.

Thus any theory concerned with the relative liquidity of auction and dealer markets should model the relationship between transparency and liquidity. Our paper suggests one such model. We compare the price formation process in various types of auction and dealer markets. We model transparency as the degree to which the size and direction of the current order flow are visible to the competing market makers involved in setting prices. Both pre- and post-trade information are useful in gauging the order flow. Post-trade transparency provides explicit information about recent trades, and pretrade transparency allows market professionals to infer their competitors' order flow from their pricing behavior.

We focus on the visibility of the order flow to price-setting agents rather than to the end users of the market. Our view is that the information available to

[1] See *The Economist,* 4 July 1992, pp. 76–79.

[2] Part of a limit order can be hidden from the public, so that the limit order book appears less deep than it actually is. Röell (1992b) finds that for French equities hidden orders enhance the depth of the market by about ⅓ to ½.

[3] *Stock Exchange Quarterly,* April–June 1992, and October–December 1993.

[4] *Stock Exchange Quarterly,* January–March 1991, p. 18.

competing market makers[5] is a more important determinant of customers' trading costs than these customers' own direct access to order flow information. In our model greater visibility of the order flow enhances the precision of market makers' inferences about whether orders are information- or liquidity-driven. For this reason market makers can generally afford to offer lower trading costs to uninformed traders in a more transparent market.

Note that our notion of transparency does not concern the degree to which agents can trade anonymously. Market makers are assumed to know nothing about whether the agents placing orders with them are insider traders or not; they can only make inferences by observing the order flow. This approach differs from a number of recent models that focus on the effect of market makers knowing the identity of some traders (Röell (1990a), Admati and Pfleiderer (1991), Fishman and Longstaff (1992), and Madhavan (1995)). In these models, a subset of liquidity traders are identified as such either following a public announcement ("sunshine trading") or because some market professionals are already acquainted with them. Insofar as our concept of transparency refers to order flows rather than to identities of market participants, it better captures the issue of the current policy debate.

Our notion is closer to that of Biais (1993), who defines transparency as the visibility of the limit orders or market maker quotes and analyzes competition among risk-averse market professionals with differing inventory positions. In our model, we consider the visibility of the order flow, not of quotes. More importantly, we assume that there are traders with privileged information who generate an adverse selection problem, as in much recent literature on market microstructure: market makers set their bid-ask spread so as to protect themselves against the losses they incur by trading with insiders, rather than to cover their inventory holding costs as in Biais (1993). Empirical research (Stoll (1989), Hasbrouck (1988), Madhavan and Smidt (1991), and others) suggests that adverse selection is the more important of these two determinants of liquidity.

As Spatt (1991) points out,

> *"though adverse selection is certainly one of the central issues in market microstructure, relatively little attention has been directed to what degree the design of mechanisms for trade itself reflects market efforts to address the adverse selection problem efficiently"* (p. 387).

The design of the trading mechanism determines how hard it is for a market maker to detect the presence of an insider and infer his trading strategy. In particular, one would not expect adverse selection to affect liquidity equally in markets with different degrees of transparency. Our article addresses precisely this issue.

[5] We use the term "market maker" to denote any speculator involved in providing liquidity, be it a designated market maker in a dealer market or a limit order placing speculator in an auction market.

The article is organized as follows. In Section I we start with a stylized description of the most common trading systems, explaining how they differ with respect to our notion of market transparency.[6] In Section II we analyze market liquidity in two types of market organization that are polar opposites as far as transparency is concerned: a simultaneous auction market where all individual orders coming to the market are known to all market participants, and a dealer market where each dealer observes only the part of the order flow that he himself intermediates. In this section, we assume that an insider would choose the same trading strategy in all types of markets. In Sections III and IV, we deal with the more complex case in which the trading strategy of the insider is an endogenous optimal response to the price schedule, rather than held constant irrespective of the market setting. Section V concludes.

I. Description of Markets

Although trading systems differ along many dimensions, we consider only the degree of *transparency,* defined as the extent of intermediaries' knowledge of the rest of the current order flow when they price and satisfy a particular order. In practice, this is a matter of degree. We distinguish four very stylized types of markets.

(A) *Transparent auction:* all traders simultaneously submit their orders to a central auction mechanism (an auctioneer). The speculators who absorb the orders of other traders (noise or informed traders) are able to condition their orders on knowledge of *all individual orders.* All the orders are filled at a common price. Depending on the details of the *tâtonnement* process preceding the price fixing, some call auctions can arguably be placed in this category.

(B) *Batch auction:* like the transparent auction, this involves simultaneous clearing of orders at a common price. The speculators set price-quantity schedules and thus, in effect, condition their price on the *total net demand* conveyed to the market by other traders. In other words, prices are based on knowledge of the aggregate order flow. The opening call auctions in Paris, New York, Tokyo, Milan, and Madrid are examples of such auctions.

(C) *Continuous auction:* prices are formed over time upon observing the history of the order flow up to that moment. Market orders are executed one by one immediately upon placement. In determining limit order prices, speculators observe *past* transactions and other limit orders. This kind of exchange is generally automated. Examples are Toronto (CATS: Computer Assisted Trading System), Paris (CAC: Cotation Assistée en Continu), Milan, Madrid, and the New York Stock Exchange.

(D) *Dealership:* each order is satisfied separately by a single dealer, who does not know the orders received by other dealers. Prices are contingent only on

[6] Others have focused on other differences between trading systems. For example, Madhavan (1992) stresses the different nature of competition among strategic traders in auction and dealer markets. He models market makers as competing in demand schedules in auction markets and in prices in dealer markets.

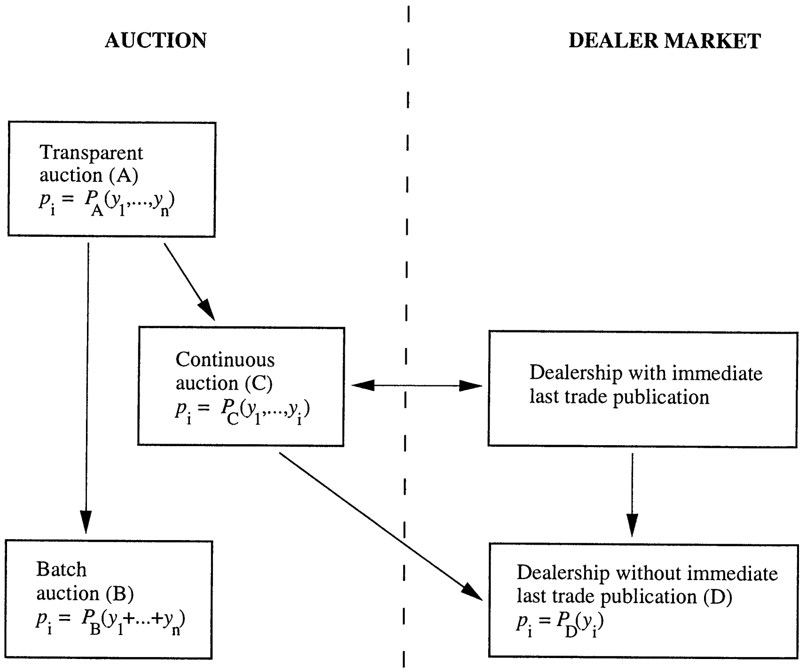

Figure 1. Stylized trading systems, ranked by decreasing transparency. The figure gives a partial ranking of trading systems in terms of their transparency and summarizes price formation in each system. Arrows point in the direction of *decreasing* transparency. Arrows point in both directions when two trading systems have the same degree of transparency. Trading systems not connected by arrows cannot be ranked vis-à-vis each other. For each market, the price p_i for the i-th order coming to the market ($i = 1, \ldots, n$) is determined as a function (P_A to P_D) of the order flow information available to those who price it, where y_i denotes the (signed) size of the i-th order. The index i of the order is assumed to convey no information about the identity of the trader who placed it. The arguments of the pricing functions P_A to P_D indicate exactly what information is available in each of the markets A to D when the price is formed.

each order separately. This assumes, in effect, delayed publication of trades. With immediate publication, each market maker could condition his price for an order on all past transactions, hence we would be in a situation formally equivalent to the continuous auction. In practice, dealer markets do not lend themselves to prompt last-trade publication because dealers have every incentive (at the individual level) to postpone trade reports. Examples of dealership systems are Nasdaq and London's Seaq.

A partial ranking of these trading systems in terms of transparency is given in Figure 1.

In the transparent auction (A), price-setting agents have the maximum amount of information, as they can see all individual orders at the time that the price is formed. The other three types of market are less transparent.

In the batch auction (B), prices are conditioned on the total order flow without knowledge of its breakdown into the component orders. In the dealer market without trade publication (D), each order is priced separately by a dealer who knows nothing about orders going to other dealers. Thus both markets (B) and (D) are less transparent than (A). But (B) and (D) cannot be ranked relative to each other in terms of transparency: depending on the circumstances, the size of a single order may or may not be more informative than the sum of all orders.

The continuous auction (C) (equivalent to a dealer market with immediate trade publication) can be regarded as an intermediate case between the transparent auction (A) and a dealer market with no publication of trades (D): the first order to arrive within a trading period is priced with no information about the rest of the order flow, the second is priced given information concerning only the first order, etc. The very last order is priced given information about all the other orders. Thus within any trading period, price formation starts out as in the dealer market and ends up as in the transparent auction.

II. Trading Costs with Exogenous Insider Trading Strategies

We consider a setting in which one potential informed trader and several potential uninformed traders come to the market. As in Kyle (1985), both place market orders rather than limit orders. They fix their order size before observing the price to be paid, and cannot adjust the quantity traded to price movements induced by other agents' trades.[7]

In this section, we compare market price formation in different trading systems for an exogenously given trading strategy of the informed trader, invariant to the type of market. In practice, an insider may adopt different trading strategies in auction and dealer markets. We defer analysis of this point to Sections III and IV, where we solve for the optimal strategy of the insider and investigate how it varies with the type of market in which he operates. The results of the present section, where the insider's strategy is held constant across different markets, can be viewed as a building block for the subsequent analysis, but are also to be valued on their own; their level of generality is higher, because treating the insider's strategy as endogenous complicates the analysis considerably.

Throughout the article we assume, without attempting a game-theoretic justification, that Bertrand competition among risk-neutral uninformed speculators or "market makers" generates prices equal to the expected value of the security, conditional on all the information available to market makers.[8] This information of course includes the size and direction of the order that is being priced. It does not include any direct information about the identity of the traders who bring orders to the market, such as whether they have superior information or not.

[7] This approach differs from that of Kyle (1989) and Rochet and Vila (1994), where the insider can condition his demand on the market price. This is equivalent to assuming that the insider can condition his order on the noise traders' order flow. An extension of our analysis to this setting is left for future research.

[8] In the dealer market, we assume that there are more market makers than potential orders, and that each market maker can only process one order within the trading period.

A. The Transparent Auction and the Dealer Market

Our first theorem compares the two stylized trading systems at the polar extremes of our "transparency scale": the transparent auction market, where the size and direction of all orders coming onto the market are known to all participants; and the dealer market without immediate trade publication, where each dealer knows only the orders that he is presented with and trades only once in each trading interval. We find that uninformed traders get a better expected price in the transparent auction than in the dealership market. Remarkably, this is true for the whole range of possible trade sizes.

To obtain this result, we need to impose the following fairly weak restrictions on the class of insider trading strategies considered:

ASSUMPTION X. *The insider can place only a single order X on the market. His (possibly random) trading strategy $\tilde{X}(v)$, which specifies the size of his order X as a function of his information v, satisfies the following properties:*

(i) symmetry: for any v, $\tilde{X}(\bar{v} + v)$ and $-\tilde{X}(\bar{v} - v)$ have the same distribution, where $\bar{v}$ is the mean of v;
(ii) weak monotonicity:[9] *$\tilde{X}(v)$ is nondecreasing in the sense that if $v' > v$, then $\tilde{X}(v') \geq \tilde{X}(v)$ with probability 1.*

The following result then obtains:[10]

THEOREM 1: *Comparison of Transparent Auction and Dealer Markets, with Exogenous Informed Trader Strategy. Assume that:*

A. there is one insider who knows the final value of the security, v, where $v \sim G(v)$, and m uninformed traders who trade $u_1, \ldots, u_m$, independently drawn from $F(\cdot)$;
B. both $G(v)$ and $F(u)$ are symmetric distributions about $\bar{v}$ and 0 respectively;
C. the insider's trading strategy $\tilde{X}(v)$ is the same in both types of market and satisfies assumption X.

Then the expected transaction cost to uninformed traders is lower in the transparent auction than in the dealership market, for all trade sizes.

Intuitively, the proof of this theorem is based on the fact that in the transparent auction the market price is based on more information: the size of all

[9] The optimal strategy of a risk-neutral insider is always weakly monotonic in the sense described. To see this, let $P(x)$ be the price he expects to pay if he submits an order of size x. By revealed preference, if $x \in \tilde{X}(v)$ and $x' \in \tilde{X}(v')$:

$$x(v - P(x)) \geq x'(v - P(x'))$$

and

$$x'(v' - P(x')) \geq x(v' - P(x)).$$

Subtracting one equation from the other, we obtain $(x' - x)(v' - v) \geq 0$.

[10] Proofs are relegated to the Appendix.

individual orders, not just the size of a single order. Accordingly, insiders have less scope to "hide" behind uninformed traders, and the latter get a better deal.

COROLLARY. *In the special case where the distribution of the insider's trades is identical to that of the noise traders, the expected trading costs of noise traders are the same in the dealer market as in the transparent auction.*

In the case considered in this corollary, the insider and the noise traders are totally indistinguishable, so in both markets nothing can be inferred about the identity of a trader by looking at the size of his trade. Hence, the liquidity of the two markets is identical.

It is worth discussing the assumption that traders cannot split their orders. This may appear restrictive, considering that the insider might be able to capture a greater expected profit by doing so. In practice, though, market makers ask their customers whether their trade is part of a sequence and penalize liars by refusing to trade with them again.[11] In addition, splitting orders would be more tempting in the dealer market. In the auction market, all of the insider's multiple orders would be visible to market makers; while in the dealer market each dealer would not know about the rest of the order flow. It is therefore plausible that the result of Theorem 1—that the auction's greater transparency makes it a more liquid market—would be reinforced in a setting where traders were allowed to split their orders.

B. The Batch Auction

We stated above that a batch auction provides less information than the transparent auction. In particular, when prices are formed only net total demand is visible—not its composition in terms of individual orders. Nonetheless it turns out that the expected transaction cost for the uninformed trader is not necessarily lower in the transparent auction for all possible trade sizes. This is illustrated in the example of Table I, where the noise traders who wish to buy or sell *one* unit are better off in the batch auction; otherwise, they are better off in the transparent auction or in the dealer market.

It is easy to construct examples in which uninformed traders would do better with the transparent auction for *all* trade sizes. We conjecture that the batch auction cannot provide lower expected transaction costs to uninformed traders at *all* trade sizes, but have been able to show this only for some special cases. It remains an open question whether it is always true under the general distributional assumptions used in Theorem 1.

C. Summary

Before analyzing the various trading systems when the insider's trading strategy is endogenous, it is worth summarizing the results obtained so far. Assuming that the insider's trading strategy is exogenous and the same irrespective of the type of trading system, we have found that the expected

[11] Here we do not attempt to model the degree with which such discipline can be enforced.

Table I

Pricing and Liquidity in a Batch Auction: An Example

An uninformed trader places orders of −2, −1, 0, 1, or 2 units with probability ⅕ each. An informed trader knows the value of the security, normalized to −1, 0, or 1, with probability ⅓ each. He trades −1, 0, or 1 units respectively. The resulting prices in the different trading systems are summarized in Table I. To see how the figures in Table I are computed, consider the third line. The total quantity traded is −1, which corresponds to one of the three pairs of orders: (0, −1), (−1, 0), or (−2, 1), where the first figure refers to the order of the uninformed trader and the second to that of the insider. These events correspond to the fundamental values −1, 0, and 1, respectively. Since they are equally likely, the batch auction price (which is the best estimate of fundamental value conditional on the net order flow) is 0. On the right-hand-side of Table I, we compute the expected price faced by an uninformed trader as a function of his order size, shown in the third column. If he places an order of −1, the total quantity traded is −2, −1, or 0 with equal probability, so that—from the first column—the expected price in the batch auction is (−½ + 0 + 0)/3 = −⅙. In the transparent auction, the market makers would see one of the three pairs of orders: (−1, −1), (−1, 0), or (−1, 1) with equal probability. The three estimates of the security's value conditional on these three pairs of orders are −1, −½, and 0, so that the expected price in transparent auction is (−1, −½ + 0)/3 = −½. Finally, in the dealer market an order of −1 may have been placed by an uninformed trader with probability ⅕ or by an insider with probability ⅓. The dealer will then fill the order at the price (0 · ⅕ − 1 · ⅓)/(⅕ + ⅓) = −⅝.

Total Quantity Traded	Batch Auction Price as a Function of Total Demand	Size of Order of Uninformed Trader	Expected Price to an Uninformed Trader as a Function of the Order He Places in: Batch Auction	Transparent Auction	Dealer Market
−3	−1				
−2	−½	−2	−½	0	0
−1	0	−1	−⅙	−½	−⅝
0	0	0	0	0	0
1	0	1	⅙	½	⅝
2	½	2	½	0	0
3	1				

transaction cost for uninformed traders is lower in the transparent auction than in the dealer market without immediate trade publication. This result holds irrespective of the size of the uninformed trader's order. Thus, in comparing the two trading systems, market liquidity goes hand in hand with transparency. No unambiguous ranking is possible, however, for the batch auction.

The reader will have noticed that we have said nothing about the continuous auction. The reason is that we have taken the informed trader's strategy to be a function $X(v)$ of his fundamental information v only. In a continuous auction, as trading progresses over time, the prices quoted by the speculators will change. Accordingly, an informed trader will revise his trading plans. They will typically depend on the posted price schedule at the time he trades, which is a function of the order flow history up to that moment: $x_i = X(v, P_c^i(x_1, \ldots, x_{i-1}, \cdot)$, so that, in effect, his order is conditioned on the past order flow. It makes little sense to analyze the liquidity of the continuous auction under the static assumptions of this section, where x_i is just a function of the security's value: $x_i = X(v)$. We defer a treatment of continuous auctions to a special case in Section IV.*A*, where we simultaneously solve for the optimal strategy of the informed trader, allowing it to develop over time along with market prices.

III. Endogenous Insider Trading Strategy with Precommitment

A key assumption underlying Theorem 1 is that the insider adopts the same trading strategy, $X(v)$, regardless of market type. But since the expected price schedule facing him will generally differ between the two markets (as shown above), his trading strategy need not be the same either. From now on, we will explore what happens when a risk neutral informed trader chooses his trading strategy $X(v)$ to maximize expected profits.

We can distinguish two possible settings: one in which he can precommit to his trading strategy, and one in which he cannot. In the first scenario, the insider can choose his strategy $X(v)$ ex ante, and commits himself to follow it even if ex post (upon observing v) he might wish to deviate from it.[12] We refer to this as the "precommitment" case. While we do not regard this as a realistic case, the result that we obtain for this setting is a useful stepping stone to the analysis of the "non-precommitment" case in Section IV.*A*.

Denote the optimal ex ante strategies in the auction and dealer market by x_A^* and by x_D^*, respectively. These strategies are optimal in the sense that combined together with the pricing function that they induce they maximize the insider's expected profit. Hence, by construction:

$$\pi_D(x_D^*) \geq \pi_D(x) \tag{1}$$

where $\pi_D(\cdot)$ is the insider's expected profit in the dealer market as a function of his trading strategy, and x is any other strategy.

By Theorem 1, we know that if the insider employs the same strategy in both markets, the expected trading costs of noise traders in the dealer market exceed those that they face in the transparent auction market. Since the noise traders' expected trading costs are equal to the insider's expected profits, the latter are higher in the dealer market:

$$\pi_D(x) \geq \pi_A(x). \tag{2}$$

where $\pi_A(x)$ is the expected profit obtained in the auction market from any strategy x. Combining this with inequality equation (1), we obtain that:

$$\pi_D(x_D^*) \geq \pi_A(x), \qquad \forall x, \tag{3}$$

i.e., no strategy in the auction market can be more profitable for the insider than his ex ante optimal strategy in the dealer market. In particular, this

[12] Note that precommitting to a trading strategy can never damage the insider, since at the very worst he can precommit to the strategy that he would adopt in the equilibrium without precommitment.

applies to the case in which x is the ex ante optimal strategy in the auction market, x_A^*:

$$\pi_D(x_D^*) \geq \pi_A(x_A^*) . \tag{4}$$

Since the expected profit of the insider is equal to the expected transaction cost paid by the noise traders, we can conclude that:

PROPOSITION 1: *Comparison of Transparent Auction and Dealer Markets, with Informed Trader Precommitment. If the insider is risk-neutral (i.e., maximizes expected profits) and able to precommit to a trading strategy, the expected trading costs of uninformed traders in the dealer market are higher than (or equal to) those in the transparent auction.*

Notice that this proposition applies only ex ante, that is, before the noise trader finds out his desired trade size, unlike Theorem 1. There may well be a range of trade sizes for which a noise trader obtains a better price on the dealer market. But on average, *over all trade sizes,* he cannot obtain a better price than in the auction market.

IV. Endogenous Insider Trading Strategy Without Precommitment

We now turn to the more realistic case in which the insider does not precommit to a trading strategy, so that $X(v)$ must be an optimal response ex post, i.e., the trader will not want to depart from it after observing v.[13] This greatly complicates the relationship between transparency and liquidity; distributional assumptions on noise trades and the insider signal now become critical. We can still show that transparency reduces the *average* trading costs incurred by uninformed traders (or at worst leaves them unchanged) in some of the leading models of the market microstructure literature, even though so far we have been unable to establish this result at the level of generality of our previous results.

First, in Section IV.*A* we show that transparency enhances liquidity if all noise traders' orders are of the same size. This is a class of cases widely analyzed in the literature, starting with the seminal model of Glosten and Milgrom (1985). In this setting, we are also able to model a continuous auction and show that its liquidity is intermediate between that of the dealership and that of the transparent auction.

Second, in Section IV.*B* we identify a special set of cases where the liquidity of the market is identical irrespective of its degree of transparency. Here it is assumed that there is a single noise trader and that the distributions of his

[13] Note that by "ex post" we mean after observing v, but not the market price. We do not allow the trader to retract a market order in the light of the price that he obtains for it. If he could, the analysis of the transparent auction and the batch auction would change, because in both of those, the informed trader does not know the price for sure at the time he places an order. An analysis of this setting, which would allow traders to submit price-quantity schedules using limit orders, is left for future research.

trade size and of the insider's information are suitably similar in shape. This includes settings where both are normal distributions, as in Kyle (1985) and many other models.

Finally, in Section IV.*C* we analyze a setting with two trade sizes due to Easley and O'Hara (1987), illustrating that, when the insider adapts his trading strategy to the type of market, transparency may not enhance liquidity for *all* noise traders, regardless of trade size. In fact, a noise trader placing a small order may prefer the dealer market to the transparent auction. Even so, the transaction costs of noise traders, *averaged across all trade sizes,* are lower in the transparent auction than in the dealer market.

A. The Case of a Fixed Trade Size

When all noise traders place orders of the same size, a case studied by Glosten and Milgrom (1985) and many others, the result of Theorem 1 remains in force when the informed trader's strategy is endogenous: transparent auction markets are more liquid than dealer markets. To show this, we first establish

LEMMA 1: *Optimal Strategy of Informed Trader in Dealer Market. If all noise traders place orders of the same size, then under the assumptions of Theorem 1, the equilibrium strategy of a risk-neutral insider in the dealer market is the same with or without precommitment.*

We know from the argument used to derive Proposition 1 (in particular, from equation (3)) that the insider's expected profit from his optimal precommitment strategy is at least as large as that obtained by any strategy in the auction market. Hence, Lemma 1 implies

PROPOSITION 2: *Comparison of Transparent Auction and Dealer Markets with Fixed Size of Noise Trades. Suppose that all noise traders place orders of the same size and that a risk-neutral insider endogenously chooses his trading strategy without being able to precommit to it. Then under the assumptions of Theorem 1, noise traders' expected trading costs are higher in the dealer market than in the transparent auction.*

We now turn to an analysis of a continuous auction. We can conceive of a continuous auction market as one in which potential traders arrive in a random sequence and submit market orders for execution. When the first trader's order is filled, the other orders are not yet known. Upon execution, its size and price are publicly announced, and price quotes are updated. Then the second trader formulates his order, which is filled at a price equal to the best estimate of the security's value, given the size and direction of both the first and the second orders. This process continues until the last order is filled at a price equal to the best estimate of the security's value given all the orders.

As mentioned before, this trading system is generally harder to analyze because the informed trader's strategy must be made dependent on market conditions, which change over time as the order flow unfolds. This is why we confine our analysis of continuous auctions to the easier current case of fixed order sizes, and focus on the following simple example, for which we analyzed the transparent auction and the dealer market in Pagano and Röell (1992).

The security's value is either high (V_H) or low (V_L) with probability ½ each, so that its expected value is $\underline{V} = (V_H + V_L)/2$. There are only two potential traders, arriving in random order: a noise trader who either buys or sells a unit of the security (with probability $z/2$ each) and an informed trader who knows the security's true value (with probability q). In pricing the first order, the market makers of the continuous auction market have exactly the same information that they would have in a dealer market, and thus set the price at the same level that would be chosen by a dealer. When the second order arrives, the size and direction of the other order is already public knowledge. Its price will therefore be identical to the transparent auction price, provided that the informed trader's placement strategy does not depend on the past history of the order flow. But in this simple example that is readily seen to be the case. In both periods, the equilibrium strategy of the informed trader is identical: he buys a unit if he knows that the security is worth V_H, sells it if he knows that it is worth V_L, and does not trade otherwise.[14]

Since a noise trader arrives first or second with equal probability, this argument shows that the expected price he pays is the average of the dealer quote and the expected auction market price. Thus trading costs in the continuous auction are lower than in a dealer market but higher than in the transparent auction.[15]

B. Cases Where Transparency Has No Effect on Liquidity

In general, one would not expect trading costs to be invariant to the degree of transparency. Yet, there are instances in which this happens, such as the static case of Kyle's (1985) model, with a monopolistic insider and normally distributed value and noise trades. In this subsection we characterize a general class of cases in which this irrelevance result obtains.

In all these cases, a risk-neutral monopolistic insider chooses the same equilibrium strategy irrespective of the type of market. Moreover, his strategy generates the same distribution of trade sizes as the noise trades. As we know from the corollary to Theorem 1, when the insider chooses such a "perfectly camouflaged" strategy, market transparency does not affect trading costs.

Consider a single liquidity trader and a single risk-neutral insider, each placing one market order of stochastic size. Let the order of the liquidity trader u be distributed with cumulative density function $F(u)$. The key assumption is

[14] This is the optimal strategy for the insider, because the ask price will lie in the range $[\underline{V}, V_H]$ and the bid price in the range $[V_L, \underline{V}]$. For instance, the ask price will be V_H after a buy order, $\underline{V}$ after a sell order, and in between if no trade has occurred before. The precise prices are computed in Pagano and Röell (1992), Table 1, p. 617, and in Section IV.*C* below for the special case $z = z_0 = 1$.

[15] We conjecture that this result may carry over to more general settings: see Theorem 2 of the working paper version (Pagano and Röell (1993c)).

that the cumulative distribution function $G(\cdot)$ of the insider's information v satisfies a linear rescaling condition:

$$F(x) = G(\alpha + \beta x), \qquad \forall x, \qquad \text{with} \quad \beta > 0. \tag{5}$$

In words, the security's value, when linearly rescaled by deducting a constant α and dividing by a constant β, has the same distribution as the noise trade. Note that if $F(\cdot)$ is a zero mean distribution, the constant α can be interpreted as $\bar{v}$, the mean value of the security. This condition is always satisfied when both variables are normally distributed—a common assumption in the literature on market microstructure.

If condition (5) holds, the equilibrium price function turns out to be linear irrespective of the market type. In effect, the "linear rescaling" assumption allows the insider to mimic the distribution of the liquidity trades using a linear trading rule of the form $x = (v - \alpha)/\beta$. It so happens that a single risk-neutral insider will always choose to do so in the linear equilibria that we consider.

Proposition 3: *Sufficient Conditions for the Irrelevance of the Market Mechanism. Consider a market with competitive, risk-neutral market makers, a single noise trader, and a monopolistic, risk-neutral insider. The trade size of the noise trader u has a distribution $F(u)$, where $E(u) = 0$ (for convenience). The insider observes the true value of the security v, where $v \sim G(v)$. Assume that the linear rescaling condition (5) holds. Then there exists an equilibrium where the pricing rule takes the linear form:*

(a) $p(y_1, y_2) = E(v|y_1, y_2) = \alpha + \beta(y_1 + y_2)/2$ in the transparent auction,
(b) $p(y_i) = E(v|y_i) = \alpha + \beta y_i/2$ in the dealer market, and
(c) $p(y_1 + y_2) = E(v|y_1 + y_2) = \alpha + \beta(y_1 + y_2)/2$ in the batch auction,

where $y_i (i = 1, 2)$ is an order from one of the two traders (of unknown identity).
In all three cases, the insider's equilibrium trading strategy is $X(v) = (v - \alpha)/\beta$, and the liquidity of the market is identical.

Note that Proposition 1 of Kyle (1985) is a special case of Proposition 3(c). Kyle considers a single batch auction where the market makers only observe the aggregate order flow. He assumes that $v \sim N(P_0, \Sigma)$ and $u \sim N(0, \sigma^2)$, so that both $G(\cdot)$ and $F(\cdot)$ are normal distributions with the relevant rescaling constants being $\alpha = P_0$ and $\beta = \sqrt{\Sigma/\sigma^2}$. Our proof is simpler than Kyle's in that it does not require knowledge of the formulas for updating normal distributions.

Proposition 3 as a whole shows that if the "noise" demand comes from a single uninformed trader, then the insider's strategy and the noise trader's expected transaction cost will be the same in a batch auction, a transparent auction and a dealer market. So Proposition 3 tells us that, if we reformulate Kyle's single auction model as a dealer market where an insider and a noise trader trade with different dealers in parallel, the equilibrium expected transaction price would be the same as that derived by Kyle.

Another example of this proposition is a special case of the model of Pagano and Röell (1992), in which the insider's information about the value of the security can take two values—"high" or "low"—with equal probability, and the noise trader buys or sells one unit with equal probability. If the arrival probability of the insider, q, and of the noise trader, z, are the same, the distribution functions $F(\cdot)$ and $G(\cdot)$ satisfy the linear rescaling assumption, so that Proposition 3 applies.

The general insight offered by Proposition 3 is that even when the trading strategy of the insider is endogenized, Theorem 1 may be applicable because the insider may choose the same strategy under different forms of market organization.[16] The assumptions of Proposition 3 ensure that, in addition, the corollary to Theorem 1 applies, and the insider perfectly mimics the noise trader's distribution of trade sizes, so that the degree of market transparency becomes irrelevant in determining liquidity.

Proposition 3 also illustrates that these alternative market mechanisms are naturally ranked in terms of execution risk. The batch auction (as well as the transparent auction) gives a riskier price, because the price at which orders are satisfied reflects the net balance of all the other orders. The dealership market has no execution risk; no information about other orders is contained in the price that is paid in each trade. It should be emphasized that execution risk in this model is the direct result of the incorporation of information into prices. Thus a market with greater execution risk is not necessarily inferior, since its transaction prices are generally closer to the final best estimate of the security's value. To capture the welfare costs of execution risk as well, one would have to abandon this article's assumption of risk neutrality. In the model of Pagano and Röell (1993a), for instance, where the price pressure of the order flow arises entirely from intermediaries' risk aversion (rather than from informed trading), execution risk is unambiguously damaging to traders.

C. *The Case of Two Trade Sizes*

In this section, we use the model of Easley and O'Hara (1987) to illustrate that if the optimal strategy of the insider differs from the auction to the dealer market, the liquidity of the auction market may no longer be unambiguously greater for all noise traders. Greater market transparency may reduce trading costs for some trade sizes but increase them for others (in contrast with the result of Theorem 1, which holds for all trade sizes). But even so, *on average,* noise traders benefit from greater transparency. Their trading costs, averaged across all trade sizes, are lower.

Assume that a single noise trader arrives on the market with probability 1. With probability z_0 he places a small order (which, without loss of generality,

[16] This insight extends beyond the restrictive assumptions of Proposition 3. For instance, in the model of Pagano and Röell (1992), Theorem 1 always applies because the insider chooses the same trading strategy in all trading systems, whatever the values of his own arrival probability, q, and of the noise trader, z. However, Proposition 3 applies only under the more restrictive assumption that the two arrival probabilities are the same ($q = z$).

is assumed to be of unit size). With probability z_1, where $z_0 + z_1 = 1$, he places a large order of size $Y > 1$. In either case, he buys and sells with equal probability. An insider receives information about the value v of the security with probability $q \leq 1$. The information can be "good news" ($v = V_H$) or "bad news" ($v = V_L < V_H$), with probability $q/2$ each. For notational convenience we shall use the normalization $V_H = 1$ and $V_L = -1$. The insider is a risk-neutral, profit-maximizing monopolist, and places a small or a large order with endogenously determined probabilities q_0 and q_1 respectively (where $q_0 + q_1 = q$).

Table II shows the possible combinations of orders arriving on the market, their probabilities, and the transparent auction price, i.e., the best estimate of the value of the security given the order flow. The latter is computed by taking a probability-weighted average of the underlying true value of the security in all cases where the corresponding set of orders arises.

From Table II we compute the average price P_A obtained in the auction market for both trade sizes and both types of trader by averaging prices over the set of all possible trades by the other trader:

$$P_A(B_0, N) = \frac{1}{2} q_0 \frac{(1 - z_0)q_0 + (2 - z_0)q_1}{(1 - z_0)q_0 + z_0 q_1}, \tag{6}$$

$$P_A(B_1, N) = \frac{1}{2} q_1 \frac{z_0 q_1 + (1 + z_0)q_0}{(1 - z_0)q_0 + z_0 q_1}, \tag{7}$$

$$P_A(B_0, I) = \frac{1}{2} \frac{2q_0 - 3z_0 q_0 + z_0^2(q_0 + q_1)}{(1 - z_0)q_0 + z_0 q_1}, \tag{8}$$

$$P_A(B_1, I) = \frac{1}{2} \frac{q_0 - 2z_0 q_0 + z_0 q_1 + z_0^2(q_0 + q_1)}{(1 - z_0)q_0 + z_0 q_1}, \tag{9}$$

where N denotes the noise trader, I the informed trader, B_0 a small buy order, and B_1 a large buy order.

Because of the symmetry of the setting, the average prices for sell orders are the negatives of the average prices for the corresponding buy orders: $P_A(S_i, j) = -P_A(B_i, j)$, for $i = 0, 1$ and $j = N, I$. From now on, we deal only with the buy side; that is, the case in which the informed trader has received "good news" ($v = 1$). The sell side is completely symmetric.

The corresponding prices in the dealer market reflect the relative odds of trading with an insider:

$$P_D(B_0) = \frac{q_0}{z_0 + q_0}, \tag{10}$$

$$P_D(B_1) = \frac{q_1}{1 - z_0 + q_1}. \tag{11}$$

Table II

Order Flow and Auction Prices in the Easley and O'Hara (1987) Model

The first two columns display all possible order flow configurations. B_0 denotes a buy order of 1 unit, B_1 a buy order of Y units, S_0 a sell order of 1 unit, and S_1 a sell order of Y units. The third column shows the probability of each combination of orders, assuming that the informed trader always buys if $v = 1$ and sells if $v = -1$, and that his order is small (large) with probability z_0 (z_1). The fourth column displays the true value of the asset in each case: it is 1 (-1, 0) if the insider buys (sells, does nothing). The last column shows the transparent auction price, the best estimate of the asset value given the size of the two orders. It is calculated as follows. Each possible combination of order sizes (e.g., B_0 and S_1) appears in two lines of the table; the price for that combination is the weighted average (with probability weights taken from the third column) of the asset's true value (from the fourth column) in those two lines. For brevity, in the table we use the notation $\gamma \equiv z_0 q_1 - (1 - z_0)\, q_0 \div (z_0 q_1 + (1 - z_0)\, q_0)$.

Order Size of Noise Trader	Order Size of Informed Trader	Probability	True Value of Asset	Auction Price
B_0	B_0	$\frac{1}{4}z_0q_0$	1	1
B_0	B_1	$\frac{1}{4}z_0q_1$	1	1
B_1	B_0	$\frac{1}{4}z_1q_0$	1	1
B_1	B_1	$\frac{1}{4}z_1q_1$	1	1
B_0	S_0	$\frac{1}{4}z_0q_0$	-1	0
B_0	S_1	$\frac{1}{4}z_0q_1$	-1	$-\gamma$
B_1	S_0	$\frac{1}{4}z_1q_0$	-1	γ
B_1	S_1	$\frac{1}{4}z_1q_1$	-1	0
B_0	—	$\frac{1}{2}z_0(1-q)$	0	0
B_1	—	$\frac{1}{2}z_1(1-q)$	0	0
S_0	B_0	$\frac{1}{4}z_0q_0$	1	0
S_0	B_1	$\frac{1}{4}z_0q_1$	1	γ
S_1	B_0	$\frac{1}{4}z_1q_0$	1	$-\gamma$
S_1	B_1	$\frac{1}{4}z_1q_1$	1	0
S_0	S_0	$\frac{1}{4}z_0q_0$	-1	-1
S_0	S_1	$\frac{1}{4}z_0q_1$	-1	-1
S_1	S_0	$\frac{1}{4}z_1q_0$	-1	-1
S_1	S_1	$\frac{1}{4}z_1q_1$	-1	-1
S_0	—	$\frac{1}{2}z_0(1-q)$	0	0
S_1	—	$\frac{1}{2}z_1(1-q)$	0	0

In the auction market, if the insider knows that $v = 1$, his expected profit is given by

$$\max\{1 - P_A(B_0, I)\, ,\, [1 - P_A(B_1, I)]Y\}, \tag{12}$$

while in the dealer market, it is given by

$$\max\{1 - P_D(B_0)\, ,\, [1 - P_D(B_1)]Y\}. \tag{13}$$

We can show first that in equilibrium the insider (if he has information) will never choose the small size B_0 with probability 1, in either market. He will never set $q_0 = q$, but he may randomize over the two trade sizes, when he is indifferent, or choose the large size with probability 1, depending on the

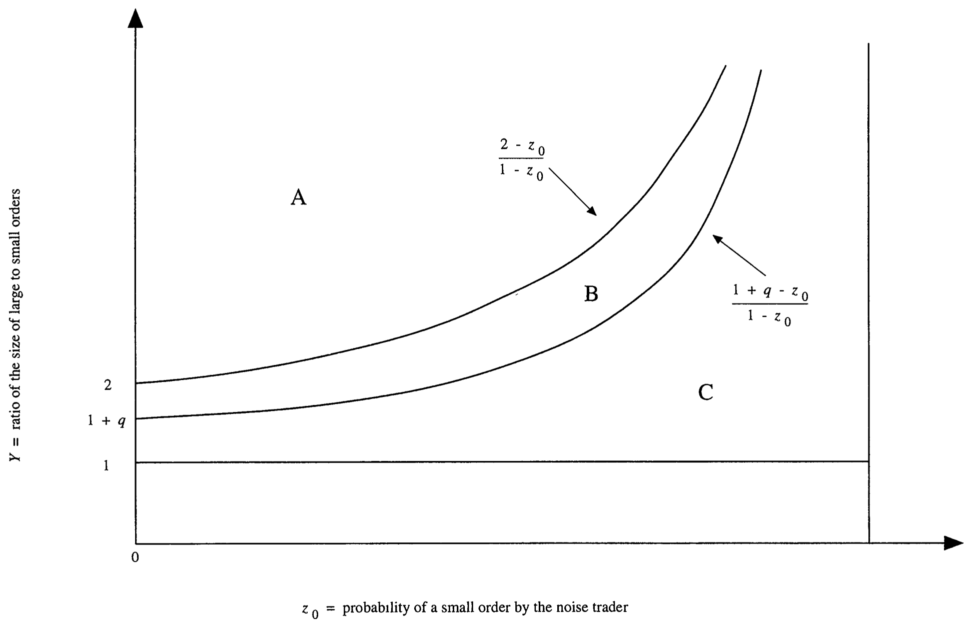

Figure 2. Insider's strategy and model parameters. Regions show how the strategy played by the insider in equilibrium depends on the relative probabilities of small and large noise trades and on their relative sizes. In region A, the insider only places large orders in both auction and dealer markets. In region B, he adopts a mixed strategy only in the auction market, while in region C he mixes in both.

parameters z_0 and Y (results already established for the case of the dealer market by Easley and O'Hara (1987)). The demonstration starts by positing that the insider always chooses B_1 (i.e., we assume $q_0 = 0$), then checking in which regions of the parameter space this is indeed more profitable than choosing B_0. Lastly, we determine the region in which the insider randomizes and solve for his equilibrium $q_0 \in (0, q)$. All the relevant derivations are reported in the Appendix. The results are summarized in Figure 2, which illustrates how the insider's strategy varies in the two markets according to the configuration of parameters.

In region A, the insider always chooses to trade the large size in both markets. Thus his strategy is constant across the two markets and Theorem 1 applies: for both small and large orders, in the dealer market noise traders obtain prices worse than (or equal to) those that they can obtain in the auction, i.e., in the more transparent market.[17]

In region B, the insider always places large orders in the dealer market, while he randomizes over the two trade sizes in the auction. Similarly, in region C, the frequency with which the insider places large orders is higher in

[17] The same would happen in general if either z_0 or z_1 were assumed to be zero. This case has been analyzed by Pagano and Röell (1992), who in fact show that the auction market always dominates the dealer market, in accordance with Theorem 1.

the dealer market than in the auction market. In both cases, when operating in the less transparent market, he trades more aggressively on the basis of his information. It turns out that in region B the dealer market offers lower expected trading costs to a noise trader who places a small order, whereas in region C this is true only for some values of the parameters Y, q, and z_0.[18] In both regions B and C, noise traders who place large orders face higher expected trading costs in the dealer market, because in this case they are more easily confused with the insider.

Thus, depending on the size of his order, a noise trader may prefer either the dealer or the auction market. This example shows that positing that the insider follows the same order placement strategy in both types of market is essential to the strong result of Theorem 1. If this assumption is removed, it no longer holds that the more transparent market gives a better price to noise traders *irrespective* of their order size. But a weaker form of the result in Theorem 1 still applies even after removing this assumption:

PROPOSITION 4: *Comparison of Transparent Auction and Dealer Market in the Easley-O'Hara Model. In a model with two trade sizes and high-low security value, the expected trading costs of noise traders in the transparent auction, averaged over all trade sizes, are unambiguously lower than in the dealer market.*

D. Summary

In *all* the models examined in this section, greater transparency reduces, or at least does not increase, the *average* trading costs of noise traders. In all the cases that we have examined, the result that transparency enhances market liquidity still holds when the insider's strategy is treated as endogenous. It is still an open question whether this conclusion can be extended to as general a setting as that of Theorem 1, where almost no restrictions are placed on the distribution of insider information and noise trades.

However, our results are weaker than those obtained when the insider's strategy is held constant across trading systems. While greater transparency tends to lower average trading costs for noise traders, it may not do so for all trade sizes.

V. Conclusion

Our results support the view that the transparency of the market mechanism generally enhances liquidity. In our model, the more transparent a market, the more price setters know about the order flow. The more they know, the better they can protect themselves against losses to insiders, allowing

[18] In region C, a small noise trader prefers the auction market if Y is small and z_0 and q are large. Otherwise, he prefers the dealer market. For instance, if $Y = 1.5$, a noise trader prefers the auction market if $z_0 = q = 0.6$, and prefers the dealer market if $z_0 = q = 0.5$.

them to narrow their spreads; therefore, the implicit bid-ask spread in a transparent auction is tighter than in a less transparent dealer market.

This link between transparency and liquidity needs some qualification. Because informed traders adapt their trading strategy to the market mechanism they face, we find it is possible that in a more transparent market, prices are less favorable over some range of order sizes. Even so, in all the cases we analyze, the expected trading costs of noise traders, averaged across all trade sizes, are lower in the more transparent market.

Thus, our model suggests that if policy makers want to reduce trading costs for uninformed traders, they should publicly disseminate order flow information as promptly as possible. There are several policy implications. First, trade publication should be immediate. This favors centralized electronic order execution systems, where trade reporting is automatic and real-time publication is technically feasible. It also favors consolidation of trading on a centralized exchange or an integrated network of exchanges with common tight publication requirements. Second, our analysis supports measures to raise pretrade transparency, such as wider access to the information available from interdealer networks.

By and large, the predictions of our model are consistent with empirical evidence on spreads for cross-listed European stocks traded on dealer and automated auction markets.[19] They may also help to understand why lately dealer markets are under increasing pressure from the more transparent automated auction systems.[20] However, our model fails to explain why some traders still prefer trading in dealer markets. For example, despite the increasing popularity of the competing auction markets, London's dealers still retain a clientele of wholesale international equity dealing.

A possible reason is that traders do not care only about expected trading costs. The dealer market provides a firm price quote for each order size, whereas in the auction market there is execution risk because the price depends on other contemporaneous orders. Accordingly, agents who are averse to execution risk might prefer the implicit insurance offered by the dealer market (see Pagano and Röell (1993a)).

Other explanations for the popularity of dealer markets may lie in aspects of transparency not captured by the narrow definition of our paper (see O'Hara (1995) for a broad discussion of transparency). In a dealer market, large trades

[19] Seaq International quotes are invariably wider than domestic auction market spreads in France (Pagano and Röell (1993b), Röell (1992b), De Jong et al. (1995)), Belgium (Anderson and Tychon (1993)), Germany (Schmidt and Iversen (1992), Brown (1994)) and Italy (Impenna et al. (1995)). Home-country informational advantage is not enough to explain these differences, as shown in a study of a matched sample of American stocks quoted on Nasdaq and German stocks traded on IBIS, the German automated market (Booth et al. (1994)). To some extent these studies overestimate trading costs in dealer markets, where within-the-quote transactions preponderate. But studies based on transaction data reach the same conclusion for French stocks (see Röell (1992b) and De Jong et al. (1995) and for Belgian stocks (see Degryse (1995)), although for German stocks, Brown (1994) finds roughly equal spreads.

[20] See the evidence reported in Pagano (1996).

are negotiated via personal contact, so that there is some scope for distinguishing between informed and noise traders. Pagano and Röell (1992, section 3.2) argue that this allows dealers to offer better prices to demonstrably uninformed traders, as in the literature on trader anonymity cited in the introduction.

Secondly, in a dynamic context traders may prefer a less transparent regime. Röell (1990b, 1992a), Madhavan (1995), and Naik et al. (1994) argue that dealers may be able to offer a better price for trades that are not publicly disclosed, because they can profit in subsequent trading from the private information they infer from their current trades. In equilibrium there is an opposite effect. Dealers widen their spreads to protect against the adverse selection due to their competitors' information. On balance, the uninformed traders who place large orders may actually gain from the market's lack of transparency, but this comes at the expense of smaller uninformed traders.

Thirdly, we have focused exclusively on transparency in the sense of visibility of the order flow to market makers. If greater transparency also allows market makers to condition their order strategy on knowledge of the order flow, this might increase their profits at the expense of uninformed traders. If so, uninformed traders would prefer a less transparent market (this may explain the popularity of "hidden" limit orders on otherwise transparent electronic exchanges).

All the settings analyzed in this article share a basic set of simplifying assumptions that may limit the generality of our results: static framework, risk neutrality, monopolistic insider, market orders, exogenous noise trading. Testing the robustness of the results when these assumptions are relaxed is a task for future research.

Appendix

Proof of Theorem 1: For convenience, the security's value is normalized so that $\bar{v} = 0$. Therefore, the proof is phrased in terms of deviations of the security's value from its ex ante expected value $\bar{v}$.

It is useful to define two functions, $V(\cdot)$ and $H(\cdot)$, that are directly related to the insider's trading strategy $\tilde{X}(\cdot)$. $H(x)$ is the cumulative distribution function of the insider's trades, unconditional on v:

$$H(x) = \int_v \text{Prob}(\tilde{X}(v) \leq x) dG(v). \tag{A1}$$

$V(x)$ is defined as the expected value of the security given that the insider chooses to trade x:

$$V(x) = \mathrm{E}[v | \tilde{X}(v) = x]. \tag{A2}$$

For x outside the range of $\tilde{X}(v)$ for all v, $V(x)$ is not defined.

In the special case where the insider's trading strategy $X(v)$ is deterministic and strictly increasing, $H(\cdot)$ and $V(\cdot)$ are given directly by:

$$V(x) = X^{-1}(x), \qquad \forall x,$$

and

$$H(x) = G(V(x)), \qquad \forall x.$$

For notational convenience, we assume in the remainder of this proof that $F(\cdot)$ and $H(\cdot)$ are continuously differentiable, with densities $f(\cdot)$ and $h(\cdot)$, respectively. But the proof carries over directly to the case in which these distributions are discrete or, indeed, arbitrary.

The Dealership Market

Suppose that an order of size y arrives. The market makers do not know whether it comes from the insider or from one of the m noise traders. Hence the price is set as:

$$P_D(y) = E(v|y) = \frac{h(y)\ V(y)}{h(y) + mf(y)}. \tag{A3}$$

This is the price that a trader expects to obtain from the dealer when placing an order of size y. The average transaction cost for an uninformed trader placing an order of size y_0 then is:

$$y_0 P_D(y_0) = \frac{h(y_0)}{h(y_0) + mf(y_0)}\, y_0 V(y_0). \tag{A4}$$

The Transparent Auction

Suppose that orders of size $y_0, y_1, \ldots, y_m$ arrive on the market. Since market makers do not know who placed the orders, they will set the market price of the security equal to:

$$P(y_0, y_1, \ldots, y_m) = \mathrm{E}(v|y_0, y_1, \ldots, y_m) = \frac{\sum_{i=0}^{m} h(y_i) V(y_i) \prod_{j\neq i} f(y_j)}{\sum_{i=0}^{m} h(y_i) \prod_{j\neq i} f(y_j)}. \tag{A5}$$

This is the expected value of the security given that market makers observe all the trade sizes $y_0, y_1, \ldots, y_m$ and that they know that there is only one insider (whose trades have density function $h(\cdot)$) and that there are m noise traders (whose trades have density functions $f(\cdot)$).

From the viewpoint of an uninformed trader who places an order of y_0, the expected price $P_A(y_0)$ is:

$$P_A(y_0) = \mathrm{E}[P(y_0, y_1, \ldots, y_m)|y_0]$$
$$= \int_{y_1} \ldots \int_{y_m} P(y_0, y_1, \ldots, y_m)\, f(y_1) \ldots f(y_{m-1}) h(y_m) dy_1 \ldots dy_m \quad \text{(A6)}$$

Observe that we can rewrite equation (A5) as:

$$P(y_0, y_1, \ldots, y_m) = \frac{h(y_0)V(y_0) \prod_{j\neq 0} f(y_j)}{\sum_{i=0}^{m} h(y_i) \prod_{j\neq i} f(y_j)} + \frac{\sum_{i=1}^{m} h(y_i)V(y_i) \prod_{j\neq i} f(y_j)}{\sum_{i=0}^{m} h(y_i) \prod_{j\neq i} f(y_j)}. \quad \text{(A5')}$$

Inserting this expression in the integral of equation (A6), the second term integrates to zero, by the symmetry assumptions:

$$f(y) = f(-y), \qquad h(y) = h(-y), \qquad \text{and} \qquad V(y) = -V(-y). \quad \text{(A7)}$$

Thus the expected price from the viewpoint of uninformed trader 0 is:

$$P_A(y_0) = \int_{y_1} \ldots \int_{y_m} \frac{h(y_0)V(y_0) \prod_{j\neq 0} f(y_j)}{\sum_{i=0}^{m} h(y_i) \prod_{j\neq i} f(y_j)} f(y_1) \ldots f(y_{m-1}) h(y_m) dy_1 \ldots dy_m \quad \text{(A8)}$$

The expected trading cost for an uninformed dealer in the auction market is $y_0 P_A(y_0)$. This is to be compared with the expression for $y_0 P_D(y_0)$ in equation (A4), i.e. the trading cost that trader 0 would expect to pay in the dealer market for the same order. Since $yV(y) \geq 0$, the expected cost is higher in the dealer market if $R_D > R_A$, where

$$R_D = \frac{1}{h(y_0) + mf(y_0)} \quad \text{(A9)}$$

and

$$R_A = \int_{y_1} \ldots \int_{y_m} \frac{\prod_{j\neq 0} f(y_j)}{\sum_{i=0}^{m} h(y_i) \prod_{j\neq i} f(y_j)} f(y_1) \ldots f(y_{m-1}) h(y_m) \mathrm{d}y_1 \ldots \mathrm{d}y_m. \quad \text{(A10)}$$

Note that we can rewrite $R_A = IR_D$, where:

$$I = \int_{y_m} \cdots \int_{y_1} \frac{1 + m(f(y_0)/h(y_0))}{1 + (f(y_0)/h(y_0)) \sum_{i=1}^{m} (h(y_i)/f(y_i))} f(y_1) \ldots f(y_{m-1}) h(y_m) \mathrm{d}y_1 \ldots \mathrm{d}y_m . \tag{A11}$$

Let us denote:

$$A \equiv \frac{f(y_0)}{h(y_0)} \quad \text{and} \quad K(y_i) \equiv \frac{h(y_i)}{f(y_i)}, \quad \forall i \neq 0; \tag{A12}$$

so that equation (A11) can be rewritten as:

$$I = \int_{y_m} \cdots \int_{y_1} \frac{1 + mA}{1 + A \sum_{i=1}^{m} K(y_i)} f(y_1) \ldots f(y_m) K(y_m) \mathrm{d}y_1 \ldots \mathrm{d}y_m . \tag{A11$'$}$$

In this expression y_m can be interchanged with any of the $y_i (i = 1, \ldots, m-1)$, so that:

$$I = \int_{y_m} \cdots \int_{y_1} \frac{1 + mA}{1 + A \sum_{i=1}^{m} K(y_i)} f(y_1) \ldots f(y_m) K(y_j) \mathrm{d}y_1 \ldots \mathrm{d}y_m , \tag{A11"}$$

$$\forall j = 1, \ldots, m .$$

Averaging this expression over all $j = 1, \ldots, m$, we get:

$$I = \frac{1}{m} \int_{y_m} \cdots \int_{y_1} \frac{(1 + mA) \sum_{j=1}^{m} K(y_j)}{1 + A \sum_{i=1}^{m} K(y_i)} f(y_1) \ldots f(y_m) \mathrm{d}y_1 \ldots \mathrm{d}y_m . \tag{A13}$$

Consider first the inner integral:

$$I_1 \equiv \int_{y_1} \frac{(1 + mA) \sum_{j=1}^{m} K(y_j)}{1 + A \sum_{i=1}^{m} K(y_i)} f(y_1) \mathrm{d}y_1 . \tag{A14}$$

Introducing the notation $B_1 \equiv \Sigma_{i=2}^{m} K(y_j)$, this equation can be rewritten as:

$$I_1 \equiv \int_{y_1} \frac{(1 + mA)[K(y_1) + B_1]}{1 + A[K(y_1) + B_1]} f(y_1)\mathrm{d}y_1. \qquad \text{(A14')}$$

The fraction in this integral is a concave function of $K(y_1)$, and $\int K(y_1)f(y_1)\mathrm{d}y_1 = \int h(y_1)\mathrm{d}y_1 = 1$, because $h(\cdot)$ is a probability density function. Hence, by Jensen's inequality,

$$I_1 \leq \frac{(1 + mA)(1 + B_1)}{1 + A(1 + B_1)}, \qquad \text{(A15)}$$

so that:

$$I \leq \frac{1}{m}\int_{y_m} \cdots \int_{y_2} \frac{(1 + mA)[1 + \sum_{j=2}^{m} K(y_j)]}{1 + A[1 + \sum_{i=2}^{m} K(y_j)]} f(y_2)\ldots f(y_m)\mathrm{d}y_2\ldots\mathrm{d}y_m. \qquad \text{(A16)}$$

Now consider the inner integral I_2:

$$I_2 \equiv \int_{y_2} \frac{(1 + mA)\ \sum_{j=2}^{m} K(y_j)}{1 + A\ \sum_{i=2}^{m} K(y_i)} f(y_2)\mathrm{d}y_2$$

$$= \int_{y_2} \frac{(1 + mA)[K(y_2) + B_2]}{1 + A[K(y_2) + B_2]} f(y_2)\mathrm{d}y_2, \qquad \text{(A17)}$$

where $B_2 \equiv \Sigma_{i=3}^{m} K(y_j)$. Repeating the argument used above for I_1, we obtain:

$$I_2 \leq \frac{(1 + mA)(2 + B_2)}{1 + A(1 + B_2)}, \qquad \text{(A18)}$$

so that:

$$I \leq \frac{1}{m}\int_{y_m} \cdots \int_{y_3} \frac{(1 + mA)[2 + \sum_{j=3}^{m} K(y_j)]}{1 + A[2 + \sum_{i=3}^{m} K(y_j)]} f(y_3)\ldots f(y_m)\mathrm{d}y_3\ldots\mathrm{d}y_m. \qquad \text{(A19)}$$

Repeating the argument again for I_3 to I_m, we obtain:

$$I \leq \frac{1}{m}\frac{(1 + mA)\ m}{1 + Am} = 1. \qquad \text{(A20)}$$

Since $R_A = IR_D$, this shows that $R_A \leq R_D$, and hence that:

$$|P_D(y_0)| \geq |P_A(y_0)| \quad \text{or, equivalently,} \quad y_0P_D(y_0) \geq y_0P_A(y_0), \qquad \text{(A21)}$$

i.e., in the dealer market expected trading costs for noise traders are higher than expected trading costs in the transparent auction (or at least equal to them). Q.E.D.

Proof of the corollary to Theorem 1: The corollary is proved simply by observing that in this case $I = 1$ in the proof of Theorem 1. In this special case the price set by the dealers is:

$$P_D(y_0) = \frac{1}{m+1} V(y_0), \tag{A22}$$

and the corresponding price to be expected in the auction market is:

$$P_A(y_0) = \mathrm{E}\left[\frac{\sum_{i=0}^{m} V(y_i)}{m+1} \middle| y_0 \right] = \frac{1}{m+1} V(y_0). \tag{A23}$$

Proof of Lemma 1: As before, $G(v)$ denotes the distribution of the true value of the security, v, and $g(v)$ denotes its density. The distribution of each of the m noise trades, $F(u)$, is now simply given as follows. The noise trader either does not trade with probability 1-z or trades 1 unit with probability z. If he trades, he buys or sells with probability ½ each.

Consider first the equilibrium strategy of the informed trader when he can precommit. Clearly he cannot trade any quantities other than -1, 0, or 1 unit without being identified as an informed trader. Therefore his strategy is fully characterized by a threshold value v^* such that he does not trade if $v \in (-v^*, v^*)$, he buys 1 unit if $v > v^*$ and sells 1 unit if $v < -v^*$. The threshold v^* is found by maximizing his expected profit, unconditional on v:

$$\underset{v^*}{\mathrm{Max}}\ 2[1 - G(v^*)] \left[\frac{\int_{v^*}^{\infty} v g(v)\ dv}{1 - G(v^*)} - P_D \right], \tag{A24}$$

where the term 2 [1 − G(v*)] is the probability that the insider trades 1 unit, the second term in brackets is the expected profit of the insider conditional on $|v| > v^*$, and the dealer's ask price P_D is the expected value of the security given that a trade occurs:

$$P_D = \frac{\int_{v^*}^{\infty} v\ g(v)\ dv}{1 - G(v^*) + m(z/2)} \tag{A25}$$

The first order condition for this problem is:

$$v^* = \frac{\displaystyle\int_{v^*}^{\infty} v\, g(v)\, dv}{1 - G(v^*) + m(z/2).} \tag{A26}$$

Now consider the case in which the informed trader cannot precommit to a threshold v^* ex ante. Since ex post the informed trader will want to trade if and only if $|v| > P_D$, there is an additional constraint on the threshold, namely that$v^* = P_D$. But (A25) and (A26) imply that v^* satisfies this condition. Hence, the ex post optimality constraint does not bind. Q.E.D.

Proof of Proposition 3: We start by noting that $X(v)$ is an optimal strategy for the insider in all three markets given the postulated pricing rules (a) to (c). This is immediate since his problem is:

$$\operatorname*{Max}_{x} \mathrm{E}[x(v - p)] = x[v - \alpha - \beta x/2], \tag{A27}$$

in all three markets. Using the trading strategy $X(v)$, one sees that $G(v) = G(\alpha + \beta x) = F(x)$ by the linear transformation assumption, so that the insider's order x and the noise trader's order u are independently and identically distributed (i.i.d.).

Now we shall prove that conditions (a) to (c) in the text of the proposition are equilibrium pricing rules given the above strategy for the insider. We shall make use of the following three lemmas:

LEMMA A1. *Let x and u be i.i.d. and suppose that we observe y_1 and y_2 where either $\{y_1 = x$ and $y_2 = u\}$ or $\{y_1 = u$ and $y_2 = v\}$ with equal probability. Then*

$$\mathrm{E}(x|y_1, y_2) = (y_1 + y_2)/2\,.$$

Proof. By symmetry, $\mathrm{E}(x|y_1, y_2) = \mathrm{E}(u|y_1, y_2)$. Also, since $x + u = y_1 + y_2$ for sure, we have that $\mathrm{E}(x|y_1, y_2) + \mathrm{E}(u|y_1, y_2) = y_1 + y_2$. Hence the result follows immediately.

LEMMA A2. *Let u and x be i.i.d. with mean zero. Suppose $w = x$ or $w = u$ with probabilities λ and $(1 - \lambda)$ respectively. Then $E(x|w) = \lambda w$.*

Proof. Because x and u are i.i.d., observing the value of w is not informative about whether x or u is observed. Hence the posterior probabilities of having observed x and u are still λ and $(1 - \lambda)$, respectively. Hence, $\mathrm{E}(x|w) = \lambda \mathrm{E}(x|w = x) + (1 - \lambda)\, \mathrm{E}(x|w = u) = \lambda w$.

LEMMA A3. *Let $y = x + u$, where x and u are i.i.d. Then $E(x|y) = y/2$.*

Proof. Suppose not, and let $\mathrm{E}(x|y) = z$, with $z \neq y/2$. Since x and u are i.i.d., $\mathrm{E}(u|y) = z$ as well. But then $\mathrm{E}(y|y) = \mathrm{E}(x + u|y) = z + z \neq y$, which is a contradiction.

Lemma A1 shows that in the transparent auction market $E(x|y_1, y_2) = (y_1 + y_2)/2$. Hence $E(v|y_1, y_2) = \alpha + \beta\, E(x|y_1, y_2) = \alpha + \beta\, (y_1 + y_2)/2$.

Lemma A2 shows that in the dealer market $E(x|y_i) = y_i/2$, for both $i = 1$ and $i = 2$. Hence, $E(v|y_i) = \alpha + \beta\, E(x|y_i) = \alpha + \beta\, y_i/2$.

Lemma A3 shows that in the batch auction $E(x|y_1 + y_2) = (y_1 + y_2)/2$. Hence (c) follows. Q.E.D.

Derivation of the Insider's Optimal Strategy in the Parameter Regions of Figure 2

Case 1. Assume $q_0 = q$. Then:

$$P_A(B_0, I) = \frac{1}{2}(2 - z_0), \tag{A28}$$

$$P_A(B_1, I) = \frac{1}{2}(1 - z_0), \tag{A29}$$

$$P_D(B_0) = \frac{1}{1 + z_0}, \tag{A30}$$

$$P_D(B_1) = 0. \tag{A31}$$

In both markets, the insider makes more profit placing order B_1, because he pays a lower price and buys the larger quantity Y. Thus $q_0 = q$ cannot be an equilibrium strategy.

Case 2. Assume $q_0 = 0$, i.e. $q_1 = q$. Then:

$$P_A(B_0, I) = \frac{1}{2} z_0, \tag{A32}$$

$$P_A(B_1, I) = \frac{1}{2}(1 + z_0), \tag{A33}$$

$$P_D(B_0) = 0, \tag{A34}$$

$$P_D(B_1) = \frac{q}{1 - z_0 + q}. \tag{A35}$$

In the auction market, the expected profit from buying Y is larger if:

$$[1 - P_A(B_1, I)]Y > 1 - P_A(B_0, I), \tag{A36}$$

where the expression on the right-hand side is the expected profit from buying 1 unit only. Substituting for $P_A(B_0, I)$ and $P_A(B_1, I)$ from (A32) and (A33), the inequality in (A36) can be rewritten as:

$$Y \geq \frac{2 - z_0}{1 - z_0}. \tag{A37}$$

If this condition holds, buying Y is an equilibrium strategy for the insider in the auction market. The corresponding condition in the dealer market can be derived as:

$$Y \geq \frac{1 + q - z_0}{1 - z_0}. \tag{A38}$$

Condition (A37), being stronger than its dealer market analogue (A38), guarantees that in equilibrium the insider buys the large quantity Y in both markets. This defines the boundary of region A, where the insider's probability of buying the small quantity is zero in the auction as well as in the dealer market: $q_0^A = q_0^D = 0$.

If condition (A38) holds, but the stronger condition (A37) does not, i.e.,

$$\frac{1 + q - z_0}{1 - z_0} < Y \leq \frac{2 - z_0}{1 - z_0}, \tag{A39}$$

the insider's optimal strategy in the dealer market is still to place a large order ($q_0^D = 0$), but in the auction market there is no pure strategy equilibrium. As shown below, a mixed strategy equilibrium exists: $q_0^A \in (0, q)$. Condition (A39) defines the boundaries of region B in Figure 1.

If even the weaker condition (A38) is violated, then also in the dealer market there is only a mixed strategy equilibrium: $q_0^D \in (0, q)$. This occurs in region C of Figure 2.

Case 3. Assume $q_0 \in (0, q)$. Then the insider must be indifferent between buying 1 unit and buying Y units. In the auction market, this means:

$$1 - P_A(B_0, I) = [1 - P_A(B_1, I)]Y, \tag{A40}$$

and hence:

$$q_0^A = z_0 q \, \frac{2 - z_0 - (1 - z_0)Y}{(1 - z_0)Y + z_0}. \tag{A41}$$

Similarly, in the dealer market we obtain:

$$q_0^D = z_0 \frac{1 + q - z_0 - (1 - z_0)Y}{(1 - z_0)Y + z_0}. \tag{A42}$$

It is readily verified that

$$q_0^A > q_0^D, \qquad \text{i.e. } q_1^A < q_1^D, \qquad \forall Y > 1, \tag{A43}$$

so that the insider trades more aggressively in the dealer market (that is, q_1^D is higher so that he places more weight on the larger trade size).

Ranking of the Two Markets by Noise Traders' Costs in Regions B and C

To show that in region B a noise trader wanting to place a small order would prefer the dealer market, observe that in that region the dealer's bid-ask spread for small orders is zero (see equation (A34)), whereas the auction's expected trading cost for such orders is:

$$P_A(B_0, N) = \frac{1}{2}\,\frac{1 - (1 - z_0)(Y - 1)}{Y - z_0(Y - 1)}\,\frac{Yq}{1 + z_0(Y - 1)}, \tag{A44}$$

which is positive whenever $Y < (2 - z_0/1 - z_0)$ (the boundary with region A).

To show that in regions B and C a noise trader intending to place a large order would prefer the auction market, recall from (A43) that $q_1^A < q_1^D$, and from (11) that the price charged by the dealer for large buy orders, $P_D(B_1)$, is an increasing function of q_1^D. Together, these two facts imply that:

$$P_D(B_1) = \frac{q_1^D}{1 - z_0 + q_1^D} \geq \frac{q_1^A}{1 - z_0 + q_1^A}, \tag{A45}$$

where the right-hand side is the price that would ensue on the dealer market if the insider were to use the same strategy that he chooses in the auction market. But by Theorem 1, we know that if the strategy of the insider is held constant, the dealer market features trading costs higher than (or equal to) the auction market:

$$\frac{q_1^A}{1 - z_0 + q_1^A} \geq P_A(B_1)\,. \tag{A46}$$

Hence, $P_D(B_1) \geq P_A(B_1)$.

Proof of Proposition 4: For the average trading costs of noise traders to be lower in the auction, the expected profits of the insider must be higher in the dealer market.

Let us first compute the expected profits of the insider in the dealer market, π_D. In regions A and B, $q_0^D = 0$ and the relevant price is given by equation (A35), so that

$$\pi_D = qY(1 - P_D(B_1)) = qY\,\frac{1 - z_0}{1 - z_0 + q}. \tag{A47}$$

In region C, the insider's randomization is such that his profits are the same irrespective of his order size: $1 - P_D(B_0) = Y(1 - P_D(B_1))$. So his expected profits can be written:

$$\pi_D = q_0(1 - P_D(B_0)) + q_1 Y(1 - P_D(B_1)) = q(1 - P_D(B_0)) = q\,\frac{z_0}{z_0 + q_0^D}$$
$$= q\,\frac{(1 - z_0)Y + z_0}{1 + q}, \qquad \text{(A48)}$$

where in the last two steps $P_D(B_0)$ and q_0^D have been substituted out using equations (10) and (A42), respectively.

The expected profits of the insider in the auction market are obtained in similar fashion. In region A, where the insider sets $q_0^A = 0$,

$$\pi_A = qY(1 - P_A(B_1, I)) = \frac{1}{2}\,qY(1 - z_0). \qquad \text{(A49)}$$

In the second step of (A49) we have used equation (9) in conjunction with $q_0^A = 0$. To compute the insider's expected profits in region B and C, notice that equations (A40), (A41), (8), and (9) together imply:

$$\pi_A = q_0(1 - P_A(B_0, I)) + q_1 Y(1 - P_A(B_1, I)) = q(1 - P_A(B_0, I))$$
$$= \frac{1}{2}\,\frac{qY}{1 - z_0 + z_0 Y}. \qquad \text{(A50)}$$

In each of the three regions, the expected profits that the insider earns in the dealer market exceed those that he gets in the auction. In region A, the expression for π_D in (A47) is larger than that for π_A in (A49) because $1 - z_0 + q < 2$ (as $q \leq 1$). In region B, the condition for π_D in (A47) to exceed π_A in (A50) is seen to be equivalent to:

$$(1 - z_0)Y > \frac{3}{2} - z_0 - \frac{1 - q}{2z_0}. \qquad \text{(A51)}$$

From the left-hand-side inequality in (A39), we know that $(1 - z_0)\,Y > 1 + q - z_0$. Hence, a sufficient condition for $\pi_D > \pi_A$ in region B is that the expression $(1 + q - z_0)$ exceed the right-hand-side expression in (A51), which is easily shown. Finally, in region C, one must compare the expression for π_D in (A48) with that for π_A in (A50). One finds that $\pi_D > \pi_A$ if:

$$\frac{1}{2}\,(1 + q)Y < [(1 - z_0)Y + z_0](1 - z_0 + z_0 Y) = Y + z_0(1 - z_0)(Y - 1)^2. \qquad \text{(A52)}$$

This condition always holds, because the left-hand side is smaller than Y (because $q < 1$), whereas the right-hand side is larger than Y (as $Y > 1$). Q.E.D.

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