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Security Prices and Market Transparency

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Many recommendations for reforming securities markets are predicated on the belief that providing information on order flow and other market variables to traders (i.e., increasing *market transparency*) will increase liquidity and improve price efficiency. This paper demonstrates that market transparency can actually increase price volatility and lower market liquidity. This occurs even though transparency increases the precision of traders' predictions about the asset's value. In a sufficiently large market, transparency always reduces volatility and improves market quality. We use these results to assess various policy proposals concerning the disclosure of trading information. *Journal of Economic Literature Classification Numbers:* D82, D83, G12, G14.

1. INTRODUCTION

The relation between trading arrangements and asset prices is the subject of increasing interest to financial econmists. An important attribute of a trading system is *market transparency*, defined by O'Hara (1995) as "the ability of market participants to observe the information in the trading process." Information, in this case, can refer to knowledge about current or past prices, quotes, or volumes, the sources of order flow, and the identities and motivations of market participants. Consequently, transparency has many dimensions.

Issues of transparency concerning the disclosure of information on quotes and transactions have been central to some recent policy debates. In London, for example, the question of whether to delay the reporting of large

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trades has been highly controversial (Naik *et al.*, 1994; Gemmill, 1994; Board and Sutcliffe, 1995). Recent academic research has also focused on the importance of disclosing price information. Biais (1993) shows that quotation transparency will increase market efficiency and increase liquidity. Lyons (1994) argues that the lack of trade disclosure in foreign exchange markets leads to a "hot potato" effect when a large trade is passed from dealer-to-dealer, creating excess volatility. Madhavan (1995) shows that dealers and large traders may benefit from the absence of a unified trade reporting system. Thus, market integration may necessitate rules that require dealers to publicly disclose their past trades.

This paper analyzes another dimension of transparency, the impact of disclosing information about the composition of order flow to market participants. Specifically, order flow can be thought of as consisting of price-sensitive and price-insensitive (or inelastic) components. This distinction is useful because the two components have very different effects on price formation. The price-sensitive component of order flow arises from the strategic decisions of speculative traders and liquidity providers, given their information regarding asset value. This component is fundamental to price formation since in the absence of price contingent orders, there is no mechanism to achieve market clearing and price discovery. The price-insensitive component of order flow arises from the liquidity demands of traders, possibly including portfolio hedging trades by speculative traders and liquidity providers. This portion of order flow is, by definition, unrelated to information about the asset's fundamental value and is the source of transitory order imbalances. Such order flow does not contribute directly toward price discovery, although it does have a transitory impact on asset prices. Given these differences, disclosing information about the composition of order flow to market participants may have significant effects on price formation.

Transparency of this form lies at the heart of many important issues concerning the design and regulation of securities markets. At the most general level, transparency regarding the composition of order flow has implications for the choice of trading design. In a totally automated trading system, where the components of order flow cannot be distinguished, transparency is not an issue. However, most floor-based trading systems offer some degree of transparency regarding the composition of order flow. For example, on the New York Stock Exchange (NYSE), the identity or reputation of the broker representing the order may provide valuable information about the source and motivation for the trade. Benveniste *et al.* (1992) provide a model of this type. Thus, an examination of the role of transparency regarding order flow may shed some light on the relative merits of floor versus automated trading systems.

There also are many other current issues concerning the disclosure of order flow information. For example, sunshine trading, where traders can preannounce their orders prior to trading, represents transparency of this form. A related issue concerns the desirability of publicizing order imbalances arising from the accumulation of retail orders or the expiration of derivative securities in other markets. Similarly, there is debate about whether certain types of orders (e.g., program trading) should be disclosed to market participants.[1] Finally, this aspect of transparency underlines the logic for trading halts (or ‘‘circuit breakers’’) intended to reduce price volatility in times of market stress by publicizing information on transitory order imbalances to market participants.

There is a widespread belief that disclosing information about the composition of order flow, and order imbalances in particular, will improve market quality. The argument is straightforward. Publicizing information on price-inelastic order imbalances prior to trading will induce speculative traders (e.g., floor traders or locals) and market makers to place stabilizing orders. This in turn will reduce short-run price volatility and increase market liquidity. This logic has immediate practical implications. For example, it implies that excess volatility arising from transitory imblances (arising, say, from option expirations or the accumulation of small retail orders) could be reduced by publicizing these imbalances prior to trading. Similarly, if the imbalance in question arises from a large block trade placed by a liquidity trader, the logic above would argue that the trader would prefer to publicize the order prior to trading, i.e., to do a sunshine trade. Finally, the argument could be used to justify trading halts to allow the resubmission orders when faced with large, transitory order imbalances.

Although the argument in favor of transparency appears compelling, a more formal analysis is warranted given the practical importance of this issue. We develop a theoretical model with strategic traders to examine the effects of publicizing order imbalances. The imbalances in our model, as noted above, may be interpreted as arising from a variety of sources, including trades related to the expiration of derivatives, the accumulation of small retail orders routed through automated systems, or even a sunshine trade by a large institutional trader. Thus, a variety of different cases of interest can be examined in the context of our model.

We obtain three principal results. First, we demonstrate conditions under which transparency exacerbates the price volatility generated by transitory order imbalances. This can occur despite the fact that such imbalances are themselves the source of transitory price movements. Market quality can also suffer with lower liquidity and higher implicit transaction costs. Transparency can also induce less liquidity trading by price sensitive traders,

[1] For example, specialists on the New York Stock Exchange (NYSE) can identify program trades routed to them through the NYSE’s SuperDot system. See, Hasbrouck (1994).

even if their orders are not observed by other market participants. However, transparency implies strictly more informative prices.

Second, we prove that transparency can induce a form of market failure even in a large auction market.[2] This can occur because greater transparency reduces the effective amount of noise in the market, lowering market liquidity and making prices more sensitive to undisclosed liquidity trades.

Third, we show that transparency reduces price volatility and increases market liquidity if the market is sufficiently large and liquid, provided that transparency does not cause market failure as noted above. In a very liquid market, transparency leads to more stable prices because traders' strategies are not significantly altered by information on the composition of order flow.

These results have important policy implications. For example, the results here may shed light on the choice between floor-based systems and fully automated, typically anonymous, trading systems. Specifically, suppose that, as suggested by Benveniste *et al.* (1992), traders obtain better information on the portion of the order flow that is price inelastic on an exchange floor than in an automated trading system. Floor-based systems may be more transparent because traders can observe the identities of the brokers submitting orders and make inferences regarding the motivations of the initiators of those orders. Unless it is explicitly designed to function in a nonanonymous fashion, such inferences are extremely difficult in a system with electronic order submission. If this is the case, our results show that traditional exchange floors may be preferred over automated systems for the active issues while the opposite may be true for inactive issues. This appears to be the case in many countries. Similarly, the results indicate that a trading halt to disclose information on transitory order imbalances may actually exacerbate the price movement associated with this shock. In short, so-called "circuit breakers" may have unintended effects. Finally, the results provide insights into why some liquidity traders may avoid sunshine trades, even if they can benefit from reputation signalling.

It is worth emphasizing how our results differ from those of other papers that study the disclosure of information about the sources and motivation of trades. Forster and George (1992) model the effect of anonymity in securities markets. They show that market makers' private information regarding the distribution of noise trading can significantly affect asset prices. In this respect, their analysis complements ours. Röell (1990) and Fishman and Longstaff (1992) model dual-capacity trading. In these models, broker-dealers can trade based on their private information regarding the order flow directed to them by their own customers. In contrast, the information disclosed here is made public. Admati and Pfleiderer (1991) provide

[2] The result applies to the linear equilibrium which is the focus of much of the previous literature. However, there may be nonlinear equilibria that exist when linear equilibria fail.

a model of sunshine trading where some liquidity traders can preannounce the size of their orders while others cannot. They show that those investors who are able to preannounce their trades enjoy lower trading costs, but the costs for liquidity traders who are unable to preannounce their trades rises. Intuitively, preannouncement identifies the trade as uniformative, but increases the adverse selection costs for other traders. This is not the case in our model; there are conditions under which a liquidity motivated trader will choose not to disclose his trade, even if this trade can be identified as uninformative. In other circumstances, disclosure may be optimal even though, unlike Admati and Pfleiderer (1991), the number of speculative traders is constant in the short-run.

At a more general level, our analysis provides a contrast to theoretical papers that conclude that transparency is beneficial under relatively general conditions. Pagano and Röell (1996) compare and contrast various trading systems, concluding that transparent systems generally provide higher welfare for uninformed investors. However, they assume implicitly that the strategic behavior of traders is the same in all markets even though information varies with the degree of transparency. In contrast, in this paper traders are strategic and transparency induces a change in their behavior that may result in higher price volatility and lower liquidity. Madhavan (1995) concludes that transparency increases price efficiency and reduces volatility. This result, however, applies to transparency through the disclosure of trade price information, as opposed to transparency through the disclosure of order flow information. The exact form that transparency takes is crucial.

The paper is organized as follows: In Section 2 we describe the theoretical framework and in Section 3 we analyze a nontransparent trading mechanism. Section 4 examines a transparent market mechanism and Section 5 compares the two equilibria using a variety of criteria. We demonstrate conditions under which transparency affects market performance and discuss a number of applications of our results. Finally, Section 6 concludes the paper. All proofs are in the Appendix.

2. THE ANALYTICAL FRAMEWORK

Consider an economy with two financial assets: a risky asset and a riskless bond. The risky asset is traded at time 0 in an auction market. We discuss two alternative trading protocols for this market that differ in the amount of market information provided to traders at the time of order submission. The exact details of the protocols are explained after we establish the basic framework and notation.

The value of the risky asset in period 1 in the future is represented by a random variable, $\tilde{v}$. The stochastic payoff, $\tilde{v}$, can be thought of either as a liquidating dividend or the full information price following a public announcement. In this market, there are N traders (indexed by $i = 1, \ldots, N$), each of whom enters the market with an initial endowment of x_i of the risky asset and initial wealth W_{0i}. Each trader views other traders' asset endowments as a normally distributed random variable with mean 0 and precision $\psi > 0$. Precision is the inverse of the variance. Negative endowments are interpreted as short positions. The assumption of a zero mean is simply a convenient normalization.[3]

Traders can be thought of as individual investors (referred to as speculative traders) or as market makers, and in the latter case, x_i is interpreted as their inventory position. Another interpretation for x_i is that off-exchange investors place orders with market makers, so that $-x_i$ is the net demand of these investors, i.e., the amount of securities that market maker i has promised to deliver.

Each trader receives a private information signal concerning the payoff of the risky asset. Trader i's information signal, $\tilde{y}_i$, is a random variable $\tilde{y}_i = v + \tilde{\varepsilon}_i$ where v is the realized value of the risky asset and $\tilde{\varepsilon}_i$ is normally distributed with mean 0 and precision $\tau > 0$. The realization of the information signal $\tilde{y}_i$ is denoted y_i. Assuming all traders have diffuse prior beliefs, trader i's prior distribution of $\tilde{v}$ is normal with mean y_i and precision τ.[4] The private information of trader i is the pair (x_i, y_i).

We assume traders have negative exponential expected utility functions over final period wealth, W_{1i}, of the form $U(W) = -e^{-\rho W}$, where $\rho > 0$ is the coefficient of risk aversion. Let q_i represent the order quantity of trader i, with the convention that securities purchases are represented by positive numbers and trader sales by negative numbers. Information is not the sole motivation for trade in this model. Since traders are risk averse and enter the market with nonzero endowments, a portion of transaction volume arises from portfolio hedging. As a result, liquidity trading arises endogenously.

In addition to the demands of the speculative traders/market makers, there is another component of order flow, denoted by $\tilde{Z}$, that represents the imbalance arising from traders whose demands are price inelastic. We assume that (unconditionally) $\tilde{Z}$ is normally distributed with a mean normalized to zero and variance σ_z^2. The realized order imbalance is denoted Z, with the convention that $Z > 0$ represents excess demand and $Z < 0$ represents excess supply of the risky asset.

[3] Note that because there are a finite number of traders in the market, the realized total endowment is nonzero. This fact presents no difficulty if the traders present are thought of as being chosen from a very large pool of potential traders with a new endowment of zero.

[4] The assumption of independent signals is mathematically equivalent to specifying a diffuse prior distribution for traders. This assumption is made purely for convenience and can be relaxed without altering the qualitative conclusions.

We compare and contrast two trading systems that differ in their degree of transparency: The first system is opaque in that trading is completely anonymous and traders do not receive any information about the composition of order flow. The second system, in contrast, is fully transparent in that Z is disclosed to market participants prior to trading. Different interpretations of the order flow shock correspond to different views of transparency.

Transparency in automated routing systems. In many exchanges, including the NYSE, the overnight accumulation of orders, presumably from those traders whose demands are price inelastic, through automated trading systems is disclosed to floor participants prior to trading. If Z is interpreted as the consolidation of small retail trades through an automated system, transparency corresponds to disclosing the imbalance on this system prior to trading. In this case, it is important to note that the variance σ_z^2 is itself directly proportional to the number of traders participating in each auction, and hence is positively related to the time between successive auctions. The greater the time between auctions, the greater the number of trader arrivals, and σ_z^2 becomes large. Thus, in the context of our model, the distinction between transparent and opaque protocols is greatest in thin markets with infrequent trading.

Transparency through voluntary disclosure. If we interpret Z as the order of a large uninformed trader, transparency takes the form of sunshine trading, where a trader can preannounce his trading intentions. This can be formally modeled within the current framework. If, as we show, prices are unbiased predictors of true value, a risk-averse uniformed trader will hedge a constant fraction of the endowment using a market order. Thus, Z represents the aggregate amount of hedging demand. Informed traders will not choose to disclose their trades if given the opportunity to do so, since this means revealing valuable information to competitors before prices are determined.

Transparency through floor-trading. In a floor-based trading system, the identities of floor brokers may provide clues to the source and motivations of initiators they represent, as in Benveniste *et al.* (1992). Further, as prices are determined through a process of open outcry, participants on the trading floor can observe each trader's reaction as prices adjust toward their equilibriating level. Thus, Z can be interpreted as the orders originating from traders with inelastic demands. Note that in this case the assumption that the realization of the order imbalance is observed without error is strong since some brokers may represent orders from multiple traders. This assumption was made purely for convenience; the model can be generalized to accommodate the case where disclosure takes the form of an imperfect signal about the realized imbalance without altering our basic conclusions, as we discuss in more detail below.

3. TRADING WITHOUT TRANSPARENCY

The first protocol we consider for the auction market at time 0 is one in which traders submit orders, either price-contingent limit orders or market orders, that are accumulated for simultaneous execution at a single market clearing price.[5] This protocol is opaque because traders do not receive any information about the composition of order flow.

Trading is modeled as a game characterized by the number of players, their reward functions, information signals, endowments, and beliefs. Let W_{0i} denote the cash holdings (initial wealth) of trader i. The private information of trader i is represented by $I_i = (W_{0i}, x_i, y_i) \in \mathscr{R}^3$ for $i = 1, \ldots, N$.[6] Trader i's (pure) strategy is a mapping $q_i: \mathscr{R} \times \mathscr{R}^3 \to \mathscr{R}$, mapping price and the initial state into desired order quantity. The opaque or nontransparent trading mechanism is described as a game $M^{\text{nt}} = (N, u(\cdot), \{I_i\}, \{q_i(\cdot)\})$. We define an equilibrium for this trading mechanism using a Bayes–Nash solution concept, as in Madhavan (1992).

DEFINITION 1. An equilibrium for the mechanism M^{nt} is a price p^*, and a set of strategy functions, $\{q_i(p; I_i)\}$, such that:

(i) Excess demand is zero at the equilibrium price

$$\sum_{i=1}^{N} q_i(p^*; I_i) + Z = 0.$$

(ii) Trader i maximizes the expected utility of final period wealth, W_{1i}, given the strategies of other traders

$$q_i(p^*; I_i) \in \underset{\{q_i\}}{\operatorname{argmax}}\{E[u(\tilde{W}_{1i}) \mid I_i, p^*)\},$$

where

$$\tilde{W}_{1i} = (\tilde{v} - p^*)q_i + \tilde{v}x_i + W_{0i}$$

for $i = 1, \ldots, N$.

[5] Examples include batch markets for inactive stocks and closed-bid auctions of various types.

[6] We assume throughout the paper that $N > 2$, to eliminate trivial cases where, say, a monopolist insider sets arbitrarily high prices. This would not be a problem if the mean of $\tilde{Z}$ were price dependent.

Condition (i) requires that the equilibrium price clears the market. Condition (ii) requires that the strategy function selected by trader i be a best response to the conjectured strategy functions of other traders. In forming their best response, traders use Bayes' rule to form their beliefs using the statistical information generated by the mechanism, including the price. The price not only determines the equilibrium allocation but also conveys information to traders with rational expectations. Thus, traders' probability assessments are determined endogenously in equilibrium. Implicit in condition (ii) is the idea that traders choose strategies knowing that they not only influence prices directly through their order size, but also indirectly through the effect their actions have on the beliefs of other players. In what follows, we will focus on linear equilibria because these have been the primary focus of the previous literature. Proposition 1 demonstrates that there exists a linear equilibrium for the opaque trading protocol; i.e., M^{nt} has a solution with linear price and strategy functions.

PROPOSITION 1. *There exists an equilibrium for the exchange mechanism* M^{nt} *described above where the optimal strategy functions*, $\{q_i(p;\ I_i)\}$, *and market clearing price*, p^*, *are given by*

$$q_i(p; I_i) = \gamma[(1-\delta)(y_i - p) - \alpha x_i]$$

$$p^* = \frac{1}{N}\left(\sum_{i=1}^{N}\left[y_i - \left(\frac{\rho}{\tau}\right)x_i\right] + (N-1)\lambda Z\right)$$

for $i = 1, \ldots, N$, *where* α, δ, γ, *and* λ *are positive constants described in the Appendix.*

Proposition 1 provides a closed-form solution for the opaque system M^{nt}.[7] A trader's optimal strategy has two components: the first component is $\gamma(1-\delta)(y_i - p)$, i.e., a constant proportion of the difference between the information signal and price. This represents the *speculative* or information-motivated part of trade. The second component, $-\alpha\gamma x_i$, is a negative fraction of the endowment, and represents *portfolio hedging*. This component is not based on private information signals.[8]

From the discussion above, liquidity trading has two dimensions: (i) A portion Z that is disclosed, and (ii) a portion $-\alpha\gamma x$, that is not disclosed.

[7] The proposition does not rule out the existence of equilibria with nonlinear strategies. We do not examine these possibilities. The linear equilibrium is a natural object of attention since it imposes the fewest computational burdens on agents, exhibits stability, and yields a closed-form solution.

[8] In our framework, if x_i is not observable to traders other than i, there is no credible way for trader i to separate the speculative component of his or her order from the portfolio hedging component.

The expected volume of portfolio hedging, $E[|\alpha\gamma x|]$, is proportional to the standard deviation of risky asset endowments, $1/\sqrt{\psi}$, while the expected size of the order imbalance, $E[|Z|]$, is proportional to σ_z.[9]

The following result demonstrates a positive relation between transitory price volatility and the level of noise trading.

PROPOSITION 2 (Noise Trading and Pricing Errors). *The expected absolute deviation of price from fundamental value increases with the expected volume of noise trading.*

Proposition 2 confirms our intuition that noise trading is the source of transitory pricing errors that cause prices to deviate from value. The central question in many issues regarding market transparency is whether providing information about such order imbalances will reduce price volatility. While such an inference appears intuitive, it need not always be true, as we show below.

4. TRADING IN A TRANSPARENT MARKET

We turn now to an analysis of a *transparent* market where information on current market conditions is disseminated to traders prior to trading.[10] Consider a trading protocol or mechanism, denoted M^{t}, where Z is displayed to traders before they submit their demands. The only difference between this system and the opaque system M^{nt} is that trader i ($i = 1, \ldots, N$) observes Z before choosing $q_i(p)$. We retain the Bayes–Nash equilibrium concept of Definition 1. The next result establishes the existence of a well-defined solution to the game M^{t}.

PROPOSITION 3. *If $\tau < \tau^* \equiv \rho^2(N-2)/\psi N$, there exists a linear Bayes–Nash equilibrium for the transparent mechanism M^{t} where the optimal strategy functions, $\{q_i(\cdot; I_i)\}$, and market clearing price, p^*, are given by*

$$q_i(p; I_i) = \gamma_1(1-\delta_1)(y_i - p^*) - \gamma_1\alpha_1 x_i - \gamma_1\delta_1\kappa Z,$$

$$p^* = \frac{1}{N}\left\{\sum_{i=1}^{N}\left[y_i - \left(\frac{\rho}{\tau}\right)x_i\right] + \left[\frac{1-N\zeta}{\gamma_1(1-\delta_1)}\right]Z\right\}$$

for $i = 1, \ldots, N$, where γ_1, δ_1, α_1, ζ, and κ are positive constants defined in the Appendix.

[9] This follows from the normality of $\tilde{x}_i$ and $\tilde{Z}$.

[10] Examples include the opening procedures for continuous trading systems in which traders receive indicated prices based on the current excess demand prior to the opening. The NYSE opening auction provides some transparency by displaying information on the overnight accumulation of market orders.

There are two major differences between this equilibrium and the equilibrium in the opaque, fully anonymous system M^{nt}. First, the conditions necessary for the existence of a linear equilibrium are more stringent. The precision of private information, τ, must be bounded above for existence. Even with large numbers of traders, existence is not assured since $\lim_{N\to\infty} \tau^* = \rho^2/\psi > 0$. Interestingly, this result obtains even though agents are symmetric as far as the *quality* of their information signals is concerned. Intuitively, if traders obtain high quality information signals (i.e., τ is high) and there is very little endogenous liquidity trading (i.e., ψ is high and ρ is low), traders are unwilling to reveal their information to others and less willing to share risk by trading. Thus, transparency may induce a form of market failure. Note, however, that this comment applies only to linear equilibria which are the focus of this paper and much of the previous literature. There may be nonlinear strategies that allow trading even when there is no linear equilibrium. Further, in taking limits, we assumed implicitly that the precision of the private information signal remained constant. An alternative specification, where the total quantity of private information was constant (i.e., that allowed $\tau \to 0$ as $N \to \infty$) would mitigate this result. From an economic viewpoint, both limiting cases appear plausible.

Second, unlike Proposition 1, a trader's strategy, q_i, depends not only on price but also on the disclosed volume Z. Since the coefficient of Z is negative, traders' speculative actions partly accommodate the order flow shock. This effect is offset by changes in the strategies of traders that increases the price impact of noise shocks and reduces the volume of endogenous liquidity trading, as shown below:

PROPOSITION 4. *Traders' strategy functions are less price sensitive in a transparent mechanism:*

$$\gamma_1(1 - \delta_1) < \gamma(1 - \delta).$$

Further, transparency lowers the volume of portfolio hedging trade.

The strategy functions in a transparent market are less price sensitive than the strategies in a nontransparent system. Traders scale back the size of their order for any given discrepancy between their signal and the price. Equivalently, traders demand a larger deviation between the transaction price and their signals in order to absorb a given number of securities. Consequently, as traders' demand schedules become less responsive to price, the sensitivity of prices to portfolio hedging demands that are not disclosed increases.

Proposition 4 also shows that transparency has another effect on trader's demand, i.e., a reduction in endogenous liquidity trading. This result is an additional source of concern regarding disclosure because it implies less risk sharing; it is analogous to the Admati–Pfleiderer result that liquidity traders who cannot preannounce are hurt by sunshine trading.

To summarize this discussion, transparency has complex effects on traders' strategies: First, transparency may be stabilizing because it allows strategic traders to place orders to offset transitory shocks. Conversely, however, transparency may decrease the price-responsiveness of trader's demands, thereby leading to larger price movements in response to liquidity demand shocks. Finally, the reduction in the volume of endogenous liquidity trading trends to create more informative prices and less volatility. Consequently, the net effect on price volatility and market liquidity is unclear. It is to this issue that we now turn.

5. TRADING ARRANGEMENTS AND PERFORMANCE

5.1. *Price Volatility, Informativeness, and Transparency*

The discussion above suggests that transparency has mixed effects on security prices. To analyze this issue in more depth, we consider first the impact of transparency on price informativeness. Our measure of informativeness is the precision of a trader's forecast of the final period asset value. This measure is a natural one to summarize the relevant price related information available to market participants based on their prior beliefs and on the signals conveyed by the trading process. Formally, our measure of price informativeness is defined to be $\text{prec}[\tilde{v} \mid y_i, p^*] = 1/\sigma^2(\tilde{v} \mid y_i, p^*)$.

PROPOSITION 5. *In a transparent trading system, prices are more informative than under an opaque trading system.*

Proposition 5 confirms our intuition that greater transparency allows traders to form more accurate forecasts of asset values. Intuitively, security prices embody not only the imperfect information signals of traders, but also the effects order flow shocks and undisclosed liquidity trading. In a transparent protocol, participants observe the influence of order flow shocks on prices, and as a result can form more accurate forecasts of the asset's fundamental value. In an opaque system, such a decomposition is impossible, and the dispersion of beliefs is inherently wider. In both systems, however, conditional forecasts are correct on average.

The fact that price movements reflect both signals and order flow shocks suggests that we distinguish between price informativeness and price volatility. A natural measure of volatility is the variance of transaction prices around the asset's fundamental value, i.e., $\sigma^2(v - p^*)$. Since market prices in both systems are unconditionally centered on asset value, this measure summarizes the effectiveness of trading protocols in promoting price discovery. In addition, since the price is normally distributed with mean v, the standard deviation of our volatility measure is proportional to the expected deviation from fundamental values, or mean pricing error (i.e., to $E[|v - p^*|]$), another variable that is featured prominently in policy debates.

The following proposition provides conditions under which price volatility is higher in a transparent mechanism.

PROPOSITION 6. *There exists a constant* $k_N \in (0, 1)$ *such that price volatility is lower in a transparent mechanism if*

$$\frac{\tau\psi}{\rho^2} < k_N.$$

Price volatility is higher in a transparent mechanism if

$$k_N < \frac{\tau\psi}{\rho^2} < 1$$

and σ_z^2 *is sufficiently high.*

COROLLARY 1 (Large Markets). *Price volatility is always under transparency if the market is sufficiently large, provided that an equilibrium exists with a transparent system.*

The proposition states that transparency can increase price volatility if markets are sufficiently thin. This can occur even though (from Proposition 2) noise trading itself is destabilizing and (from Proposition 5) transparency leads to more informative prices. The source of the seemingly paradoxical result here lies in the effects of disclosure. Transparency allows traders to condition their trades on the known imbalance, and as a result their conditional expectations regarding the asset's value are more accurate. However, market clearing prices also reflect the impact of order flow shocks. Transparency, by eliminating some of the uncertainty regarding the magnitude of liquidity trading, effectively reduces the level of noise in the system. In a thin market, this reduction in noise can lead to greater price sensitivity, as shown by Proposition 4, lowering liquidity. As a result, the net impact of transparency can be to increase the absolute price movements associated with a given order flow shock, hence increasing price volatility while also increasing price informativeness.

This argument applies to thin markets where the effects of the reduction in the perceived level of noise trading are the greatest. This suggests that transparency will reduce price volatility provided the market is sufficiently competitive. Indeed, from the proof of Proposition 6, $\lim_{N\to\infty} k_N = 1$ so that price volatility is always lower in a transparent mechanism if the market is sufficiently competitive, provided of course that equilibrium exists in the first place. Transparency thus increases stability in markets that are already large and liquid. However, transparency is not a major issue in such markets.

Indeed, given a finite number of traders, however, there is a *range* of values for τ, ρ, σ_z^2, and ψ under which transparency is destabilizing. This implies that there is no critical size above which transparency leads to greater stability. Finally, the result shows that the equilibria for M^{nt} and M^{t} are different unless $\sigma_z^2 = 0$. The key point is that an opaque system can operate in economies where a transparent system may not be viable.

From Proposition 6, it also follows that the expected absolute risk premium (measured by the deviation of the clearing price from the full information price of the security, $E[|\tilde{p} - v|]$) can be larger if traders are permitted to submit their demands after information on other imbalances is disclosed.

5.2. *Liquidity and Transaction Costs*

Price volatility is only one aspect of market performance. In this section, we consider the impact of transparency on liquidity, transaction costs, and welfare. We measure liquidity by the ability of the market to accommodate order flow without substantial price movements. Following Kyle (1985), we focus on *market depth*, represented by the order flow necessary to change prices by one unit. Formally, let Υ represent market depth, where

$$\Upsilon = \left(\frac{dp^*}{dZ}\right)^{-1}.$$

Note that our definition of depth applies only to exogenous order flows. In our model, price contingent orders jointly determine prices and quantities, so that the usual definition of depth is meaningful only for price inelastic orders. Nevertheless, for traders who place price contingent orders, a measure of liquidity can be constructed because a trader who places a larger demand, at every possible price, will tend to push prices upward. Since prices move in the direction of the trade, there is an analog to the bid–risk spread even in a single-price auction. This "effective spread" is a measure of the transaction costs faced by traders who place price contingent orders.

In the Appendix we show that the equilibrium price can be expressed as an increasing function of trader i's demand, which we denote $p(q_i)$. Then we can define the effective bid–ask spread $s(\cdot)$ as the difference between the market clearing price if an order of size q_i was to buy and the price if the order was to sell:

$$s(q_i) = p(|q_i|) - p(-|q_i|).$$

Proposition 7 shows that there is a trade-off between price volatility and depth, but the effective spread is higher in a transparent market.

PROPOSITION 7. *Price volatility and market depth are inversely related; the mechanism with greater price volatility also provides less market depth. From the perspective of a strategic trader, however, the effective bid–ask spread for an order of given size is strictly greater in a transparent market.*

The proposition shows that order imbalances have a greater price impact in markets where price volatility is high. The practical implication of this result is that a change in transparency that lowers price volatility will also reduce the execution costs (and expected losses) of liquidity investors whose trades create the imbalance Z. This is consistent with some of the concern over "small investors" evidenced by policy makers in debates over transparency.

Interestingly, the effective spread (which captures the execution costs of a strategic trader) is strictly greater in a transparent market. In a transparent market the actions of an informed trader convey more information than under an opaque system. A trader's action has an indirect effect through the actions of others (represented by the conjectural variation) in addition to the direct effect on prices, leading to wider effective spreads.

Although the measures of market quality discussed so far figure prominently in policy discussions, they are not necessarily relevant from a welfare perspective. As the impact of transparency depends on the parameters of the model we would expect the same to be true for welfare. Under our assumptions, traders care about only the mean and the variance of future wealth. However, improved information need not increase utility because it can eliminate opportunities for risk-sharing. In particular, we can show that the volume of endogenous liquidity trading is strictly lower in a transparent market. As a result, we cannot make unambiguous welfare statements about market organization. Cost considerations would favor the opaque system, since there is no need to create systems to provide disclosure.

5.3. *Policy Implications*

Our results help explain some of the observed variation in transparency across different markets. For example, in many equity markets, active securities are traded in floor-based systems while inactive securities are traded through anonymous limit-order book systems. Specifically, suppose that traders obtain information on the portion of the order flow that is price inelastic in floor-based systems. This may occur because of the reputations of brokers, as suggested by Benveniste *et al.* (1992). In contrast, but in a fully automated system where orders are submitted anonymously, such information is not available. In this case, our previous results would suggest that a floor-based system offering greater transparency would be preferred for active securities, while an anonymous system may be preferred in thin markets. This appears consistent with casual observation.

The results also provide insights into why some liquidity traders may avoid sunshine trades, even if they can benefit from reputation signaling. In a sunshine trade, a trader prediscloses the size and direction of their order, with a view toward reducing the price impact associated with the trade. Informed traders are unlikely to find it profitable to expose their orders in such a manner because they will effectively reveal their private information. Thus, sunshine trading has been viewed as a method by which liquidity traders can reduce the costs of their trades.

Admati and Pfleiderer (1991) provide a model of sunshine trading where some, but not all, liquidity traders can preannounce their orders. They demonstrate conditions under which investors who can preannounce their trades enjoy lower trading costs, but that sunshine trading increases the cost for those liquidity traders who are unable to preannounce their trades. In their model, preannouncement identifies the trade as liquidity motivated, benefitting the initiator. However, because the adverse selection costs for undisclosed trades increases, other traders may be made worse off.[11]

In our model, however, a liquidity trader can increase her utility by not preannouncing the trade. To see this, suppose that the imbalance Z arises from a single liquidity trader such as a pension fund. In a sunshine trade, the initiator discloses Z prior to trading. Thus, the transparent mechanism M^{t} describes the operation of the market when the initiator makes a sunshine trade. It follows from our earlier results that the expected losses of the uninformed trader can, in a sufficiently thin market, be larger than the losses from nondisclosure. Intuitively, in a thin enough market, volatility increases with disclosure. This volatility takes the form of a wider expected absolute difference between asset value and transaction price. As the initiator is always on the wrong side of the market (i.e., buying when price exceeds the conditional expectation of the asset's value or vice versa), the initiator's expected losses are higher with a sunshine trade. So, uninformed traders with large liquidity trades need not always be better off under sunshine trading. This difference arises because of the strategic behavior of traders in our model; if the market is sufficiently competitive, the initiator is strictly better off with a sunshine trade.

Another interesting implication of the results is that coordinated trading halts to provide information on imbalances in the event of sharp market movements may actually exacerbate the price movement associated with the initial shock. To see this, observe that a coordinated trading halt with

[11] This result is unambiguous when the cost of entry for speculative traders is zero.

disclosure of imbalances is equivalent to a move to a transparent system, where Z is now interpreted as the portion of the accumulated order imbalance that is disclosed. Observe also that the expected absolute price deviation from value is a positive monotonic transformation of the dispersion in prices around the asset's value, our measure of price volatility. Proposition 6 shows that in thin markets, greater transparency can increase price volatility because disclosure reduces the perceived level of noise trading, which in turn is the essential lubricant for trade to take place. It follows therefore that a trading halt to disclose information on transitory order imbalances can increase the price decline associated with a given sell imbalance, i.e., worsen a potential crash. So-called "circuit breakers" may have unintended effects.

Finally, it is useful to assess the importance of the various assumptions in driving these results. The key element here is the recognition that the strategies of rational traders are functions of their information set. Hence, the degree of competitiveness among traders is an important factor in determining the relation between market transparency and security prices. We also assumed for simplicity that the entire amount of the price inelastic component of order flow was revealed in the transparent mechanism. As a practical matter, it seems unlikely that a system could provide for full disclosure of price inelastic demands. However, the qualitative results would hold even if only a portion of this imbalance were observed by market participants. Intuitively, the portion of the noise shock that is not disclosed has the same effects on price volatility as the noise induced by the hedging demands of the strategic traders. Finally, in our contrast of the two mechanisms, we held constant the variance of the noise shock, Z. However, it seems reasonable that small retail traders may trade smaller amounts if their trades were disclosed. If so, the variance of Z would be smaller in the transparent system. In this case, our conclusion that transparency may exacerbate price volatility and possibly induce market failure would hold under broader conditions.

6. CONCLUSIONS

Underlying many policy recommendations for improving the operation of financial markets is the presumption that increased transparency is beneficial. This argument arises in many different contexts, including discussions regarding market anonymity, sunshine trading, the effectiveness of circuit breaker mechanisms, and the choice of floor-based or automated trading systems. This paper investigates the impact of greater transparency during the process of price formation on asset prices and market liquidity.

There are three principal results: First, greater transparency can exacerbate the price volatility generated by order imbalances. This is true even though these imbalances are a source of transitory pricing errors. Market quality also can suffer with lower liquidity and higher implicit transaction costs. Second, there may not exist a linear equilibrium if the market is too transparent. Surprisingly, this may occur even in an auction market with large numbers of traders. Third, transparency reduces price volatility and increases market liquidity if the market is sufficiently large and there is sufficient noise trading.

We use these results to assess various policy proposals related to market transparency. For example, the results may explain why stock exchanges prefer automated trading systems over floor-based systems for inactive securities, while the reverse is true for active stocks. Specifically, if floor-based systems somehow convey information on the portion of the order flow that is price inelastic, transparency is not desirable in markets where trading is thin. Similarly, the results indicate that a trading halt to disclose information on transitory order imbalances may actually exacerbate the price movement associated with this shock. Consequently, "circuit breakers" may work in the opposite of the way predicted. Finally, the results provide insights into why some liquidity traders may avoid sunshine trades, even if they can benefit from reputation signaling. Contrary to popular belief, the potentially adverse effects of transparency are likely to be greatest in thin markets.

APPENDIX

Proof of Proposition 1. The proof follows Kyle (1989). For completeness, we include all the steps, constructing the Bayes–Nash equilibrium by solving for a trader's best response to the conjectured strategies adopted by other traders and then showing that the conjectures are consistent.

Step 1 (Traders' conjectures and the clearing price). For notational convenience index traders other than i by $h = 1, \ldots, i-1, i+1, \ldots, N$. Suppose trader i conjectures that all other traders adopt linear strategy functions

$$q_h(p; I_h) = A_h(I_h) - Bp, \tag{1}$$

where $I_h = (W_{0h}, x_h, y_h)$ and B is a constant. Note that I_h is private information and is known only to trader h, so that A_h is also private information. Suppose trader i places an order for q_i. Using (1) and the market clearing condition we obtain

$$\sum_{h \neq i}^{N} A_h - (N-1)Bp + q_i + Z = 0. \tag{2}$$

From Eq. (2) we can express price as a function of q_i, denoted $p(q_i)$,

$$p(q_i) = p_{-i} + \lambda q_i, \tag{3}$$

where p_{-i} and λ are defined as

$$p_{-i} = \frac{\sum_{h \neq i}^{N} A_h + Z}{(N-1)B} \tag{4}$$

$$\lambda = \frac{1}{(N-1)B}. \tag{5}$$

For trader i, p_{-i} is a random variable (denoted $\tilde{p}_{-i}$) because neither A_h nor Z is observable at the time of order submission. To construct the trader's strategy, we first consider the case where trader i actually observes the realization of $\tilde{p}_{-i}$. We relax this in Step 2 below. Trader i then chooses her optimal order quantity q_i^* to maximize her expected utility of wealth. With $p^* = p(q_i^*)$, final period wealth is

$$W_{1i} = (v - p^*)q_i^* + vx_i + W_{0i}, \tag{6}$$

where W_{0i} is the initial cash holdings of trader i. It is well known that maximizing the expected utility of wealth (assuming $\tilde{W}_{1i}$ is normally distributed) is equivalent to maximizing

$$E[\tilde{W}_{1i} \mid I_i, p^*] - \frac{\rho}{2}\sigma^2(\tilde{W}_{1i} \mid I_i, p^*), \tag{7}$$

where $E[\cdot \mid \cdot]$ and $\sigma^2(\cdot \mid \cdot)$ are the conditional expectation and variance operators. Substituting (6) into Eq. (7), we obtain

$$E[\tilde{v} \mid I_i, p^*](q_i + x_i) - p(q_i)q_i + W_{0i} - (\tau/2)\sigma^2(\tilde{v} \mid I_i, p^*)(q_i + x_i)^2.$$

Trader i's optimal order quantity, q_i^* is found by differentiating this expression with respect to q_i^*

$$E[\tilde{v} \mid I_i, p^*] = p(q_i^*) + p'(q_i^*)q_i^* + \alpha_i(q_i^* + x_i), \tag{8}$$

where $\alpha_i \equiv \rho\sigma^2(v \mid I_i, p^*)$. The second order condition for a maximum is

$$2p'(q_i^*) + p''(q_i^*)q_i^* + \alpha_i > 0. \tag{9}$$

Step 2 (Construction of the best response function). Suppose trader i conjectures that $\tilde{p}_{-i}$ is normally distributed with mean v and precision π (i.e., variance $1/\pi$). In equilibrium, trader i's conjectures concerning $q_h(\cdot)$ and p_{-i} will be correct. Trader i cannot invert the market clearing price p^* to infer the realization of $\tilde{p}_{-i}$ because p^* is not observed at the time of order submission. We claim that trader i can effectively condition on p^*, and thus p_{-i}, by submitting a demand schedule that specifies her demand at every price. To show that this is feasible, suppose the realization of $\tilde{p}_{-i}$ is p^*_{-i}. Then, trader i's optimal order quantity q_i^* is determined from (8) with trader i acting as the "marginal" trader who determines the price. This yields a point $(p^*_{-i}, q_i^*) \in \mathscr{R}^2$. From (3), the corresponding price is $p(q_i^*)$ so that uniquely associated with the point (p^*_{-i}, q_i^*) is the pair $(p(q_i^*), q_i^*)$, a point on trader i's demand schedule. Repeating this exercise for $p^*_{-i} \in \mathscr{R}$ leads to a curve in $\mathscr{R}^2$, the graph of $(p(q_i^*), q_i^*)$, trader i's demand function in (p, q)-space.

The next step is to construct the trader's demand function, denoted $q_i(p; I_i)$, as outlined above, given one point on it. Suppose trader i believes p_{-i} is the realization of $\tilde{p}_{-i}$. Under our assumptions concerning the distribution of y_i and p_{-i}, trader i's conditional expectation of $\tilde{v}$ is obtained from a standard result in statistical decision theory (see, e.g., DeGroot, 1970, p. 169)

$$E[\tilde{v} \mid I_i, p^*] = (1 - \delta)y_i + \delta p_{-i},$$

where $\delta = \pi/(\pi + \tau)$ is a constant. Further, it can be shown that $\sigma^2(\tilde{v} \mid I_i, p^*) = (\pi + \tau)^{-1}$. From (8), the optimal order quantity $q_i^* = q_i(p^*)$ satisfies

$$q_i^* = \frac{E[\tilde{v} \mid I_i, p^*] - p^* - \alpha_i x_i}{\alpha + \lambda}, \tag{10}$$

where $\alpha = \rho/(\pi + \tau)$ is a constant for all i. In (10), q_i^* depends upon $E[\tilde{v} \mid \cdot]$ which depends upon the conjectured value of p_{-i} through p^*. We must ensure that each price–quantity pair on the demand schedule is consistent with the posterior beliefs generated by observing the realization of that particular trade. To do this, substitute the value of $E[\tilde{v} \mid \cdot]$ given above into Eq. (10). Since $p_{-i} = p^* - \lambda q_i^*$, we obtain

$$q_i(p^*; I_i) = \gamma(1 - \delta)(y_i - p^*) - \gamma\alpha x_i, \tag{11}$$

where

$$\gamma \equiv \frac{1}{(\alpha + \lambda + \delta\lambda)}. \tag{12}$$

Equation (11) is the optimal demand given $p = p^*$; the demand schedule, $q_i(p; I_i)$, is the graph of $(q_i(p^*), p^*)$. Inspection of (11) shows that the optimal strategy of trader i is of the form conjectured in (1) with

$$A_i(I_i) = \gamma[(1-\delta)y_i - \alpha x_i] \tag{13}$$

$$B = \gamma(1-\delta). \tag{14}$$

Step 3 (Existence). Traders have the same price sensitivity although their reservation prices A_i vary with the initial state I_i. To show that the strategy functions are well-defined, we must express the unknown values of the strategy functions, α, λ, γ, δ, and π in terms of the parameters N, ρ, τ, and ψ, and verify that the initial conjectures are satisfied. From the definition of B and λ write

$$\lambda = \frac{1}{(N-1)\gamma(1-\delta)}. \tag{15}$$

Since $\alpha = \rho/(\pi + \tau)$ and $\delta = \pi/(\pi + \tau)$, $\alpha/(1 - \delta) = (\rho/\tau)$. Then, from (11) and the market clearing condition, the equilibrium price is

$$p^* = \frac{1}{N}\left(\sum_{i=1}^{N}\left[y_i - \left(\frac{\rho}{\tau}\right)x_i\right] + \frac{Z}{\gamma(1-\delta)}\right). \tag{16}$$

The formula for p_{-i} is identical to (16), except that the summation excludes trader i:

$$p_{-i} = \frac{1}{N-1}\left(\sum_{h\neq i}^{N}\left[y_h - \left(\frac{\rho}{\tau}\right)x_h\right] + \frac{Z}{\gamma(1-\delta)}\right). \tag{17}$$

The variable p_{-i} has mean v and variance $1/\pi$, where

$$\frac{1}{\pi} = \omega_0 + \frac{\omega_1}{\gamma^2(1-\delta)^2}, \tag{18}$$

where

$$\omega_0 = \frac{\tau^{-1} + \psi^{-1}(\rho/\tau)^2}{(N-1)} \tag{19}$$

$$\omega_1 = \frac{\sigma_z^2}{(N-1)^2} \tag{20}$$

are constants. Observe that when Z is known, the precision (or inverse of the variance) of the signal conveyed is $\pi_0 = 1/\omega_0$. When $\sigma_z^2 > 0$, $\omega_1 > 0$ and (18) can be inverted to express γ as a function of π:

$$\gamma = \left(\frac{\pi + \tau}{\tau}\right)\sqrt{\frac{\omega_1}{(\pi^{-1} - \omega_0)}}. \tag{21}$$

Write (21) as $\gamma = g(\pi)$. Next, we derive a second function relating γ to π. The equilibrium values of γ and π are the solutions to these two nonlinear equations. Substituting (15) into (12), we obtain

$$\frac{1}{\gamma} = \alpha + \frac{(1+\delta)}{(N-1)\gamma(1-\delta)}.$$

Write this equation as

$$\gamma = \frac{(\pi + \tau)[(N-2)\tau - 2\pi]}{(N-1)\rho\tau}. \tag{22}$$

Equation (22) expresses γ as a function of π. Denote this function by $\gamma = f(\pi)$. A solution to the game M^{nt} exists if there exists π^*, where $\pi^* > 0$, solving $f(\pi^*) = g(\pi^*) > 0$.

Step 4 (Equilibrium). From (21), $g(\pi)$ is a continuous function of π on the interval $(0, \pi_0)$, where π_0 is:

$$\pi_0 = \frac{1}{\omega_0}, \tag{23}$$

where ω_0 is defined in (19). Then, $g(\pi) \geq 0$ and $g'(\pi) > 0$. It is easy to show that $g(0) = 0$ and that $g(\pi) \to \infty$ as $\pi \to \pi_0$. Examining (22), $f(\pi)$ is continuous in π, for $\pi \in [0, \pi_0]$. Putting $\pi = 0$ in (22) yields $f(0) = (\tau/\rho)(N-2)/(N-1)$, which is strictly positive for $N > 2$.

Note that $|f(\pi)| < \infty$, for $\pi \in [0, \pi_0]$. Define $R(\pi) \equiv f(\pi) - g(\pi)$. Clearly, $R(\pi)$ is continuous in π on the interval $[0, \pi_0)$. Note that $R(0) > 0$ and that the limit of $R(\pi)$, as $\pi \uparrow \pi_0$ is $-\infty$. Applying the Intermediate Value Theorem, there exists $\pi^* \in (0, \pi_0)$ such that $R(\pi^*) = 0$. Since $g(\pi)$ is positive for $\pi \in (0, \pi_0)$, $\gamma^* > 0$. This argument establishes the proposition. ■

Proof of Proposition 2. Using Eq. (16), we see that the pricing error is given by

$$v - p^* = -\frac{1}{N}\left(\sum_{i=1}^{N}\left[\varepsilon_i - \left(\frac{\rho}{\tau}\right)x_i\right] + \frac{Z}{\gamma(1-\delta)}\right). \tag{24}$$

It is clear that the pricing error is a linear function of the order imbalance Z. Taking variances on both sides, we obtain

$$\sigma^2(v - p^*) = \frac{N-1}{N}\left(\omega_0 + \frac{N-1}{N}(\pi^{-1} - \omega_0)\right), \tag{25}$$

where ω_0 and ω_1 are constants defined in the previous proposition.

Now consider two possible values for σ_z^2, say σ_1^2 and σ_2^2, where $\sigma_2^2 > \sigma_1^2 > 0$. From (22) above, it follows that $f(\cdot)$ does not depend on σ_z^2. However, the function $g(\cdot)$ depends on σ_z^2 through the constant ω_1. Let $g_1(\pi)$ represent Eq. (21) when $\sigma_z^2 = \sigma_1^2$ and similarly define $g_2(\pi)$. From (21),

$$g_2(\pi) > g_1(\pi)$$

for $\pi \in (0, \pi_0)$. Suppose π_1 is the solution to $f(\pi) = g_1(\pi)$, where $f(\cdot)$ is defined by (22). Consider the function $R_2(\pi) \equiv f(\pi) - g_2(\pi)$. From (21), $R_2(\pi_1) < 0$. As $R_2(0) > 0$, the Intermediate Value Theorem implies there exists $\pi_2 \in (0, \pi_1)$ such that $R_2(\pi_2) = 0$. Since $\pi_2 < \pi_1$, it follows that $\sigma^2(v - p^*)$ is higher when $\sigma_z^2 = \sigma_2^2$. Similarly, the variance of prices around value also increases with the level of endogenous liquidity trading. Since $v - p^*$ is normally distributed with mean zero, the expected absolute deviation from value (i.e., the pricing error) $E[|v - p^*|]$ is proportional to the standard deviation of the pricing error, $\sigma(v - p^*)$. Similarly, the expected volume of noise trading $E[|Z|]$ is also proportional to σ_z. It follows therefore that an increase in the expected volume of noise trading leads to an increase in the expected absolute pricing error. ■

Proof of Proposition 3. Suppose that trader i believes that $q_h(p)$ is a linear policy

$$q_h(p; q_{-h}) = A_h(I_h) - Bp - CZ \tag{26}$$

for $h, j = 1, \dots, N$; $j \neq h$. The market clearing condition is

$$\sum_{h \neq i}^{N} A_h - (N-1)Bp^* - C(N-1)Z + q_i + Z = 0. \tag{27}$$

In this mechanism p^* conveys statistical information concerning I_h to other traders. To make this explicit, suppose trader i regards (A_h/B) as a draw from an independent normal distribution with mean v and precision $\pi_1/(N-1)$. This will be shown to be correct in equilibrium. Define

$$\mu_{-i} = \frac{\sum_{h \neq i}^{N} A_h}{B(N-1)}. \tag{28}$$

Under our assumptions, trader i conjectures that μ_{-i} is the realization of a normally distributed random variable $\tilde{\mu}_{-i}$ with mean v and precision π_1 that is uncorrelated with y_i and x_i. Substituting Eq. (28) into (27), we can express the price facing trader i as

$$p^* = \mu_{-i} + \lambda_1 q_i + \kappa Z, \tag{29}$$

where

$$\lambda_1 = \frac{1}{B(N-1)}$$

$$\kappa = \frac{1 - C(N-1)}{B(N-1)}.$$

The trader's conditional expectation, given the realization of $\tilde{\mu}_{-i}$, is

$$E[\tilde{v} \mid I_i, \mu_{-i}] = (1 - \delta_1) y_i + \delta_1 \mu_{-i}, \tag{30}$$

where $\delta_1 = \pi_1/(\pi_1 + \tau)$ is a constant. From (8) trader i acts as the marginal trader who actually determines the price

$$E[\tilde{v} \mid I_i, p^*] = p^* + \lambda_1 q_i + \alpha_1 (q_i + x_i),$$

where $\alpha_1 = \rho/(\tau + \pi_1)$. Substitute $\mu_{-1i} = p^* - \lambda_1 q_i - \kappa Z$ and (30) into this equation. The demand at the equilibrium price p^* is given by $q_i(p^*)$, where

$$q_i(p^*) = \gamma_1 (1 - \delta_1)(y_i - p^*) - \gamma_1 \alpha_1 x_i - \gamma_1 \delta_1 \kappa Z, \tag{31}$$

where

$$\gamma_1 \equiv \frac{1}{\alpha_1 + \lambda_1 + \delta_1 \lambda_1}. \tag{32}$$

From Eq. (31), the best-response strategy of a trader i has the same form as conjectured with

$$A_i = \gamma_1[(1-\delta_1)y_i - \alpha_1 x_i] \tag{33}$$

$$B = \gamma_1(1-\delta_1) \tag{34}$$

$$C = \gamma_1\delta_1\kappa. \tag{35}$$

The precision of μ_{-i} can be calculated directly

$$\pi_1 = \frac{1}{\omega_0},$$

where ω_0 was defined above in Eq. (19). Using the definition of λ_1, we obtain

$$\lambda_1 = \frac{1}{(N-1)(1-\delta_1)\gamma_1}. \tag{36}$$

Since the value of π_1 is identical to the value of π_0 in Eq. (23), substituting Eq. (36) into Eq. (32), we obtain an expression for γ_1 in terms of π. It is readily verified that this expression is given by Eq. (22). Then, since $\omega_1 = 0$ by definition, we can solve for γ_1 by substituting $\pi = \pi_0$ in (22):

$$\gamma_1 = \frac{(\pi_0+\tau)[(N-2)\tau - 2\pi_0]}{(N-1)\rho\tau}. \tag{37}$$

Then, we can easily show that $\delta_1 = \pi_0/(\tau+\pi_0)$, and $\alpha_1 = \rho/(\tau+\pi_0)$. Next, we verify that κ is well defined. Substituting (35) and the definition of λ_1 into Eq. (36) we obtain

$$\kappa = \frac{1}{(N-1)\gamma_1},$$

which is positive if $\gamma_1 > 0$. To ensure that the proposed solution is economically meaningful, γ_1 must be positive. From (37), $\gamma_1 > 0$ implies

$$\frac{(N-2)\tau}{2} > \frac{1}{\omega_0}.$$

We can rearrange this inequality to obtain

$$\tau < \frac{(N-2)\rho^2}{N\psi}. \tag{38}$$

Let $\tau^* \equiv (N-2)\rho^2/N\psi$, so that the second order condition (9) is satisfied if $\tau < \tau^*$. From (31), the equilibrium price is

$$p^* = \frac{1}{N}\left\{\sum_{i=1}^{N}\left[y_i - \left(\frac{\rho}{\tau}\right)x_i\right] + \left[\frac{1-N\zeta}{\gamma_1(1-\delta_1)}\right]Z\right\}, \tag{39}$$

where $\zeta \equiv \delta_1/(N-1) \in (0, \frac{1}{2})$. This establishes the existence of a linear equilibrium. ■

Proof of Proposition 4. From Eq. (22) and the definition of δ, we can write $\gamma(1-\delta)$ as

$$\gamma(1-\delta) = \frac{(N-2)\tau - 2\pi}{\rho(N-1)}. \tag{40}$$

Now, γ_1 is given by Eq. (37), and using the definition of δ_1, we can write

$$\gamma_1(1-\delta_1) = \frac{(N-2)\tau - 2\pi_0}{\rho(N-1)}. \tag{41}$$

Then, upon comparing (40) and (41) and noting that since $\pi < \pi_0$, it follows that $\gamma_1(1-\delta_1) < \gamma(1-\delta)$.

For the second part, note that from Proposition 1, the portfolio hedging component of $q_i(p; I_i)$ is $-\gamma\alpha x_i$ in M^{nt}. The expected volume of portfolio hedging is given by $N\alpha\gamma E[|\tilde{x}_i|]$, where $\gamma\alpha = \gamma((1-\delta)(\rho/\tau)$. Since $\tilde{x}_i$ is distributed normally with mean zero, the expected volume of endogenous liquidity trading is proportional to $\gamma(1-\delta)\rho/(\tau\sqrt{\psi})$. Similarly, under M^{t} the expected volume of endogenous liquidity trading is proportional to $\gamma_1(1-\delta_1)\rho/(\tau\sqrt{\psi})$, with the same factor of proportionality. The second part of the proposition follows immediately from the slope conditions derived above. ■

Proof of Proposition 5. In an opaque system, the precision of a trader's forecast of $\tilde{v}$ is (see, e.g., DeGroot, 1970, p. 169) $\text{prec}[\tilde{v} \mid y_i, p^*] = \tau + \pi$, where π is the precision of the information signal regarding value conveyed by the market price to trader i, defined in Eq. (18). By contrast, the corresponding forecast precision in a transparent system is $\tau + \pi_0$, where π_0 is defined in Eq. (23). Since $\pi_0 = 1/\omega_0$, and $\pi_0 > \pi$ (from (18) and (23) and the proof of Proposition 1), the result follows immediately. ■

Proof of Proposition 6. Using Eqs. (16) and (39), the difference in price volatility under M^{nt} and M^{t} is

$$\sigma^2(v - p^*_{nt}) - \sigma^2(v - p^*_t) = \left[\frac{\sigma_z}{N\gamma(1-\delta)}\right]^2 - \left[\frac{\sigma_z(1-\zeta N)}{N\gamma_1(1-\delta_1)}\right]^2. \quad (42)$$

From (42), $\sigma^2(v - p^*_{nt}) < \sigma^2(v - p^*_t)$ if and only if

$$\gamma_1(1-\delta_1) < (1-\zeta N)\gamma(1-\delta). \quad (43)$$

Using Eqs. (40) and (41), Eq. (43) can be written as

$$(N-2)\tau - 2\pi_0 < (1-\zeta N)[(N-2)\tau - 2\pi].$$

Rearrange this to obtain

$$2\pi < (N-2)\tau - \frac{(N-2)\tau - 2\pi_0}{1-\zeta N}. \quad (44)$$

Observe that $\delta_1 = 1/(1 + \tau/\pi_0)$. Then $\zeta = \delta_1/(N-1)$ is

$$\zeta = \frac{1}{N + (\rho^2/\tau\psi)} \quad (45)$$

using the definition of π_0. Note that $(1 - \zeta N)$ is independent of σ_z^2. Let

$$\Xi \equiv (N-2)\tau - \frac{(N-2)\tau - 2\pi_0}{1-\zeta N}.$$

Ξ is the right-hand side of (44). The following lemma shows that $\Xi > 0$ for a range of parameter values.

LEMMA 1. *There exists a constant*, $k_N > 0$, *which is independent of* ρ, τ, *and* ψ *such that* $\Xi > 0$ *in equilibrium if* $\tau\psi/\rho^2 > k_N$.

Proof of Lemma 1. Observe that Ξ is independent of the level of noise σ_z^2. Now $\Xi > 0$ is equivalent to

$$(N-2)\tau > \frac{(N-2)\tau - 2\pi_0}{1-\zeta N}.$$

Using the definition of ζ in (45) and the definition of π_0, this reduces to

$$\frac{N^2 - 4N + 2}{N^2} < \frac{\tau\psi}{\rho^2}. \tag{46}$$

From Proposition 1, when $\sigma_z^2 = 0$, existence requires that Eq. (38) hold. Comparing (38) with (46), we see that $\Xi > 0$ in equilibrium if the parameter values satisfy

$$\frac{(N^2 - 4N + 2)}{N^2} < \frac{\tau\psi}{\rho^2} < \frac{(N - 2)}{N}. \tag{47}$$

Define k_N by $k_N \equiv (N^2 - 4N + 2)/N^2$. Note that for all $N \geq 2$, $k_N < (N - 2)/N$. Only if the precision of endowments or private information is sufficiently low, i.e., $\tau\psi/\rho^2 < k_N$, is $\Xi < 0$. ■

To complete the proof of the proposition note that by Lemma 1, if ψ (or τ) is sufficiently high, i.e., if $\tau\psi > (\rho^2 k_N)$, then $\Xi > 0$. Since π is strictly decreasing in σ_z^2, there exists a critical value for σ_z^2 such that if σ_z^2 is sufficiently high, the inequality (44) is satisfied. This proves the proposition. ■

Proof of Proposition 7. In the nontransparent system, depth is the inverse of the derivative of the price functional (16) with respect to Z:

$$\Upsilon = N\gamma(1 - \delta). \tag{48}$$

Under transparency, we use Eq. (39) to obtain

$$\Upsilon_1 = \frac{N\gamma_1(1 - \delta_1)}{1 - \zeta N}. \tag{49}$$

From Eqs. (42) and (43), $\sigma^2(p_{nt}^*) < \sigma^2(p_t^*)$ if and only if

$$\gamma_1(1 - \delta_1) < \gamma(1 - \delta)(1 - \zeta N).$$

Dividing both sides of this expression by $(1 - \zeta N)$, we see that $\sigma^2(p^*) < \sigma_1^2(p^*)$ if and only if $\Upsilon_1 < \Upsilon$. Therefore, price volatility and market depth are inversely related. Turning now to the effective costs of trading, the effective spread function follows from Eq. (3):

$$s(q_i) = 2\lambda|q_i|.$$

Similarly, from (29) the effective spread in a transparent market is

$$s_1(q_i) = 2\lambda_1|q_i|.$$

From Proposition 4, it follows that $\lambda_1 > \lambda$ so that for all $q_i \in \mathscr{R}$, $s_1(q_i) > s(q_i)$. ■

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