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Noisy Trade Disclosure and Liquidity

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Noisy Trade Disclosure and Liquidity

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Noisy Trade Disclosure and Liquidity

Abstract

This paper examines the implications of noisy trade disclosure on trading and liquidity in a multiperiod security market where some traders receive private information before others. We find that an increase in the precision of trade disclosure creates a natural incentive for traders to either (i) trade aggressively in early rounds, implicitly giving up the opportunity to trade later, or, (ii) scale down trading and effectively withdraw from the market in the early rounds in order to protect their opportunity to trade later. Not surprisingly, the consequences of improved disclosure for the liquidity of the market depends on which of these two situations arises. While improved disclosure could lead to a worsening in liquidity in the early rounds of trading in the former case, it leads a worsening in liquidity in later rounds under the latter case. Traders who transact in later rounds are ambiguous in their views on improved disclosure as well, since they trade-off the corroborative effect of trade disclosure for their private information against the additional information conveyed to the market-maker who sets prices on this basis. These tradeoffs lead to liquidity being a non-monotonic function of the precision of trade disclosure. These implications for market equilibrium, which reflect the response of traders to the changes in the disclosure environment, should be incorporated into the current debate over the optimal level of transparency in security markets.

Noisy Trade Disclosure and Liquidity

1. Introduction

The internationalization of security markets has led to increased attention being paid to the appropriate form of security exchanges in a global trading , and on the need for regulatory harmonization to achieve these goals. This is reflected, for example, in the threats posed to the New York Stock Exchange by competition from both domestic and foreign exchanges over the last decade. There has been concern about the movement of trading off the Big Board, and the extent to which this is caused by differences in trading and regulatory structures. Similarly, bourses in Europe are also increasingly aware of the importance of market structure in attracting trading volume to the exchange. One aspect of the trading environment that has been especially contentious is the transparency of a security market, and the extent to which increased transparency enhances welfare.[1,2]

This paper examines the implications of one specific dimension of transparency: the extent to which the form and content of reported order flow reflects the motivations for trade.[3] The disclosure of the details of trades after they occur does convey useful information about the extent to which these trades were motivated by liquidity needs as opposed to private information about the security itself. One can therefore view the details of trade disclosure as

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[1] See, for example, the views of the SEC on the regulation of markets in the recently released Market 2000 study (especially study IV).

[2] The importance of this dimension of transparency is illustrated by the movement of order flow to London. Ninety percent of the cross-border trading in European securities occurs in London's SEAQ International (Wall Street & Technology (1993)) which is of concern to continental exchanges like Paris. One reason for this is thought to be the Paris Bourse requirement that trade details (like price, size, and the identities of the buyer and seller) be published immediately, while London's SEAQ International does not require the publication of such details until the next day, and even then only as a part of the aggregate volume of a particular stock. (Barron's (1991), Economist (1994)). In contrast, for NASDAQ-NMS securities, trade details are disclosed within 90 seconds of the trade occuring (Franks and Schaefer (1992)).

[3] There are other dimensions of transparency that have been considered in the literature as well. For example, some authors have examined the impact of the *ex ante* transparency of the stock market, as captured by the extent to which quotes, the specialist's limit order book, or details about the order flow are observed before a trade occurs (examples of formal models that examine the implications in such an *ex ante* framework are Admati and Pfleiderer (1991), Forster and George (1992), and Pagano and Roell (1993)). While these dimensions of transparency are important as well, we restrict the analysis of this paper to the implications of the transparency of the trade reporting process for the liquidity of the security market. There is also a large literature that deals with the generic implications of public disclosure. See for example Alles and Lundholm (1993) (and the references therein).

having implications for the *ex post* transparency of the market. The regulatory perspective on transparency is reflected in the following quote from Mary L. Schapiro (Commissioner at the Securities and Exchange Commission (SEC) at the time) in the Wall Street Computer Review (1991):

> *"A significant percentage of the volume in New York Stock Exchange-listed securities is now being done in markets that are less transparent. And because firms do sometimes prefer a less transparent marketplace, it does become a competitive issue for U.S. exchanges. If the standard is less {rigorous} in other countries where there are viable markets, then the U.S. may see market share move offshore."*

The SEC's approval of extended trading hours on the NYSE, during which the trade reporting requirements are much lower, can be viewed as a tacit recognition that stringent reporting requirements might lead to a movement of order flow off the exchange.[4]

Before discussing the structure and results of this paper, it would be useful to summarize the typical perspective that is taken on the benefits and costs of enhanced transparency. A good definition of market transparency is that it a measure of the ability of market participants to observe the information contained in the trading process (O'Hara (1995)). Obviously, while some aspects of transparency can be associated with the trading process itself, other aspects are discretionary, and represent policy tools under the control of regulators.[5] Furthermore, the recent literature on transparency also distinguishes between factors that influence the *ex ante* versus *ex post* transparency of markets (Madhavan (1995)).

While regulators view increased transparency as being extremely desirable, presumably because it improves liquidity and reduces the losses suffered by uninformed traders, increased transparency also reduces the incentives of traders to invest resources in the collection of

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[4] Hasbrouck, Sofianos and Sosebee (1993) provide a useful overview of the operating procedures of the New York Stock Exchange.

[5] For example, Madhavan (1992) and Pagano and Roell (1993) highlight the differences in the levels of transparency between trade and order driven systems, and also between continuous versus batch auctions. The timing and content of trade disclosure, however, is a regulatory choice variable.

information (Mulherin (1993)). Some authors have also questioned the benefits of increasing market liquidity, since it could reduce the effectiveness of the market for corporate control (Bhide (1993).

Two papers that formally examine the trade reporting dimension of market transparency are Fishman and Hagerty (1991) and Madhavan (1995). These papers view trade disclosure as either being nonexistent or perfect, and examine the consequences for liquidity, fragmentation and the regulation of markets (see also, Harris (1992)). This paper, on the other hand, is motivated by the observation that trade disclosure as a signal of the private information available to a trader is inherently a noisy proxy (as is market transparency). Delays in reporting, the aggregation of trades, the anonymity of the market, all contribute to the noisiness of the trade reporting process.[6] Consequently, examining the implications of the entire spectrum of disclosure regimes for market equilibrium might provide insights that are not available by examining the two polar extremes (i.e nonexistent versus perfect disclosure).

The analysis of the consequences of the increased precision of trade disclosure is conducted in a multiperiod model of trading in a single asset. The structure of private information available to traders is such that traders are distinguished from each other not just on the basis of whether or not they possess private information, but also based on when they obtain this information.[7] Specifically, we examine the situation where one trader obtains noisy information about the asset's payoff before the rest of the market. However, he realizes that another trader will also be receiving private information in the next period, and will be utilizing both this private information, and any information conveyed by the first round of trade, in deciding his trading strategy. Some of this information is revealed through prices, while additional information is revealed through a noisy trade reporting system that has been

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[6] Massimb and Phelps (1994) suggest, for example, that one of the differences between the open outcry system and a typical electronic trading system is that the former provides more details about completed transactions than the latter. They concede, however, that such disclosure is not perfect under the open outcry system, since participants might only be able to infer the customer's trading house, but not the identity of the customer itself.

[7] This structure is similar to that utilized in a recent paper by Hirshleifer, Subrahmanyam and Titman (1995), and is also discussed in Froot, Scharfstein, and Stein (1992). The similarities are discussed when the model is formally developed in Section 2.

put in place to enhance the transparency of the market.[8] Consequently, in formulating his trading strategy, this trader takes into account the fact that the noisy disclosure of his current trades reveals information to the traders with whom he will transact in later rounds.[9] This information arrival process seems to be consistent with the concerns that traders have about the implications of trade disclosure on their activity.

We find that an increase in the precision of the trade reporting process creates several conflicting incentives for both the trader who receives private information early and the one who receives it late. The trader who receives information early recognizes that his trades in the early rounds convey information to both the market maker and the informed trader who will be competing with him in later rounds. If he views trading in later rounds as being very lucrative, the trader responds by rationally reducing the extent to which he trades early, in order to control the amount of his private information that is revealed through trades. This behavior leads to an improvement in liquidity in the early rounds. If trading in the early rounds is viewed as being more lucrative, however, an increase in the precision of trade disclosure causes the trader to effectively forego profitable trading in later rounds by trading very aggressively in the early rounds. This leads to a worsening in liquidity in the early rounds when disclosure is made more precise.

The trader who transacts in the later rounds recognizes that increased disclosure has two distinct effects that are relevant to him. The information that is provided by trade disclosure makes his private signal more informative, which he clearly finds useful. However, the information in trade disclosure is also available to the market maker who then sets prices on this basis, thereby reducing the profits available to the trader. We show that while there

[8] The assumption that the trader who is informed early has no competition in the first round of trade leads to a much more tractable analysis of the costs and benefits of the trading strategies adopted and the manner in which they are affected by more precise disclosure. Allowing for competition would result in informed traders transacting more aggressively in early rounds, causing information to be reflected earlier in prices (Holden and Subrahmanyam (1992)).

[9] Benabou and Laroque (1992) argue that insiders can attempt to manipulate markets through "distorted" announcements. In our model, the attempts of the insider to control his trading in early rounds is motivated by the recognition that this influences the "trade report" that is announced at the end of the first round. In this sense, the incentive effects in the two papers are quite similar.

are circumstances where increased precision in trade disclosure increases competition in later rounds, there are also circumstances where the opposite occurs. The net impact of these conflicting effects is that an increase in the precision of trade disclosure need not be unambiguously preferred by the trader who transacts late.

The results of the paper highlight a general point. The impact of increased transparency on trading incentives and liquidity is complicated by the endogenous adjustment in the trading strategies of the market participants. In fact, in fairly reasonable circumstances, increased transparency can have very different effects than have been recognized so far in the literature. These insights should provide a useful starting point in the attempts of policy makers to better understand the implications of transparency in a global marketplace.

The remainder of the paper proceeds as follows. The model of trade is developed in Section 2, and the equilibrium for this model is developed in Section 3. Section 4 examines the relationship between the precision of trade disclosure and market equilibrium, while Section 5 discusses the implications and some possible extensions. Section 5 concludes.

2. A multiperiod model of trading with differential timing in receiving information

In this section, we develop the economic setting for the multiperiod model of trading, which is a simplified version of that developed in Holden and Subrahmanyam (1992), modified to incorporate the noisy disclosure of trades. Specifically, the economy consists of three time periods indexed by t=0,1,2. Trading takes place in a single asset that only pays off at t=2. The payoff on the asset is an uncertain quantity v which is distributed $N(0,\sigma_v^2)$. Trade in this asset occurs at both t=1 and t=2. There are two traders in this market who invest resources to gather information about the firm.[10] The nature of the information collection process is such that information about the terminal (t=2) asset payoff is first revealed to one of the traders before the first round of trade. In the next round, the other trader also receives some information about the final asset payoff.

Without loss of generality we refer to the trader who receives the information early as trader #1. At the beginning of the trading game, trader #1 receives a noisy signal $\theta_1 = v + \varepsilon_1$ about the terminal asset payoff. The noise in the signal, ε_1 is distributed $N(0,\sigma_1^2)$. The second informed trader (#2) receives no signal in the first round of trade, but does observe a signal $\theta_2 = v + \varepsilon_2$, but only <u>after</u> the first round of trading is over. Consequently, this trader does not participate until the second round of trading.

In addition to these informed traders, there is a random order, u_1, placed by noise traders in the first round, where $u_1 \sim N(0,\sigma_{u1}^2)$. Similarly, in the second round, noise traders place a random order, u_2, where $u_2 \sim N(0,\sigma_{u2}^2)$.[11] In each round of trader, the orders are submitted to a market maker, who sets a price based on the cumulative order flow that he observes, to ensure that he breaks even. All participants in the economy are risk neutral, and all the random variables are assumed to be independent of one another.

Market transparency is modelled as a signal that is observed by all players at the end of the first round of trade. This signal, which is related to the order placed by informed trader #1 in the first round, is denoted by $S = x_1 + \eta$, where x_1 is the order submitted, and η is

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[10] We assume, for simplicity, that both traders have incentives to invest in the information collection technologies. While an examination of the profits of the traders will provide some insights into the impact of better disclosure on the endogenous incentives to collect information, we defer a formal analysis of this issue to future research.

[11] The assumption that the liquidity traders are constrained to transact in a given round is obviously restrictive. While the model can be extended to allow for some of these traders to have the discretion on which round to trade, it is still necessary to have some amount of non-discretionary trading in each round (Admati and Pfleiderer (1988)). Alternately, one could relax the assumption of risk neutrality, in which case the hedging motives of the uninformed would result in their transacting in both rounds (see Speigel and Subrahmanyam (1992)).

the noisiness in the signal, which is distributed $N(0,\sigma_\eta^2)$. There are several motivations for modelling transparency in this manner. Much of the debate in markets centers around the reporting of previous transactions (The Economist (1992, 1994)). Moreover, different market structures also impact the ability of traders to identify the motives of trades (information versus liquidity). For example, Benveniste (1992) suggests that one of the benefits of the specialist structure is that it provides the market maker with an efficient way of inferring the motives for trade *ex ante*. Similarly, Admati and Pfleiderer (1991) suggest that to the extent that some liquidity traders are able to convey information that their trades are not motivated by private information (i.e engage in sunshine trading), this information in conjunction with aggregate order flows also provide noisy information about the trading strategies of the informed trader. In any trading system, therefore, a combination of the trading methods and disclosure requirements provide participants with (potentially imperfect) information about the motives for trade. In this paper, instead of endogenously developing the noisiness in the trade disclosure process, we model this noise exogenously, and examine the implications for market equilibrium.

The assumptions on the arrival of information, and the resultant trading strategies of the two informed traders require some elaboration as well. The assumption that the process of collecting information provides some parties with early success relative to others seems a reasonable one. It has been utilized, for example, by Hirshleifer, Titman and Subrahmanyam (1994), to explain the incentives of investors to focus on only a subset of available securities, and certain empirical trading patterns.[12] This information structure is also consistent with that utilized by Froot, Scharfstein and Stein (1992) in their examination of the impact of short-term speculation on trading patterns.

Moreover, the "first mover" advantage that it provides to the trader who receives information early is at the heart of the debate on transparency. While a regulator would like this information to be revealed to the market as soon as possible (i.e. improve informational

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[12] A few similarities and differences are worth noting. While the arrival of information is similar, HST focus on the case where the informed traders are risk averse (leading to a hedging motive), have the signals of the traders perfectly correlated, and utilize a competitive (rational expectations approach) equilibrium. Utilize their own description of FSS to characterize why it is a less that satisfactory set of assumptions.

efficiency), the trader would like to maximize the rents associated with his private information. Any trading strategy that he adopts will reflect both the information and the disclosure environment in which he trades. By assuming that this trader faces no competition in the first round of trade, we can highlight the manner in which he adjusts his trading strategies in response to changes in disclosure. In the more general environment, where he faces competition in the first round as well, the adjustment in trading strategies would also reflect his perception of the manner in which the "competition" reacts to the change in disclosure requirements. Insights into the implications of disclosure in the absence of the threat of competition can also be easily obtained from this model, since this would just be the special case where σ_2 approaches infinity. An extension of this modelling framework to allow multiple "early" and "late" informed traders will increase notational complexity considerably, without changing the basic insights of the paper.

The development of equilibrium in this model consists of identifying the trading strategies for traders #1 and #2, and price setting mechanisms for the market maker. We assume that both traders adopt trading strategies to maximize expected profits, while the market maker sets prices in each round in order to break even (i.e earn zero profits). In this economy, we conjecture the following linear equilibrium.[13] In the first round, trader #1 submits the order

$$x_1 = \alpha_1 \theta_1 \tag{1}$$

while the market maker sets prices according to

$$P_1 = \lambda\left[x_1 + u_1\right] \tag{2}$$

In the second round, the two informed traders trade according to

$$x_2 = \alpha_2\left[\theta_1 - \mu_1\right] \tag{3}$$

and

[13] While the existence of non-linear equilibria is not precluded in this model, our focus on linear equilibria is consistent with the focus of much of the literature in the area (see, for example, Madhavan (1995), who argues that the merits of restricting attention to linear equilibria are that these impose the fewest computational burdens on agents, exhibit stability, and yield closed-form solutions).

$$y_2 = \beta_2[\theta_2 - \mu_2] \tag{4}$$

while the market maker's pricing rule in this round is given by

$$P_2 = \mu_v + \Gamma[x_2 + y_2 + u_2] \tag{5}$$

where μ_v, μ_1 and μ_2 represent the conditional expectations of v, θ_1 and θ_2 based on the public information available at t=1, i.e. the market clearing price in the previous round, P_1, and the signal about past trades by informed trader #1, S. Equilibrium is therefore characterized by the parameters (α_1, λ, α_2, β_2, Γ) that are consistent with this conjectured equilibrium.

3. Market Equilibrium

The second round of trade

We begin by considering the restrictions characterizing equilibrium in the second round of trading. At this stage, all the players have observed the market clearing price in the previous round, P_1, and the signal S. Given the joint normality of all the variables, it follows that the distribution of (v, θ_1, θ_2) conditional on (P_1, S) is also multivariate normal (Anderson (1984), Theorem 2.5.1). The parameters of this distribution are given in the next proposition.

Proposition I: The distribution of (v, θ_1, θ_2) conditional on (P_1, S) is multivariate normal with conditional means

$$\begin{bmatrix} \mu_v \\ \mu_1 \\ \mu_2 \end{bmatrix} = \Psi . \begin{bmatrix} P_1 \\ S \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} \dfrac{\alpha_1 \sigma_v^2}{\lambda \sigma_{u1}^2} & \dfrac{\alpha_1 \sigma_v^2}{\sigma_\eta^2} \\ \dfrac{\alpha_1 (\sigma_v^2 + \sigma_1^2)}{\lambda \sigma_{u1}^2} & \dfrac{\alpha_1 (\sigma_v^2 + \sigma_1^2)}{\sigma_\eta^2} \\ \dfrac{\alpha_1 \sigma_v^2}{\lambda \sigma_{u1}^2} & \dfrac{\alpha_1 \sigma_v^2}{\sigma_\eta^2} \end{bmatrix} \begin{bmatrix} P_1 \\ S \end{bmatrix} \tag{7}$$

and conditional covariance matrix

$$\Omega = \frac{1}{\Delta}\begin{bmatrix} \left[1+\Phi\sigma_1^2\right]\sigma_v^2 & \sigma_v^2 & \left[1+\Phi\sigma_1^2\right]\sigma_v^2 \\ \sigma_v^2 & \left(\sigma_v^2+\sigma_1^2\right) & \sigma_v^2 \\ \left[1+\Phi\sigma_1^2\right]\sigma_v^2 & \sigma_v^2 & \left[1+\Phi\sigma_1^2\right]\left(\sigma_v^2+\sigma_2^2\right)+\Phi\sigma_v^2\sigma_2^2 \end{bmatrix} \tag{8}$$

where

$$\Delta = 1+\alpha_1^2\left(\sigma_v^2+\sigma_1^2\right)\left(\frac{1}{\sigma_\eta^2}+\frac{1}{\sigma_{u1}^2}\right) \tag{9}$$

and

$$\Phi = \alpha_1^2\left(\frac{1}{\sigma_\eta^2}+\frac{1}{\sigma_{u1}^2}\right) \tag{10}$$

Proof: All proofs are in the Appendix. ■

The elements of the Ψ matrix will be referred to as ψ_{ij}, i=v,1,2 and j=P,S, and the terms in the conditional covariance matrix, denoted Ω, will be denoted by ω_{ij} (i,j=v,1,2), for the subsequent discussion.

Based on this posterior joint density, the problem faced by the three players can be formulated. Specifically, while the two traders maximize their expected profits, the market-maker sets prices in order to break even. These strategies impose the following restrictions on the equilibrium

Proposition 2: A comparison of terms between the conjectured equilibrium, and the individually rational strategies, leads to the following parameter restrictions being imposed in the second round of trading.

$$\alpha_2 = \frac{1}{2\Gamma}\left[\frac{\omega_{v1}-\Gamma\beta_2\omega_{12}}{\omega_{11}}\right], \tag{11. a}$$

$$\beta_2 = \frac{1}{2\Gamma}\left[\frac{\omega_{v2} - \Gamma\alpha_2\omega_{12}}{\omega_{22}}\right] \tag{11.b}$$

and

$$\Gamma = \left[\frac{\alpha_2\omega_{v1} + \beta_2\omega_{v2}}{\alpha_2^2\omega_{11} + \beta_2^2\omega_{22} + 2\alpha_2\beta_2\omega_{12} + \sigma_{u2}^2}\right] \tag{11. c}$$

Proof: Appendix. ■

Notice that the preceding results characterize the manner in which the equilibrium depends on <u>any</u> distribution that is multivariate normal. To better understand the manner in which the strategy on the trader in the preceding round affects the equilibrium here, it is useful to explicitly characterize the solution both in terms of the level of disclosure and the trading intensity in the preceding round. The following result restates the restrictions implied by (8.a-d) in terms that makes this comparison easier.

Proposition 2': The equilibrium in the second round of trade can be characterized by the following parameter restrictions.

$$\alpha_2 = \frac{1-\Gamma\beta_2}{2\Gamma}\frac{\sigma_v^2}{\sigma_v^2+\sigma_1^2}, \tag{12.a}$$

$$\beta_2 = \frac{\sigma_v^2}{2\Gamma}\left[\frac{\Phi\sigma_1^2 + (1-\Gamma\alpha_2)}{(1+\Phi\sigma_1^2)(\sigma_v^2+\sigma_2^2) + \Phi\sigma_v^2\sigma_2^2}\right] \tag{12.b}$$

$$\Gamma = \frac{\left[(\alpha_2+\beta_2) + \Phi\sigma_1^2\right]\sigma_v^2}{\left[(\alpha_2+\beta_2)^2\sigma_v^2 + \alpha_2^2\sigma_1^2 + \beta_2^2\sigma_2^2 + \sigma_{u2}^2\right] + \Phi\left[\beta_2^2\sigma_1^2(\sigma_v^2+\sigma_2^2) + \sigma_v^2\sigma_2^2 + (\sigma_v^2+\sigma_1^2)\sigma_{u2}^2\right]} \tag{12.c}$$

Proof: Follows from substituting for the variance and covariance terms from (7) into the equilibrium conditions in Proposition 2. ■

As can be seen from restating the equilibrium conditions this way, the parameter Φ captures all the information that is being brought from the first round into the second round. This information is based on (i) how aggressively trader #1 transacted in the previous round (α_1), (ii) the extent to which uninformed order flow allows trader #1 to hide his information(σ_{u1}^2), and (iii) the extent to which noisiness in the trade disclosure process allows him to hide his information (σ_η^2). It is also easy to show that as Φ approaches zero, which can be interpreted as the case where no information is conveyed by the previous round of trade, the solution characterized by (12 a-c) is nothing but the equilibrium in a single round of trade with two informed traders. Similarly, an environment of perfect trade disclosure would be one where $\sigma_\eta^2 \to \infty$, or equivalently, one where $\Phi \to \alpha_1^2/\sigma_{u1}^2$.

Since Φ fully captures the effect of the first round on equilibrium in the second round of trade, it is useful to examine the relationship between it and equilibrium in the second round. Notice that the term Φ is not present in the restriction on α_2 directly, reflecting the fact that in the second round, trader #1 is primarily concerned about the strategies of the other players alone, and not about Φ itself, since he has already observed θ_1, about which P_1 and S are providing information .

For trader #2 (the trader who trades in the second round only), the increased precision of the revelation of information about the asset through the price P_1 and through trade disclosure (loosely interpreted as an increase in Φ) has conflicting effects. First, to the extent that this revelation provides information about the signal observed by the first trader (θ_1), it is useful in "corroborating" the information contained in trader #2's own signal, θ_2, and also provides this trader with information on the nature of competition in the second round. However, the disclosure announcement also conveys valuable information to the market maker, who bases his price on this information. This leads to a reduction in the value of trader #2's private information. While the corroboration effect would cause trader #2 to trade more aggressively, the revelation of the information to the market maker creates the opposite effect, suggesting that trader #2's strategy could be non-monotonic in Φ. The fact that this can happen is illustrated by the following example.

Example:

Consider the case where the model is characterized by the following set of parameters.

$$\sigma_v = 5, , \sigma_2 = 1, \sigma_{u1} = 3, \sigma_{u2} = 3, \sigma_\eta = 2.$$

The solution values of β_2 (the intensity of trading by trader #2) are computed for different levels of the precision of trader #1's signal θ_1, i.e. over the range $\sigma_1 = 0$ to 0.35, and for different values of the parameter Φ=0 to 5.[14]

These solutions are plotted in Figure 1 (all figures appear after the Conclusions), which shows that the trading intensity of the second trader can be nonmonotonic in Φ. This nonmonotonicity is most pronounced when the signal being received by trader #1 is quite precise. When the signal being received by trader #1 becomes less precise, the trading intensity of trader #2 becomes a monotonic increasing function of Φ.

These findings are consistent with the trade-off faced by trader #2 between the benefits of having knowledge about the competition and the costs of having information revealed to the market maker. Not surprisingly, trader #2 is most concerned about the revelation of information to the market maker when trader #1 receives a very precise signal, i.e. σ_1 is low. In this case, increases in Φ (loosely interpreted as an increase in the precision of trade disclosure) quickly lead to situations where any benefit (in terms of corroboration) to trader #2 are offset by the fact that this information is also revealed to the market maker. Consequently, beyond a certain point, trader #2 is forced to respond to increases in Φ by decreasing his intensity of trading (the conventional impact of disclosure).

However, as the precision of trader #1's information is lowered (i.e. σ_1 is increased) trader #2 is less concerned about the information revealed to the market maker, and is more interested in the manner in which the disclosure corroborates the information in his own signal. Since, in this case, the corroboration effect is the dominant one, an increase in Φ leads to an unambiguous increase in β_2 (at least over the range of computation).

It is important to emphasize that any insights provided by this example are only within

[14] The numerical computations were performed in MathCad (version 5). All solutions are at a precision of 1*10^-10. Details are available from the author upon request.

the context of a partial equilibrium, in the sense that, in equilibrium Φ depends endogenously on α_1 and σ_1. The example will be extended in Section 4 to include these aspects, and the insights provided here will be useful in explaining the factors that affect the overall equilibrium.

The First Round of Trade

In order to characterize equilibrium in the first round of trade, we need to know the expected profits from the second round. The expected profits to the two traders in the second round are given next.

Proposition 3: The expected profits to the two traders in the second round are given by

$$\pi_{12} = \Gamma x_2^2 = \Gamma \alpha_2^2 [\theta_1 - \mu_1]^2, \text{ and } \quad \pi_{22} = \Gamma y_2^2 = \Gamma \beta_2^2 [\theta_2 - \mu_2]^2 \tag{13}$$

where π_{ij} denotes the profits by trader i in round j.

Proof: See Appendix.

■

In selecting his optimal trading strategy in round #1, informed trader #1 solves

$$\max_{x_1} E\left\{x_1\left[\tilde{v} - \lambda_1(x_1 + \tilde{u}_1)\right]\middle|\theta_1\right\} + E_0\left[\pi_{12}(x_1)\middle|\theta_1\right] \tag{14}$$

where the first term in (14) reflects the expected profits to trader #1 from the first round of trade, while the second term reflects the implications for the expected profits from the second round of trade. Knowing the expected profits for trader #1 in the second round of trade from Proposition 3, we can now solve for the additional conditions imposed.

Proposition 4: The equilibrium restrictions imposed by the trading strategy of the informed trader in the first round and the market-maker's pricing strategy are

$$\alpha_1 = \frac{\frac{\sigma_v^2}{\sigma_v^2+\sigma_1^2} - 2\Gamma\alpha_2^2(\psi_{1P}\lambda+\psi_{1S})}{2\left[\lambda-\Gamma\alpha_2^2(\psi_{1P}\lambda+\psi_{1S})^2\right]} \tag{14}$$

where

$$\psi_{1P} = \frac{\alpha_1(\sigma_v^2+\sigma_1^2)}{\Delta\lambda\sigma_{u1}^2}, \quad \psi_{1S} = \frac{\alpha_1(\sigma_v^2+\sigma_1^2)}{\Delta\lambda\sigma_\eta^2}, \quad \Delta = 1+\alpha_1^2(\sigma_v^2+\sigma_1^2)\left(\frac{1}{\sigma_\eta^2}+\frac{1}{\sigma_{u1}^2}\right)$$

and

$$\lambda = \frac{\alpha_1\sigma_v^2}{\alpha_1^2(\sigma_v^2+\sigma_1^2)+\sigma_{u1}^2} \tag{15}$$

Proof: Appendix. ■

Notice that when ψ_{1P} and ψ_{1S} are zero, the equilibrium is identical to the single period equilibrium in Kyle (1985). This is not surprising, since this corresponds to the case where trader #1's current trades do not reveal any information, and consequently have no implications for the second round of trade.

This completely characterizes equilibrium in the model. The complete solution requires solving equations (9 a.-c.), (14), and (15) for the parameters (α_1, λ, α_2, β_2, Γ). In order to understand the complex, non-linear system characterizing equilibrium, we begin by considering equilibrium under the extreme cases of no disclosure ($\sigma_\eta = \infty$) and perfect disclosure ($\sigma_\eta=0$). This will make it easier to understand the consequences of noisy disclosure regimes on equilibrium.

4. Analysis of Equilibrium

If there is no disclosure of trades in the economic environment under consideration, i.e the noise in the disclosure process (σ_η) is infinite, the resulting equilibrium is fairly obvious, given the results of the previous section.[15] Specifically, while obvious changes are made to both the conditional means and the conditional covariance matrix in Proposition 1, the restrictions characterizing equilibrium remain unchanged. The same is true for as σ_η approaches zero, i.e. the disclosure of trades becomes perfect. However, an examination of this special case will provide some useful insights into the solution under generic levels of disclosure.

When disclosure is perfect, trader #1 has to decide whether to trade in the first or the second round only. Any trading in the first round immediately renders his information worthless for the subsequent round of trade since his trade (and therefore his private information θ_1) is disclosed before the next round of trade. Alternately, trader #1 could forego trading in the first round altogether, and trade in the second round alone. Consequently, in this extreme case, trader#1 will trade either in the first round or in the second round only. The benefit of trading in the first round is that the trader has no competition to worry about. However, if there are a large number of noise traders in the second round (i.e. $\sigma_{u2}^2 > \sigma_{u1}^2$), the trader might be willing to forego trading in the first round, and trade exclusively in the second round instead, despite the presence of competition from trader #2. His willingness to do so, of course, will also depend on the relative precision of his signal relative to the precision of the signal received by trader #2. Obviously, his choice of which round to trade i is influenced by his desire to maximize expected profits. It is well known from the existing literature that the expected profits to trader #1 in the first round are increasing in σ_v and σ_{u1}, while decreasing in σ_1. Similarly, the expected profits that he generates in the second round are increasing in σ_v, σ_{u2}, and σ_2, while they decrease in σ_1. As a consequence, trader 1 is more likely to trade in the first round when σ_{u1} is high, while he is more likely to trade in the second round if σ_{u2} and/or σ_2 are high. The implications of higher σ_v or σ_1 are less clear, since they affect profits in either round similarly.

To illustrate the types of outcomes that can occur under the cases of no disclosure and perfect disclosure, consider the following two cases.

[15] The equilibrium in this case is can be shown to be a variant of Holden and Subrahmanyam (1992), modified to allow the number of informed traders to change over time.

Case 1: $\sigma_v=3$, $\sigma_1=0.5$, $\sigma_2=1$, $\sigma_{u1}=1$, $\sigma_{u2}=1$

Case 2: $\sigma_v=3$, $\sigma_1=0.5$, $\sigma_2=1$, $\sigma_{u1}=1$, $\sigma_{u2}=1$

It should now be clear why case 1 and 2 have been parameterized the way that they have. Specifically, Case 1 corresponds to the situation where trader 1 would rather transact in the first versus the second round if there is perfect disclosure. The pool of noise traders is similar in both rounds (i.e. $\sigma_{u1}=\sigma_{u2}$) and transacting in the second round exposes trader 1 to some amount of competition, thereby reducing his expected profits. In Case 2, on the other hand, the pool of noise traders in the second round is much "larger", though trader 1 does face increased competition by transacting in this round. One would expect the benefit of having a larger amount of noise trading to dominate the "cost" of increased competition, resulting in an equilibrium where trader 1 can make superior profits by transacting in the second round alone. The equilibrium along with the expected profits of the two traders are summarized in Table 1.

Table 1: Equilibrium Under "No Disclosure" and "Full Disclosure"
(A Numerical Example)

	No disclosure ($\sigma_\eta = \infty$)		Full disclosure ($\sigma_\eta = 0$)	
	Case 1 (σ_{u1}=1)	Case 2 (σ_{u2}=2)	Case 1 (σ_{u1}=1)	Case 2 (σ_{u2}=2)
α_1	0.26365	0.20900	0.329798	0
λ	1.44423	1.33969	1.47959	0
α_2	0.32876	0.59946	******	0.48928
β_2	0.25629	0.48447	0.81284	0.42256
Γ	1.08263	0.58596	0.12035	0.70013
Π_{11}	1.44423	1.33964	1.47959	0
Π_{12}	0.65878	1.38721	0	1.55038
Π_{22}	0.42099	0.95983	0.00058	1.25014
Π_1	2.10302	2.72690	1.47959	1.55038
Π_{total}	2.5240	3.68673	1.48017	2.80052

Having understood these extreme cases will make the cases of interim levels of disclosure a little more intuitive.

The two sets of parameters considered here lead, for the case of perfect trade disclosure, to these two extreme solutions. The prior intuition that these two scenarios lead to very different solutions as $\sigma_\eta \rightarrow 0$ turns out to be useful in understanding the behavior of the solution at intermediate values of σ_η. These intermediate solutions are of interest, of course, since they represent the more plausible representation of the inherently noisy nature of disclosure. As we just saw, under perfect disclosure, in case I informed trader #1 trades exclusively in the first round, while in case II, informed trader #1 trades exclusively in the second round only.[16]

The equilibrium parameters for a these two cases, at a variety of disclosure levels, are shown in Figures 2 through 10. The parameters for Case 1 are represented by the solid line and the left hand side y-axis, while the parameters for Case 2 are represented by the dashed line and the right hand side y-axis. In Figure 2, we examine the impact of changes in the precision of disclosure on the level of Φ (the parameter utilized to characterize the information taken from the first to the second round of trade, see Proposition 2). In the absence of any adjustment in the trading strategy of trader #1 in the first round (i.e. a change in α), Φ is inversely related to σ_η. For Case 1, this relationship persists even when the endogenous adjustment in α to the changes in disclosure levels are taken into account. Since trader #1 view trading in the first round as being more lucrative in this case, he is unwilling to adjust his strategy in the first round too much. In Case 2, however, the relationship between σ_η and Φ is non-monotonic. Trader #1 is very interested in trading in the second round. At high levels of σ_η (i.e. very noisy disclosure) he is not very concerned about the implications of his first round trading on the equilibrium in the second round. However as σ_η becomes smaller (i.e trade disclosure becomes more precise), trader #1 consciously attempts to control the information

16 These examples have been replicated for a variety of different parameter values that have the same characteristics, i.e. that in the limit as disclosure becomes perfect, trader #1 prefers to trade exclusively in the first round in Case I and exclusively in the second round in Case II. The results are similar to those depicted in Figures 2-10. Space constraints preclude the inclusion of the details, but details are available upon request.

revealed in the second round by scaling back his trading activity. In order to better understand the differences across the equilibria in the two cases, we discuss each one separately next.

Case 1

The implication of changes in the precision disclosure on the strategies of trader #1 in the first round can be seen more clearly in Figure 3. Starting at high levels of σ_η, corresponding to very noisy disclosure, a reduction in the noisiness (σ_η) initially causes trader #1 to scale down the aggressiveness with which he trades in the first round (α). Correspondingly, as seen in Figure 4, the market maker reduces the sensitivity of price to order flow (λ), leading to an improvement in liquidity. Not surprisingly, the expected profits to trader #1 from the first round decrease as well (Figure 8). However, as σ_η is reduced beyond a certain point, trader #1 now begins to trade more aggressively as the noisiness in disclosure is reduced. Both the market-maker's pricing and the first round profits increase accordingly.

Intuitively, the rationale for this change in behavior can be explained based on the consequences of reduced noisiness of trade reporting on the equilibrium in the second round. The first round trading strategy of trader #1 is clearly dependent on the profits that he expects to make in the second round. As disclosure becomes more precise, trading in the first round effectively precludes any trading in the second round, since such disclosure results in the trader no longer possessing an informational advantage relative to the market. In the situation considered in Case I, trader #1 effectively "gives up" trading in the second round in order to profit in the first round. This can be seen in Figure 9, where the expected profits to trader #1 from the second round of trade approach zero as disclosure becomes more precise (i.e. σ_η approaches zero). The effect of increased transparency causes trader #1 to trade more aggressively in the second round conditional on possessing superior information. However, the reduced presence of trader #1 in the second round causes the market maker to lower the sensitivity of price to order flow (Γ) leading to an improvement in liquidity. The trading strategy of trader #2 is non-monotonic in σ_η, reflecting the trade-offs discussed in Section 3.

Case 2

In Case II, an reduction in the noisiness of trade disclosure causes trader #1 to reduce trading in the first round to concentrate on the second round. As can be seen from Figures 3,4 and 7, trader #1, reduces α leading to lower profits from the first round, and the market maker reduces λ, leading to improved liquidity in the first round as well. In this case, the interesting effects are in the second round of trade. When σ_η is high, lowering it initially causes trader #1 and trader #2 to trade more aggressively. Intuitively, at this stage, the increased disclosure helps trader #2 by corroborating his information. Trader #2 consequently trades more aggressively, and trader #1 responds. At this stage, the increased competition between the two traders allows the market maker to actually reduce Γ, as can be seen in Figure 7. This is also seen in Figures 9 and 10, where the expected profits to both traders decrease. However, as σ_η is decreased further, trader #1 scales down his trading in the first round. Since no information has been revealed to the market, both trader #2 and the market maker know much less. Consequently, trader #2 trades less aggressively (Figure 6) and the market maker increases Γ (Figure 7). Trader #1 is able to reduce β (Figure 5) and still generate higher expected profits in the second round. It is interesting to note that trader #2 prefers this solution as well, since his profits also increase.

Both these cases together suggest that the impact of increased transparency on liquidity is quite complex. In Case I, increasing transparency beyond a certain point actually worsens liquidity in the first round, since trader #1 decides to cluster all his trades there. By contrast, in Case 2, an increase in transparency leads to trader #1 deciding to trade primarily in the second round, leading to improvement in liquidity in the first round, but at the expense of reduced liquidity in the second round. This result is quite similar to that obtained by Admati and Pfleiderer (1988) in the context of discretionary noise traders. These traders will naturally gravitate towards periods of greatest liquidity, in order to minimize their losses. As shown in this example, informed traders face similar incentives, especially in the presence of noisy trade reporting. These traders naturally gravitate towards periods with the highest expected profits, leading to a reduction in liquidity in that period, while liquidity improves in the other time periods.

5. Implications

This paper has developed a multiperiod model of trading to examine the consequences of noisy trade reporting on the equilibrium trading strategies of informed traders, with a special focus on the implications of this disclosure for liquidity (in the different rounds of trading). The primary finding is that when informed traders can adjust their trading strategies to reflect the disclosure environment in which they trade, an increase in the precision of trade reporting can have ambiguous affects on liquidity. This is because the increased precision of disclosure creates incentives for traders who obtain information early to concentrate their trades in a single round. This effect is similar to that identified by Admati and Pfleiderer (1988) in the context of clustering of trades by liquidity traders. The situation where the early informed trader clusters in the later round can also be interpreted as herding.

In addition, we find that increasing the precision of trade disclosure has mixed implications for traders who receive private information later that others. This is because such disclosure has two distinct effects. First, it serves a useful role in corroborating the private information available to the trader. Second, it provides additional information to the market maker, who utilizes this information in setting prices, thereby reducing the value of the private information available to the trader. Consequently, the trader who receives private information late could find his profits either increasing or decreasing as a function of better (less noisy) disclosure.

The implication of these results for the structure of markets and regulation clearly depends on the assumed objectives (of the markets or regulators), an area of considerable ambiguity. What is clear is that the often stated objective of perfect (noiseless) disclosure is not necessarily the appropriate goal to adopt. Such disclosure, or regulations that increase the precision of existing trade disclosure policies, have complex implications for the intertemporal liquidity, volatility, volume, and the acceleration in information revelation in a security market.

The analysis in this paper exogenously specifies the noisiness in the trade reporting process in order to concentrate on the implications for market equilibrium. A useful extension of this analysis would be to model the noisiness in the reporting process as a function of the structure of the market itself. This could also provide insights on the role of such trade reporting in a multi-market setting. Finally, it would also be useful to examine other dimensions of the equilibrium, like volatility, the intertemporal correlation of prices, and the incentives to collect information under different disclosure regimes. All of these represent interesting directions for future research.

Figure 1

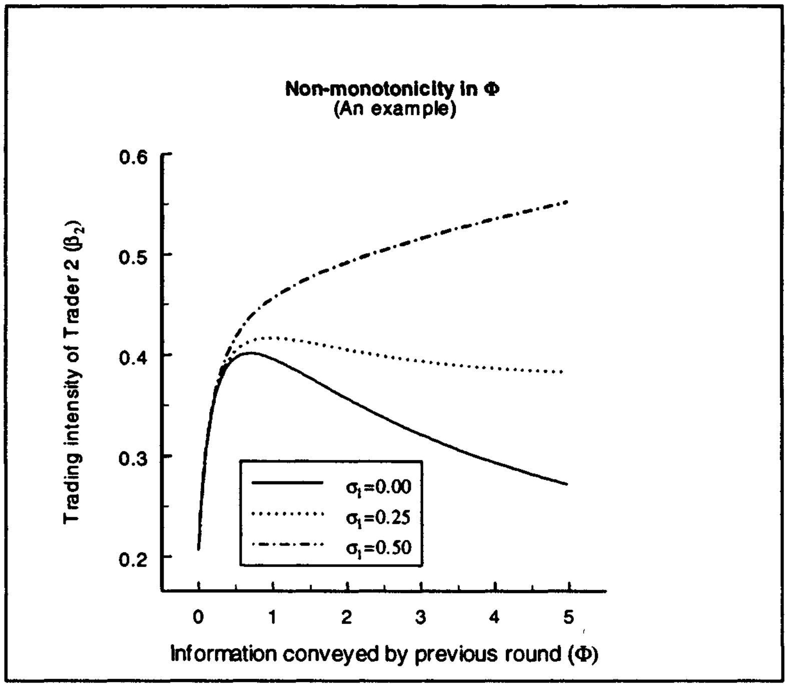


Figure 2

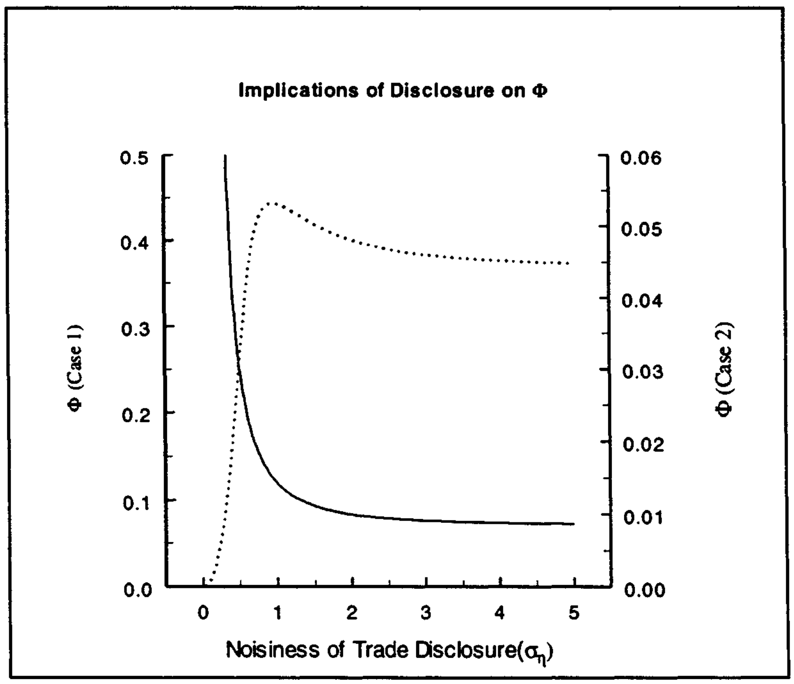


Figure 3

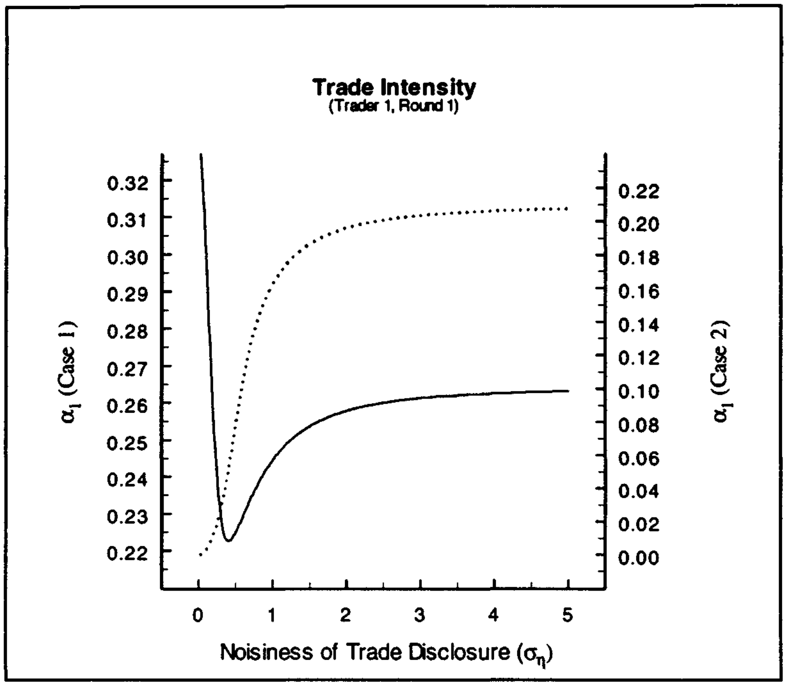


Figure 4

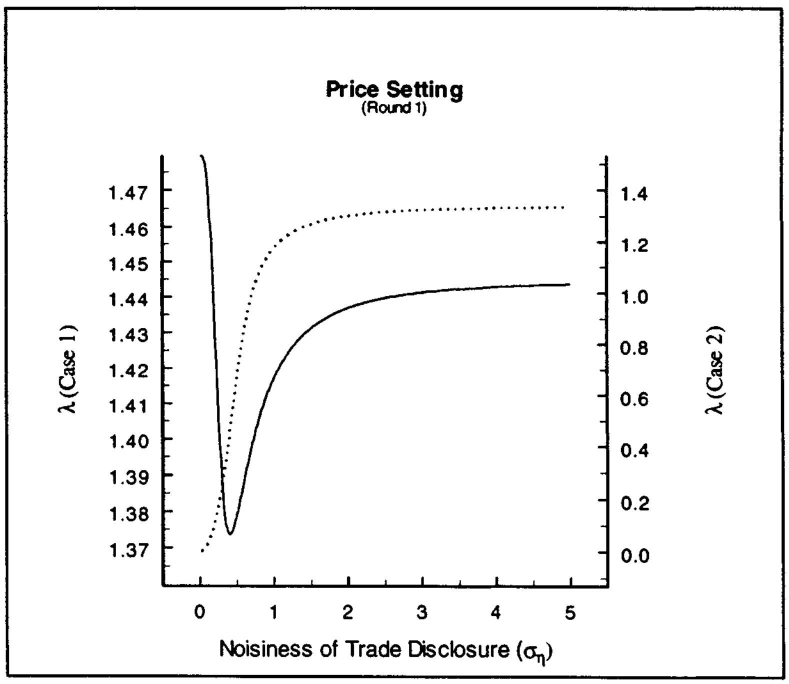


Figure 5

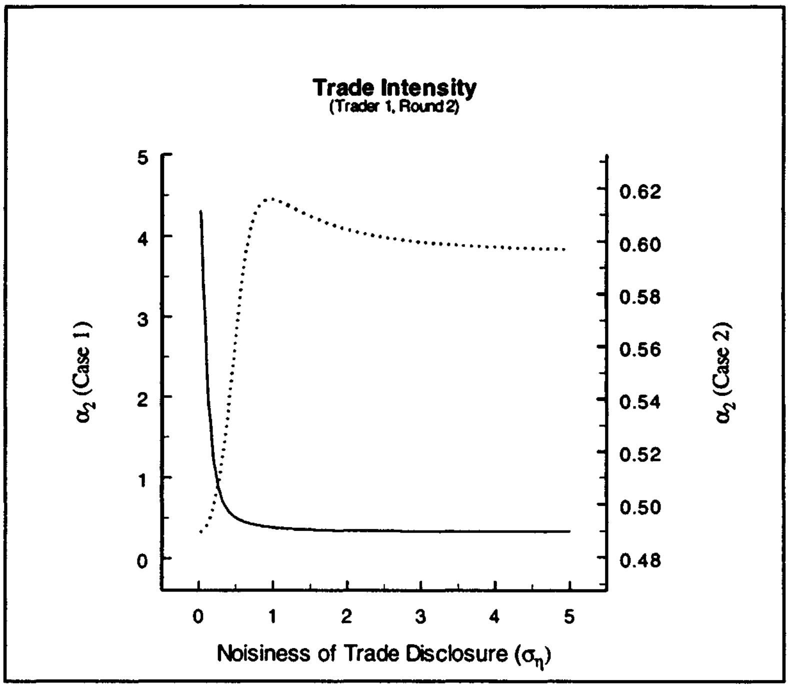


Figure 6

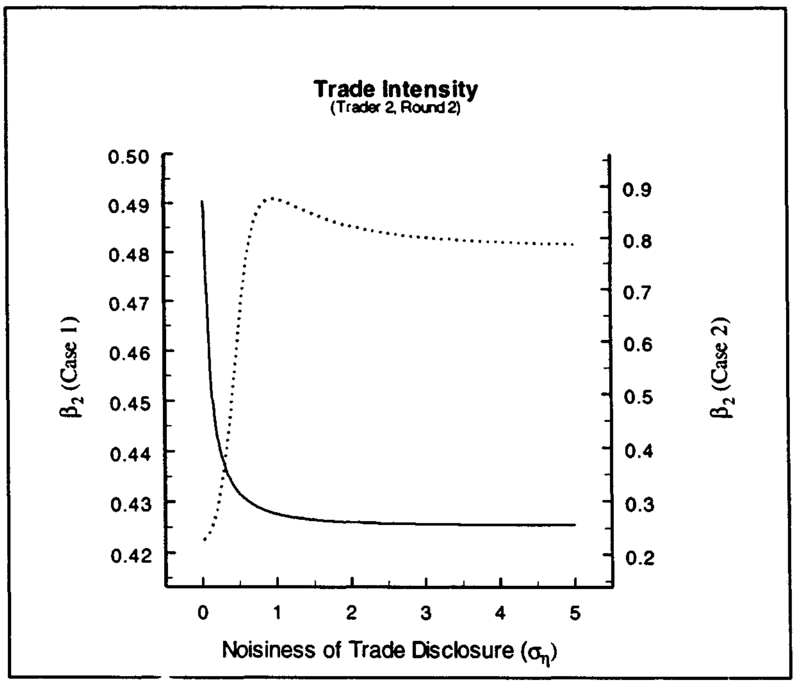


Figure 7

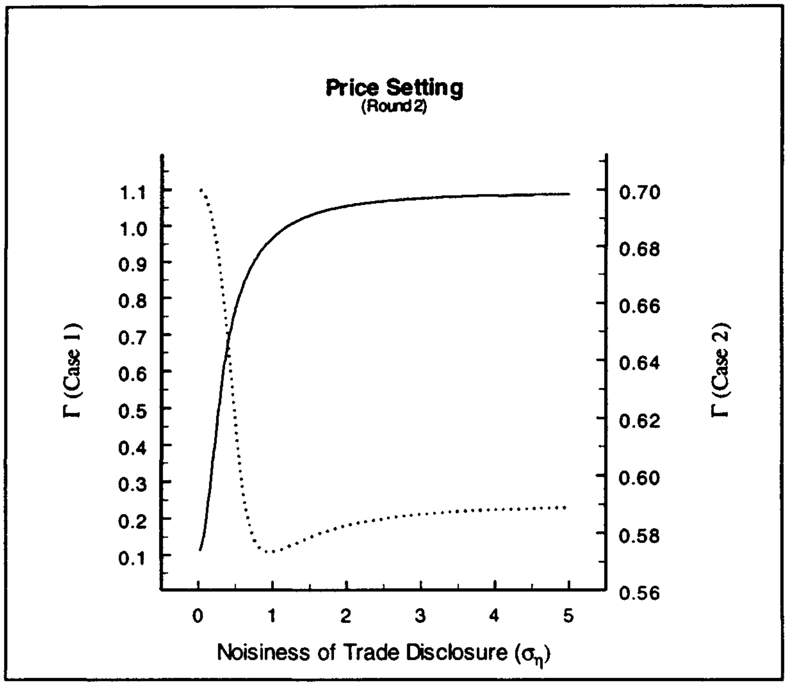


Figure 8

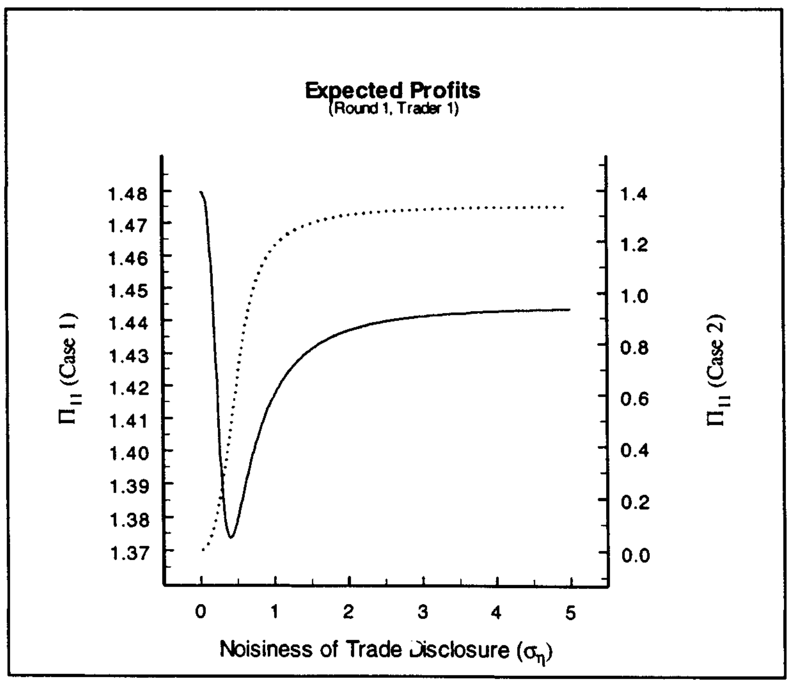


Figure 9

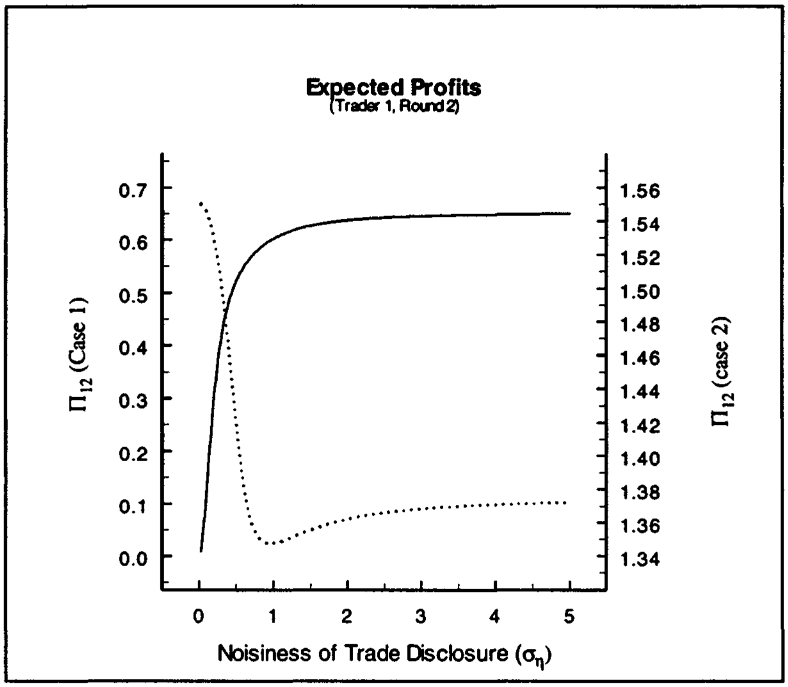


Figure 10

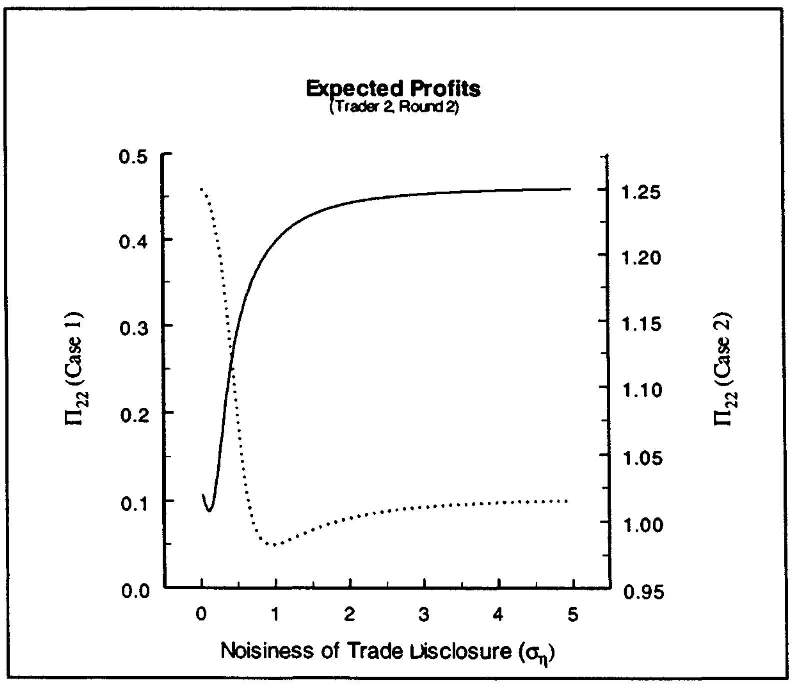


Figure 11

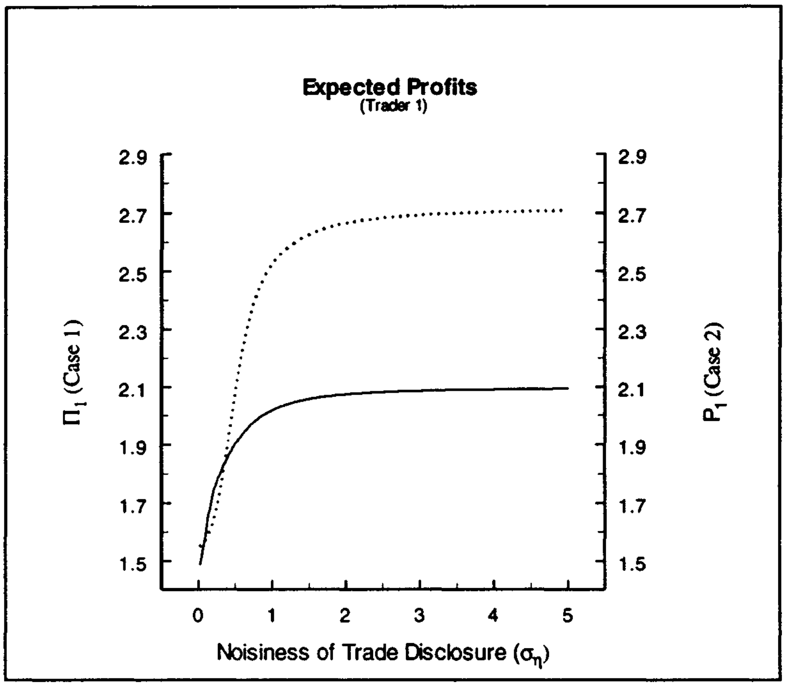
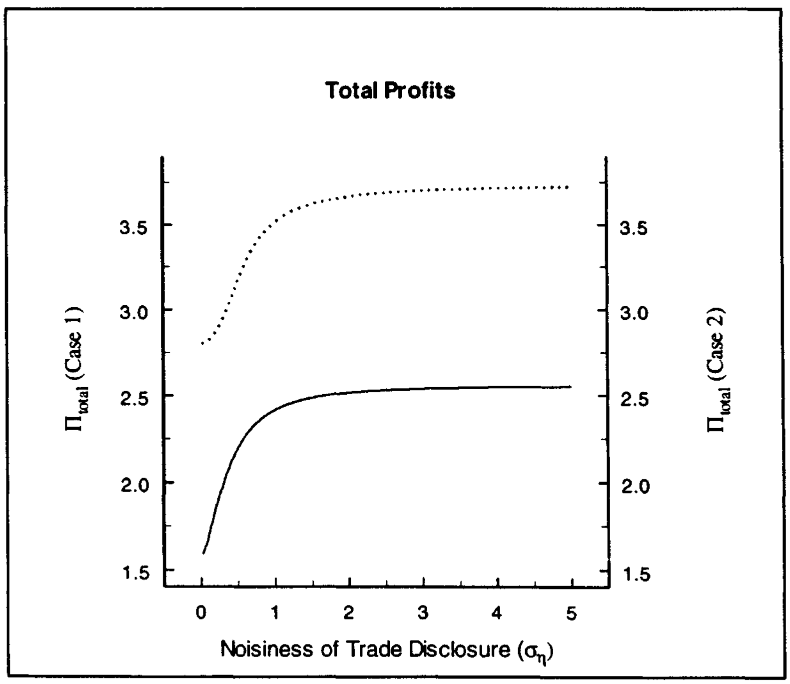


Figure 12



Appendix

Proof of Proposition 1 The unconditional distribution of the random variables [v, y_1, y_2, P_1, S] is multivariate normal, with mean zero and a covariance matrix,

$$\Sigma = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}$$

whose components are

$$\Sigma_{11} = \begin{bmatrix} \sigma_v^2 & \sigma_v^2 & \sigma_v^2 \\ \sigma_v^2 & \sigma_v^2+\sigma_1^2 & \sigma_v^2 \\ \sigma_v^2 & \sigma_v^2 & \sigma_v^2+\sigma_2^2 \end{bmatrix} \qquad (A.1)$$

$$\Sigma_{12} = \begin{bmatrix} \alpha_1\lambda_1\sigma_v^2 & \alpha_1\sigma_v^2 \\ \alpha_1\lambda_1\left(\sigma_v^2+\sigma_1^2\right) & \alpha_1\left(\sigma_v^2+\sigma_1^2\right) \\ \alpha_1\lambda_1\sigma_v^2 & \alpha_1\sigma_v^2 \end{bmatrix} \qquad (A.2)$$

$$\Sigma_{22} = \begin{bmatrix} \alpha_1^2\lambda_1^2\left(\sigma_v^2+\sigma_1^2\right)+\lambda_1^2\sigma_{u1}^2 & \lambda_1\alpha_1^2\left(\sigma_v^2+\sigma_\eta^2\right) \\ \lambda_1\alpha_1^2\left(\sigma_v^2+\sigma_\eta^2\right) & \alpha_1^2\left(\sigma_v^2+\sigma_\eta^2\right) \end{bmatrix} \qquad (A.3)$$

and $\Sigma_{21}=\Sigma_{12}^T$. Standard results from multivariate normality (Anderson (1984) imply that the conditional mean is given by

$$\begin{pmatrix} \mu_v \\ \mu_1 \\ \mu_2 \end{pmatrix} = \Sigma_{12}.\Sigma_{22}^{-1}.\left[P_1 \quad S\right] \qquad (A.4)$$

while the conditional covariance matrix is given by

$$\Omega=\Sigma_{11}-\Sigma_{12}.\Sigma_{22}^{-1}.\Sigma_{12}^T \qquad (A.5)$$

Appropriate simplifications leads to the relevant terms. ■

Proof of Proposition 2: The first informed trader (#1) faces the following optimization problem:

$$\max_{x_2} E_2\{x_2[\tilde{v} - \mu_v - \Gamma(x_2 + z_2 + u_2)] | y_1\} \tag{A.6}$$

where E_2 denotes the fact that expectations are being taken with respect to the posterior distribution characterized in Proposition 1. The associated first order condition can be rewritten to yield the following trading strategy.

$$x_2 = \frac{1}{2\Gamma}\left[\frac{\omega_{v1} - \Gamma\beta_2\omega_{12}}{\omega_{11}}\right][\theta_{11} - \mu_1] \tag{A.7}$$

Similarly, the second trader's strategy leads to

$$y_2 = \frac{1}{2\Gamma}\left[\frac{\omega_{v2} - \Gamma\alpha_2\omega_{12}}{\omega_{22}}\right][\theta_2 - \mu_2] \tag{A.8}$$

Finally, in the second round, the market maker sets prices to break even, i.e.

$$P_2 = E_2[\tilde{v} | x_2 + y_2 + u_2] \tag{A.9}$$

which leads to

$$P = \mu_v + \left[\frac{\alpha_2\omega_{v1} + \beta_2\omega_{v2}}{\alpha_2^2\omega_{11} + \beta_2^2\omega_{22} + 2\alpha_2\beta_2\omega_{12} + \sigma_{u2}^2}\right][x_2 + y_2 + u_2] \tag{A.10}$$

A comparison of terms between the conjectured equilibrium, and the individually rational strategies, leads to the following parameter restrictions being imposed in the second round of trading.

$$\alpha_2 = \frac{1}{2\Gamma}\left[\frac{\omega_{v1} - \Gamma\beta_2\omega_{12}}{\omega_{11}}\right], \beta_2 = \frac{1}{2\Gamma}\left[\frac{\omega_{v2} - \Gamma\alpha_2\omega_{12}}{\omega_{22}}\right] \tag{A.11}$$

and

$$\Gamma = \left[\frac{\alpha_2\omega_{v1} + \beta_2\omega_{v2}}{\alpha_2^2\omega_{11} + \beta_2^2\omega_{22} + 2\alpha_2\beta_2\omega_{12} + \sigma_{u2}^2}\right] \tag{A.12}$$

■

Proof of Proposition 3: We present only the proof for the profits of trader #1, since the condition for trader #2 is similar. Conditional on P_1 and S and y_1, the expected profits of trader #1 are given as

$$\pi_{12} = E_2\left[x_2\left[v - \mu_v - \Gamma(x_2 + y_2 + u_2)\right] \middle| \theta_1\right] \tag{A.13}$$

which upon simplification leads to

$$\pi_{12} = \Gamma x_2^2 = \Gamma\alpha_2^2[\theta_1 - \mu_1]^2 \tag{A.14}$$

where the last part of (A.14) follows from the fact that $x_2=\beta\ [\theta_1 - \mu_1]$.

■

Proof of Proposition 4: Recall, from proposition 3, that the expected profits to trader #1 from the second round of trading is

$$\pi_{21} = \Gamma\alpha_2^2[\theta_1 - \mu_1]^2 \tag{A.15}$$

At t=0, after having observed θ_1, the trader's expected profit (from the second round) from trading a quantity x_1 is

$$E_0\left[\Gamma\alpha_2^2(\theta_1 - \psi_{1P}P_1 - \psi_{1S}S)^2 \middle| \theta_1\right] \tag{A.16}$$

which can be rewritten as

$$E_0\left[\Gamma\alpha_2^2\left(\theta_1 - \psi_{1P}(\lambda(x_1 + u_1)) - \psi_{1S}(x + u_{11})\right)^2 \middle| \theta_1\right] \tag{A.17}$$

Taking expectations of the total profits equation (14) and differentiating with respect to x_1 leads to

$$\frac{\sigma_v^2}{\sigma_v^2 + \sigma_1^2}\theta_1 - 2\lambda x_1 + \Gamma\alpha_2^2\left[-2(\lambda\psi_{1P} + \psi_{1S})\theta_1 + 2(\lambda\psi_{1P} + \psi_{1S})^2 x_1\right] \tag{A.18}$$

which, when rearranged, yields (14) in the text.

■

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