Insiders-Outsiders, Transparency, and the Value of the Ticker [*]

Giovanni Cespa [†] and Thierry Foucault [‡]

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Abstract

We consider a multi-period rational expectations model in which speculators differ in their information on past transaction prices (the ticker). Insiders observe the entire price history whereas outsiders observe past prices with a delay. As prices are informative about the asset payoff, insiders get a strictly larger expected utility than outsiders. However, the welfare of all speculators declines with the proportion of insiders. For these reasons, charging a fee for real time information on the ticker and redistributing the related proceeds among speculators maximizes traders' surpluses. The fee is such that, in equilibrium, the market optimally features both insiders and outsiders. This two-tier market structure also maximizes the profit that an exchange can achieve by selling ticker information and trading rights. Last, we find that increasing the proportion of insiders has no effect on the informativeness of the ticker but reduces the dispersion of pricing errors.

Keywords: Market Data Sales, Latency, Transparency, Price Discovery.

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[†] Queen Mary University of London, CSEF-Universita di Salerno, and CEPR

[‡] HEC, School of Management, Paris, GREGHEC, and CEPR. Tel: (33) 1 39 67 95 69; E.mail:foucault@hec.fr

1 Introduction

Information about trades and quotes is not equally distributed among traders. For example, in open-outcry markets, floor traders enjoy a faster access to information on ongoing trades than off-floor traders. More generally, in many markets real time information on transactions and quotes is not free.[1] De facto, there is a segmentation between investors ("insiders") who, at a cost, have access to real time information, and investors ("outsiders") who obtain this information with a delay.

This situation is controversial. For instance, NYSE's recent proposal to charge a fee for the dissemination of real time information on quotes and trades in Archipelago (a trading platform acquired by the NYSE in 2006) triggered a strong opposition from some market participants.[2] Similarly, data fees charged by Nasdaq for the dissemination of prices in the U.S. corporate bond market have been the subject of heated debates.[3] Moreover, exchanges derive a significant fraction of their revenues from the sale of trade information. For instance, in 2005, the sale of market information accounted for 33% of the London Stock Exchange annual revenues and similar figures apply to Nasdaq and NYSE (respectively 21% and 17%. Source: Annual Reports). Hence, exchanges care about the pricing of market data.[4]

These observations raise intriguing questions. Why is real time access to market data so valuable? Why do exchanges create unequal access to these data? Is it simply a rent-extraction device or is it in the interest of market participants as well? How does asymmetry in the access to ticker information affect informational efficiency?

We study these questions in a multi-period rational expectations model (in the spirit of Hellwig (1980)). The model considers the market for a risky security with risk averse speculators who possess private, but imperfect, information on its payoff, and liquidity traders. Speculators submit price contingent orders (limit orders), and

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[1] Free information on past trades is generally available only after some delay (e.g., twenty minutes on the NYSE, fifteen minutes on Nasdaq and Euronext). See http://finance.yahoo.com/exchanges, for the delays after which information on transaction prices from major stock exchanges is freely released on yahoo.com.

[2] See "Latest Market Data Dispute Over NYSE's Plan to Charge for Depth-of-Book Data Pits NSX Against Other U.S. Exchanges," Wall Street Technology, May 21, 2007. See also the letter to the SEC of the Securities Industry and Financial Markets Association (SIFMA) available at http://www.sifma.org/regulatory/comment_letters/41907041.pdf

[3] See, for instance, "TRACE Market Data Fees go to SEC," Securities Industry News, 6/3/2002. See also Bessembinder and Venkataraman (2007).

[4] For 2003, the sale of market data generated a revenue of $386 million for U.S. equity markets for a cost of dissemination estimated at $38 million (see Exchange Act Rel N°$49,325$ -February, 26,2004 available at http://www.sec.gov/rules/proposed/34-49325.htm).

absorb liquidity traders' net demand. They can be "insiders" or "outsiders." Insiders observe the entire price history (the "ticker") when they arrive in the market, while outsiders observe past prices with a delay.

In this setting, transaction prices are informative about the liquidation value of the security and the clearing price in each period is not a sufficient statistics for the whole price history. Accordingly, insiders have a more precise estimate of the liquidation value. Thus, other things equal, they bear less risk and enjoy a higher expected utility. We thus define the value of the ticker as the maximum fee that a speculator is willing to pay to be an insider.

We show that the value of the ticker declines with the proportion of insiders. This finding follows from two observations. First, the clearing price in a given period aggregates the information inferred by insiders from prices yet unobserved by outsiders. This "second-hand" information is more efficiently aggregated when the number of insiders increases, which reduces insiders' informational advantage. Second, surprisingly, the informativeness of the real time ticker does not depend on the proportion of insiders. Thus, the net benefit of being an insider decreases with the proportion of insiders.

Insiders derive a higher expected utility than outsiders. Yet, unrestricted access to ticker information is not welfare maximizing for speculators. The reason is that acquisition of ticker information by one speculator exerts a negative externality on other speculators. Indeed, insiders trade more aggressively than outsiders on their information. As a consequence, they take larger long or short positions for a given differential between their forecast of the asset payoff and its price. Thus, an increase in the proportion of insiders enlarges the elasticity of speculators' aggregate demand to the difference between speculators' average forecast and the clearing price. This effect draws equilibrium prices closer to the liquidation value of the security, reducing the average return that speculators obtain on their positions. This effect is so strong that speculators are strictly better off when they are all outsiders rather than all insiders.

To sum up, *individually* each speculator benefits from observing the ticker in real time, but *collectively* speculators are worse off when they all get this information. Thus, traders can benefit from a mechanism restraining their access to ticker information without completely precluding it. We show that a market for ticker information can serve this purpose. We first consider the case in which this market is organized by a not-for-profit exchange. The exchange charges a fee to speculators obtaining the ticker in real time and redistributes the proceeds from information sales to speculators. The information fee that maximizes speculators' welfare is always high enough so that not all speculators buy information and in general it is small enough to induce some speculators to buy information. Thus, the optimal market structure for speculators is a two-tier market structure. This structure strikes an optimal balance between the negative externality associated with the dissemination of price information and the utility gain that speculators derive from being better informed.

We also consider the polar case in which the information fee is set by a (monopolistic) for-profit exchange that charges an entry fee to extract the surplus traders derive from market participation. The for-profit exchange also optimally chooses to ration access to ticker information for two reasons. First, rationing sustains a high price for ticker information since the value of the ticker is inversely related to the proportion of insiders. Second, it raises the entry fee charged on speculators since their gains from trading are inversely related to the proportion of insiders. In fact, in our set up, the proportion of speculators acquiring ticker information in equilibrium is the *same* whether the exchange is a not-for-profit or a for-profit entity. The two cases only differ in terms of the division of the gains from trade between speculators and the exchange.

These findings suggest that proposals to cap fees for ticker information must be cautiously considered since in our model high fees for ticker information maximize trading surpluses.[5] We also find that rationing access to ticker information has no effect on the informativeness of the price history but it enlarges the dispersion of pricing errors (the difference between the asset payoff and the transaction price).

Finally, we study the effect of the latency in information dissemination (i.e., the delay with which outsiders observe past transaction prices). We find that the value of the ticker increases with latency. Indeed, the larger is this latency, the noisier is the information that the current clearing price provides about the information contained in the transaction prices yet unobserved by outsiders. Thus, a larger latency increases the net benefit of being an insider. Moreover, as outsiders draw less precise inferences from prices, they require a larger compensation to absorb liquidity traders' demand. Thus, prices are more responsive to order imbalances, i.e., market liquidity is smaller. In line with this implication, Easley, Hendershott, and Ramadorai (2007) find an

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[5] We do not account for noise traders' welfare since their demands are exogenously specified in the model. In the next version of this paper, we plan to endogenize liquidity trading by considering hedging motives for speculators. Preliminary analysis of this case reveals that qualitatively our conclusions are unchanged.

increase in liquidity for stocks listed on the NYSE following a reduction in latency.

Our findings suggest that unlimited dissemination of information on past trades is not optimal, neither for a for-profit exchange nor for speculators. In this way, our analysis contributes to the literature on financial markets transparency (e.g., Pagano and Roëll (1996)) and more specifically to studies of delays in trade reporting (Madhavan (1995), Naik, Neuberger and Viswananathan (1999)).[6]

Our model is also related to the literature on markets for information (e.g., Admati and Pfleiderer (1986, 1987, 1990), Veldkamp (2007), Cespa (2007)). Admati and Pfleiderer (1986) study the sale of financial information, i.e., a signal on the payoff of a risky asset. They show that there is a dilution in the value of this signal due to its leakage through prices. This dilution effect is stronger when more traders buy information because prices are then more informative. For this reason, there is an inverse relationship between the value of financial information and the number of investors purchasing this information. Thus, it can be optimal for an information seller to restrict the number of traders with access to information.

As prices aggregate information, they constitute one type of signal on a security's payoff. However, the sale of price information does not fit the Admati and Pfleiderer (1986)'s framework for several reasons. First, the precision of prices cannot be directly controlled by the information seller as prices are determined by market forces. Second, if prices become more informative when more traders buy information then the value of prices as a signal might well increase with the number of buyers, in spite of the dilution effect. The linkage between the informational value of prices and the number of buyers is therefore à priori unclear. Thus, the sale of price information deserves a specific analysis.

There are very few papers on markets for price information. Mulherin et al. (1992) and Pirrong (2002) focus on the allocation of property rights on stock prices. Our analysis is closer to Boulatov and Dierker (2007). However, these authors do not allow traders to condition their demand on the current clearing price as we do.[7] Thus, in their model, observing past prices is valuable because it reduces the uncertainty on execution prices ("execution risk"). In our model, execution risk is not a concern since traders submit price contingent orders. Rather, the value of price information

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[6] Delays in trade reporting imply that parties in a transaction are more informed than the rest of the market on the details of this transaction and can then exploit this information.

[7] For this reason, our paper also differs from Hellwig (1982) who considers a multi-period rational expectations model in which some traders condition their demand on past prices, only.

derives from the informational content of prices.[8]

The paper is organized as follows. We describe the model in Section 2. In Section 3, we study the effects of varying the scope of information dissemination about past transaction prices and endogenize the fraction of insiders by introducing a market for ticker information. Sections 4 analyzes the effects of the latency in information dissemination. Section 5 concludes. Proofs of our findings are collected in the Appendix.

2 Model

We consider the market for a risky asset with liquidation value $v \sim N(\bar{v}, \tau_v^{-1})$. Trades in this market take place at dates $1, 2, \ldots, N$. At date $N+1$, the liquidation value is realized. There are two types of traders in this market: *(i)* a continuum of speculators (indexed by i) who submit demand functions ("limit orders") and *(ii)* liquidity traders with inelastic demands ("market orders"). We denote by u_n the aggregate demand of liquidity traders at date n. Liquidity demands are independently and normally distributed across time with mean zero and precision τ_u^{-1}. Speculators do not observe liquidity demands at any point in time.

A speculator i arriving at date n receives a private signal s_{in} about the value of the security with

$$s_{in} = v + \epsilon_{in}, \tag{1}$$

where $\epsilon_{in} \sim N(0, \tau_{\epsilon_n}^{-1})$. We assume that v and ϵ_{in} are independent for all i, n and that error terms are also independent across time and across agents. Furthermore, we assume that given v, the average signal $\int_0^1 s_{in} di$ equals v almost surely in every period n (i.e., errors cancel out in the aggregate: $\int_0^1 \epsilon_{in} di = 0$, a.s.). The model does not require speculators to be informed at each date (i.e., $\tau_{\epsilon_n} = 0$ is possible). To fix things, we assume that $\tau_{\epsilon_1} > 0$.

We denote by p_n the clearing price at date n and by p^n the record of all transaction prices up to date n: $p^n = \{p_t\}_{t=0}^n$, with $p_0 = \bar{v}$. Speculators differ in their access to

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[8] There are other important differences between our approach and Boulatov and Dierker (2007). First they use a reduced form approach. Traders in their model observe past signals observed by previous generations of informed traders rather than prices. Thus, the precision of the "price" signal purchased by investors is exogenous while it is endogenous in our model. Second, in our model traders are homogeneous (same preferences, same precision of private information). Thus, other things equal, they have the same valuation for ticker information. Yet, even in this setting, we show that restricting access to real time information can enhance revenues from the sale of real time information.

ticker information. Specifically, speculators with type I (the *insiders*) observe the ticker in real-time while speculators with type O (the *outsiders*) observe the ticker with a lag equal to $l \geq 2$ periods. That is, insiders arriving at date n observe p^{n-1} before submitting their orders and outsiders arriving at date n observe p^{n-l}. Formally

$$p^{n-l} = \begin{cases} \{p_1, p_2, \ldots, p_{n-l}\}, & \text{if } n > l, \\ \bar{v}, & \text{if } n \leq l. \end{cases} \tag{2}$$

We refer to p^n as the "*real-time ticker*" and to p^{n-l} as the "*lagged ticker*." Finally, we refer to the "*delayed ticker* " as the set of prices unobserved by outsiders (i.e., $p^n - p^{n-l}$). We refer to l as the *latency in information dissemination*. The fraction of insiders is denoted by μ. This fraction characterizes the *scope in information dissemination.*

Each speculator has a CARA utility function with risk tolerance γ. Thus, if speculator i holds x_{in} shares of the risky security at date n, her expected utility is

$$E[U(\pi_{in})|s_{in}, \Omega_n^k] = E[-\exp\{-\gamma^{-1}\pi_{in}\}|s_{in}, \Omega_n^k], \tag{3}$$

where $\pi_{in} = (v - p_n)x_{in}$ and Ω_n^k is the price information available at date n to a speculator with type $k \in \{I, O\}$. In the first period, this information is identical for insiders and outsiders since there are no prior transactions. This period can be seen as the first trading round following the overnight closure in real markets.

In period n, insiders and outsiders submit orders contingent on the price at date n and their information. Insiders, however, observe the ticker up to date $n-1$ while outsiders observe the ticker up to date $n-l$ only. Thus, in period $n \geq 2$, we denote the demand function of an insider by $x_n^I(s_{in}, p^n)$ and that of an outsider by $x_n^O(s_{in}, p^{n-l}, p_n)$. In the first period, we denote the demand function of speculator i by $x_1(s_{i1}, p_1)$. In each period, the clearing price is such that the net demand for the security is nil, i.e.,

$$\mu x_n^I + (1-\mu)x_n^O + u_n = 0. \tag{4}$$

Speculators in our model stay in the market for only one period. For this reason, they are not automatically informed about past transaction prices (since they were not involved in these transactions). This approach captures, in a simple way, the idea that investors need to buy information from data vendors because they do not participate to all trades.

Parameters μ and l control the level of market transparency. When the proportion of insiders increases, market transparency is larger since more speculators observe the ticker in real time. When latency decreases (l becomes smaller), market transparency increases since outsiders observe past transaction prices more quickly. To isolate the effect of the proportion of insiders on the value of the ticker, we first focus on the case in which $l = 2$ (insiders observe all transaction prices but the last). Then, in Section 4, we analyze the effect of increasing the latency in information dissemination.

3 Scope of Information Dissemination

3.1 Equilibrium

In our model speculators are privately (and differentially) informed about the asset liquidation value. As a consequence, the clearing price in each period aggregates speculators' private signals and provides an additional signal about the asset payoff (as in Grossman (1976) or Hellwig (1980)). As usual in the literature, we focus on rational expectations equilibria in which speculators' order placement strategies are linear in their signals and prices.

The next proposition provides a characterization of the unique linear rational expectations equilibrium of the model. We refer to $\tau_n \overset{def}{=} (\text{Var}[v|p^n])^{-1}$ as the informativeness of the real time ticker at date n. A larger value of τ_n means that informational efficiency is higher (the entire price system is more informative). Moreover we denote by $\hat{\tau}_n \overset{def}{=} (\text{Var}[v|p^{n-2}, p_n])^{-1}$, the precision of outsiders' forecast conditional on their price observations at date n. For brevity, we refer to $\hat{\tau}_n$ as the informativeness of the "truncated" ticker.

Lemma 1 *When $l = 2$, in each period, there is a unique rational expectations equilibrium. In this equilibrium, the price in each period is given by*

$$p_n = A_n v + B_n u_n + C_n u_{n-1} + D_n E\left[v \mid p^{n-2}\right], \text{ for } n \geq 2, \tag{5}$$

$$p_1 = A_1 v + B_1 u_1 + D_1 \bar{v}, \tag{6}$$

where $\{A_n, B_n, C_n, D_n\}$ are constants characterized in the proof of the proposition with $D_n = 1 - A_n$. Moreover, $A_n > 0$ iff (a) $\tau_{\epsilon_n} > 0$ or (b) $\tau_{\epsilon_n - 1} > 0$ and $\mu > 0$. In this equilibrium speculators' trading strategies in period n are

$$\begin{aligned} x_1(s_{i1}, p_1) &= \gamma(\tau_1 + \tau_{\epsilon_1})(E[v|s_{i1}, p_1] - p_1), \\ x_n^I(s_{in}, p^n) &= \gamma(\tau_n + \tau_{\epsilon_n})(E[v|s_{in}, p^n] - p_n), \\ x_n^O(s_{in}, p^{n-2}, p_n) &= \gamma(\hat{\tau}_n + \tau_{\epsilon_n})(E[v|s_{in}, p^{n-2}, p_n] - p_n), \end{aligned} \tag{7}$$

where $\tau_n = \tau_v + \tau_u \sum_{t=1}^{n} a_t^2$ *with* $a_t = \gamma\tau_{\epsilon_t}$.

A speculator's demand is proportional to the difference between her forecast of the security value and the clearing price, scaled by the precision of this forecast (e.g., $\tau_n + \tau_{\epsilon_n}$ for an insider). In line with intuition, a speculator takes a larger position, other things equal, when her forecast of the liquidation value v is more precise. The elasticity of insiders and outsiders' demands differ because the precision of their forecast differ (see below).

To gain more intuition on the determinants of the clearing price in a given trading round, we now consider some special cases. We say that "fresh" information is available at date n if the speculators entering the market at this date have private information (that is if $\tau_{\epsilon_n} > 0$).

Case 1. *No fresh information is available at date* $n-1$ *and at date* n *(for* $n \geq 3$*).* In this case, $A_n = 0$, $C_n = 0$ and $B_n = (\gamma\tau_{n-2})^{-1}$. Thus, the equilibrium price at date n can be written as follows

$$p_n = E[v \mid p^{n-2}] + (\gamma\tau_{n-2})^{-1} u_n. \tag{8}$$

In this case, the price at date n is equal to the expected value of the security conditional on the lagged ticker adjusted for the compensation required by speculators to accommodate liquidity traders' demand. For a given order imbalance, the size of this compensation is smaller when *(i)* speculators are more risk tolerant (γ large) or *(ii)* the uncertainty on the asset value is smaller (τ_{n-2} large). ■

Case 2. *Fresh information is available at date* $n-1$ *but not at date* n *(*$\tau_{\epsilon_n} = 0$ *but* $\tau_{\epsilon_{n-1}} > 0$*).* If there are no insiders in the market ($\mu = 0$), then the expression for the equilibrium price is given by equation (8). The transaction price at date $n-1$ contains information ($E[v \mid p^{n-2}] \neq E[v \mid p^{n-1}]$) but, at date n, speculators do not yet observe this price. Hence, the information available at date $n-1$ will be reflected into prices only at date $n+1$. Consequently, if realized liquidity demands are nil, the prices at dates $n-2$ and n are identical.

The situation is different if $\mu > 0$. Insiders at date n obtain a noisy signal on the liquidation value from the price realized at date $n-1$. As they trade on this signal, part of the information contained in the $(n-1)^{th}$ transaction price "percolates" into the price at date n. In this case, $A_n > 0$ and the equilibrium price at date n can be written as follows:

$$p_n = E[v \mid p^{n-2}] + A_n a_{n-1}^{-1} \left(z_{n-1} - E\left[z_{n-1} \mid p^{n-2}\right]\right) + B_n u_n, \tag{9}$$

where $z_{n-1} = a_{n-1}v + u_{n-1}$ and $a_{n-1} \equiv \gamma\tau_{\epsilon_{n-1}}$. We show (in the appendix) that z_{n-1} is the signal inferred from the $(n-1)^{th}$ transaction price by insiders. As insiders trade on this signal, the information revealed in the previous trading round is reflected into the price at date n. Thus, even if realized liquidity demands are nil, the price at date $n-2$ differs from the price at date n, because the latter impounds the information available at date $n-1$.

Thus, outsiders obtain new information from the clearing price at date n, beyond and above the information contained in the lagged ticker. Specifically, equation (9) shows that the clearing price at date n yields a signal $\hat{z}_n$ to outsiders, with

$$\hat{z}_n = a_{n-1}^{-1}\left(z_{n-1} + (A_n^{-1}B_n a_{n-1})u_n\right). \tag{10}$$

This signal is noisier than insiders' signals because the current clearing price depends both on *(i)* the innovation in insiders' expectations and *(ii)* liquidity traders' demand at date n. ■

Case 3. *Fresh information is available at date n and date $n-1$ but $\mu = 0$.* In this case, the price at date n aggregates speculators' private signals at this date and for this reason $A_n > 0$. On the other hand, no speculator observes the price realized at date $n-1$. Hence $C_n = 0$. Thus, the equilibrium price at date n can be written as follows:

$$p_n = E\left[v \mid p^{n-2}\right] + A_n a_n^{-1}\left(z_n - E\left[z_n \mid p^{n-2}\right]\right), \tag{11}$$

where $z_n = a_n v + u_n$. In this case, z_n is the signal obtained from the price by insiders and outsiders. Hence, both types of speculators have forecasts with identical precisions. ■

In the general case, fresh information is available at both dates n and $n-1$ and there are some insiders in the market ($\mu > 0$). Thus, the price at date n contains information on the liquidation value ($A_n > 0$) because *(i)* speculators trade on the private signals they receive at date n and *(ii)* insiders trade on the information contained in the price at date $n-1$. In this case, the price change between dates $n-2$ and n is in part explained by the new information available at dates $n-1$ and n. The signal obtained by outsiders from the clearing price ($\hat{z}_n$), is noisier than that obtained by insiders (z_n). For this reason, in general, the current clearing price is not a sufficient statistic for the entire price history.[9] We now study how the scope of

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[9] Brown and Jennings (1989) consider a two periods model with this property as well. In contrast, Brennan and Cao (1996) and Vives (1995) present multi periods model in which the clearing price in each period is a sufficient statistics for the entire price history. In these models, observing past prices has no value since traders can condition their orders on the current clearing price.

information dissemination affects the informativeness of the price history.

3.2 Price Discovery

Insiders and outsiders do not observe the same set of prices. Thus, we use two measures of informational efficiency: *(i)* the informativeness ($\hat{\tau}_n$) of the "truncated ticker" (the set of prices $\{p^{n-2}, p_n\}$ observed by outsiders) and *(ii)* the informativeness (τ_n) of the real time ticker. The first measure is relevant for outsiders while the second measure is relevant for insiders. We now study how the scope of information dissemination affects these measures of informational efficiency.

Obviously, the informativeness of the truncated ticker is smaller than the informativeness of the real time ticker (i.e., $\hat{\tau}_n \leq \tau_n$). Moreover, as previously explained (case 2), insiders have an edge over outsiders iff the delayed ticker contains fresh information, i.e., iff $\tau_{\epsilon_{n-1}} > 0$. Thus, if $\tau_{\epsilon_{n-1}} = 0$ then the informativeness of the truncated ticker is identical to the informativeness of the real time ticker ($\hat{\tau}_n = \tau_n$). Otherwise, as shown below, the real time ticker is strictly more informative than the truncated ticker but this informational gap reduces as the proportion of insiders enlarges.

To see this, let $\tau_n^m \overset{def}{=} (\mathrm{Var}[\hat{z}_n|v])^{-1}$. As shown in the next corollary, τ_n^m is the contribution of the n^{th} clearing price to the informativeness of the truncated ticker, i.e., $\hat{\tau}_n$. With a slight abuse of language, we refer to τ_n^m as the informativeness of the n^{th} clearing price.[10]

Proposition 1 *At any date $n \geq 2$:*

1. *The informativeness of the real time ticker does not depend on the proportion of insiders.*

2. *The informativeness of the truncated ticker, $\hat{\tau}_n$, is given by*

$$\hat{\tau}_n = (Var[v|p^{n-2}, p_n])^{-1} = \tau_{n-2} + \tau_n^m.$$

   The informativeness of the truncated ticker (i) increases with the proportion of insiders and (ii) is strictly smaller than the informativeness of the real time ticker (i.e., $\hat{\tau}_n < \tau_n$) iff $\tau_{\epsilon_{n-1}} > 0$.

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[10] This is the informativeness of the n^{th} clearing price from the point of view of outsiders after accounting for the information contained in the lagged ticker.

Thus, the informativeness of the entire price system does not depend on the proportion of insiders. Yet, the informativeness of a truncated record of prices, $\{p_n, p^{n-2}\}$, increases with the fraction of insiders. The explanation for these seemingly incompatible findings is as follows. In equilibrium, a speculator's demand can be written as

$$x_n^k(s_{in,}\Omega_n^k) = (\gamma\tau_{\varepsilon_n})s_{in} - \varphi_n^k(\Omega_n^k), \tag{12}$$

where φ_n^k is a linear function of the prices observed by a speculator with type $k \in \{I, O\}$. Thus, the sensitivity of speculators' demand to their private signals does not depend on the informativeness of the price they observe and is thereby identical for outsiders and insiders. Accordingly, the sensitivity of the n^{th} clearing price to the fresh information available in this period (i.e., $\int_0^1 s_{in}di$) does not depend on the proportion of insiders. For this reason, the informativeness of the entire price history does not depend on the proportion of insiders.

The n^{th} clearing price is also informative about the information contained in the last transaction price as insiders' demand depends on this information. This information is redundant for an observer of the entire price history but not for an outsider. For this reason, the precision of an outsider' forecast at date n is larger than at date $n-2$ ($\tau_n^m > 0$), even if there is no fresh information at date n. Moreover, τ_n^m increases in μ because the price at date n aggregates better insiders' information on the delayed ticker when the number of insiders increases.

As a consequence, an increase in the scope of information dissemination reduces the informational advantage of the insiders, i.e., the difference $(\tau_n - \hat{\tau}_n)$. To see this, notice that

$$\tau_n - \hat{\tau}_n = (\tau_n - \tau_{n-2}) - (\hat{\tau}_n - \tau_{n-2}).$$

We deduce from Lemma 1 and Proposition 1 that

$$\tau_n - \hat{\tau}_n = ((\gamma\tau_{\epsilon_{n-1}})^2 + (\gamma\tau_{\epsilon_n})^2)\tau_u - \tau_n^m,$$

which decreases with τ_n^m and therefore μ.

The variance of pricing errors, i.e., $\text{Var}[v - p_n]$ is another way to measure the quality of price discovery. For instance, this measure is often used in experimental settings (e.g., Flood et al. (1999)). Moreover, as shown below, it plays an important role for speculators' welfare. We now study the effect of a change in the proportion of insiders on this measure of price discovery.

Proposition 2 *At any date $n \geq 2$, the mean pricing error is zero ($E[v - p_n] = 0$) and its variance, ($\text{Var}[v - p_n]$), decreases with the proportion of insiders.*

The intuition for this result is as follows. As insiders have a more precise estimate of the liquidation value of the security, they bear less liquidation risk. Consequently, insiders' demand is more responsive than outsiders' demand to deviations between their estimate of the fundamental value and the current clearing price (the "perceived risk premium"). Indeed,

$$\frac{\partial x_n^I}{\partial(E[v|s_{in}, p^n] - p_n)} = \gamma(\tau_n + \tau_{\epsilon_n}) > \frac{\partial x_n^O}{\partial(E[v|s_{in}, p^{n-2}, p_n] - p_n)} = \gamma(\hat{\tau}_n + \tau_{\epsilon_n}),$$

when $\tau_{\epsilon_{n-1}} > 0$. Thus, an increase in the proportion of insiders shifts speculators from the population with a relatively low responsiveness to the population with a relatively high responsiveness to a change in the perceived risk premium. Moreover, an increase in the proportion of insiders increases the precision of outsiders' estimate at date n, $\hat{\tau}_n$. Overall, these two effects combine to make speculators' net demand function more elastic to a change in the perceived risk premium. As a consequence, an increase in the proportion of insiders intensifies competition among speculators, which intuitively narrows the difference between the clearing price and the liquidation value of the security.

One argument against restrictions on the dissemination of ticker information is that these restrictions impair price discovery.[11] Our findings provides some support for this view. Indeed, an increase in the proportion of insiders improves the informativeness of the truncated ticker and it reduces the dispersion of pricing errors. However, we also find that broadening the scope of information dissemination leaves unchanged the informativeness of the entire price history.

3.3 The ticker externality

We now consider the effect of broadening the dissemination of ticker information on investors' welfare. We restrict our attention to speculators' welfare since liquidity traders' demands are exogenous in our model. We plan in the future version of this paper to also consider the case in which these demands are endogenous. Preliminary analysis indicates that the conclusions of the paper are robust in this case.

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[11] See the letter to the SEC of the Securities Industry and Financial Markets Association (SIFMA) available at http://www.sifma.org/regulatory/comment_letters/41907041.pdf

Insiders expect larger gains from participating to the market than outsiders because they have a more precise estimate of the liquidation value. To see this, let C^I and C^O be insiders' and outsiders' entry costs, respectively. The ex-ante expected utilities for speculators entering the market at date n are given by[12]

$$E\left[U\left(\pi_{in}^I - C^I\right)\right] = -\left(\frac{\mathrm{Var}[v|s_{in}, p^n])}{\mathrm{Var}[v - p_n]}\right)^{1/2} \exp\left\{C^I/\gamma\right\}, \tag{13}$$

$$E\left[U\left(\pi_{in}^O - C^O\right)\right] = -\left(\frac{\mathrm{Var}[v|s_{in}, p^{n-2}, p_n])}{\mathrm{Var}[v - p_n]}\right)^{1/2} \exp\left\{C^O/\gamma\right\}. \tag{14}$$

In equilibrium, we have

$$(\mathrm{Var}[v|s_{in}, p^{n-2}, p_n])^{-1} = \tau_{\epsilon_n} + \hat{\tau}_n \leq (\mathrm{Var}[v|s_{in}, p^n])^{-1} = \tau_{\epsilon_n} + \tau_n,$$

and this inequality is strict iff $\tau_{\epsilon_{n-1}} > 0$. In the rest of this section, we assume that $C^I = C^O$. We obtain the following result.

Proposition 3 *At any date $n \geq 2$, an insider's ex-ante expected utility is strictly larger than an outsider's expected utility iff $\tau_{\epsilon_{n-1}} > 0$.*

Thus, individually, speculators benefit from observing the ticker in real time when the delayed ticker contains information not available in the lagged ticker (i.e., $\tau_{\epsilon_{n-1}} > 0$). This finding however does not imply that speculators are better off with an expansion of the scope of information dissemination. In fact the next proposition shows that the regime in which no speculator observes the ticker in real time always Pareto dominates the regime in which all speculators observe the ticker in real time.

Proposition 4 *At any date $n \geq 2$, speculators' welfare when the market is fully opaque ($\mu = 0$) is larger than when the market is fully transparent ($\mu = 1$).*

The intuition for this finding is as follows. When $\mu = 1$, speculators have a more precise estimate of the final value of the security than when $\mu = 0$ (because $\hat{\tau}_n < \tau_n$) and thus bear less risk. This positively affects their expected utility. However, as the proportion of insiders increases, competition among speculators intensifies. Thus, the n^{th} clearing price is on average closer to the payoff of the security (formally, $\mathrm{Var}[v - p_n]$ decreases). As shown by equations (13) and (14), this "competition effect" has a negative impact on all speculators' ex-ante expected utility. In equilibrium, this effect dominates and speculators' expected utility is smaller when $\mu = 1$ than when $\mu = 0$.

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[12] These expressions derive from Admati and Pfleiderer (1987), Proposition 3.1. See the last part of the proof of Proposition 1 in the Appendix.

[Figure 1 about here.]

Figure 1 illustrates this result when $\tau_v = \tau_u = 4$, $\tau_{\epsilon_1} = 1$, $\tau_{\epsilon_2} = 0.3$, $\gamma = 1$, and $N = 2$. In this case, outsiders' expected utility is -0.94 when $\mu = 0$ and -0.98 when $\mu = 1$. However, at $\mu = 0$, the expected utility of an investor who obtains ticker information is -0.69. Thus, if ticker information is available for free, the situation in which $\mu = 0$ is not sustainable. In the absence of coordination, each speculator uses ticker information and eventually speculators end up with a lower expected utility than if they could commit not to use ticker information at all.

Figure 1 also shows that speculators' expected utilities decline with the proportion of insiders, whether they are insiders or outsiders. This result holds true for all parameter values as shown in the next proposition.

Proposition 5 *At any date $n \geq 2$ speculators' ex-ante expected utilities decline with the proportion of insiders.*

Thus, acquisition of ticker information by one speculator exerts a *negative externality* on other speculators because it intensifies competition among speculators, as previously explained. Combined with the previous proposition, the last result suggests that restricting access to ticker information can be beneficial to *all* speculators. Hence, we now endogenize the proportion of insiders by introducing a market for ticker information and we study how the price of ticker information can be optimally set to maximize speculators' surpluses.

3.4 Optimal Scope of Information Dissemination

We first show that the scope of information dissemination can be controlled through the price charged for obtaining ticker information. To see this, let $\phi_n(\mu)$ be the maximum fee that a speculator entering the market at date n is willing to pay to observe the real time ticker. We assume that otherwise participation costs are identical for insiders and outsiders, so that

$$C^I = C^O + \phi_n(\mu).$$

We call $\phi_n(\mu)$ the value of the ticker at date n. By definition, $\phi_n(\mu)$ solves[13]

$$E\left[U\left(\pi^I_{in} - (C^O + \phi_n(\mu))\right)\right] = E\left[U\left(\pi^O_{in} - C^O\right)\right]. \tag{15}$$

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[13] We assume that C^O is small enough so that outsiders are better off paying the participation cost.

Using equations (13) and (14) and solving the last equation for $\phi_n(\mu)$, we obtain

$$\phi_n(\mu) = \frac{\gamma}{2} \ln \left(\frac{\tau_{\epsilon_n} + \tau_n}{\tau_{\epsilon_n} + \hat{\tau}_n} \right). \tag{16}$$

Not surprisingly, the value of the real time ticker at date n is strictly positive iff the real time ticker is more informative than the truncated ticker (i.e., $\tau_n > \hat{\tau}_n$). This condition is satisfied iff $\tau_{\epsilon_{n-1}} > 0$ (Proposition 1). Equation (16) can be rewritten as follows:

$$\phi_n(\mu) = \frac{\gamma}{2} \ln \left(1 + \frac{\tau_n - \hat{\tau}_n}{\tau_{\epsilon_n} + \hat{\tau}_n} \right). \tag{17}$$

Hence, the value of the ticker increases with insiders' relative informational advantage over outsiders, i.e., $(\tau_n - \hat{\tau}_n)/(\tau_{\epsilon_n} + \hat{\tau}_n)$. As explained previously, this relative advantage declines when the proportion of insiders increases. Thus, we obtain the following result:

Proposition 6 *The value of the ticker at any date $n \geq 2$ decreases with the proportion of insiders.*

Key to this finding is the fact that an increase in the proportion of insiders does not affect the informativeness of the real time ticker while it increases the precision of the signal conveyed by the n^{th} clearing price. Thus, an increase in the proportion of insiders reduces the private benefit of getting real-time ticker information at any point in time.

The last result implies that there is a one-to-one mapping between the price charged for the ticker and the proportion of insiders. Thus, a specific value of μ can be achieved by choosing adequately the price charged for ticker information (i.e., $\phi_n(\mu)$).[14]We now examine whether market organizers ("the exchange") have an incentive to ration access to ticker information. That is to choose $\phi_n(\mu)$ so that $\mu < 1$.

We allow the exchange to charge an entry fee, which gives the right to trade and an information fee, which gives access to the ticker in real time. We consider two cases: *(i)* the case in which the exchange is organized as a for-profit entity and *(ii)* the case in which the exchange is not-for-profit and maximizes the welfare of the speculators (its members). We assume that at the beginning of each period, before

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[14] More formally, all speculators acquire ticker information if its price is less than or equal to $\phi_n(1)$. No speculator acquires ticker information if its price is more than or equal to $\phi_n(0)$. A proportion $\mu \in (0, 1)$ of speculators acquires ticker information if and only if the fee for this information is $\phi_n(\mu)$.

receiving their private signals, speculators decide *(i)* whether to enter the market or not and *(ii)* whether to purchase ticker information or not.[15] We also assume that the cost of disseminating information on past transaction prices does not depend on the proportion of insiders (we set it equal to zero).

The for-profit exchange. The for profit exchange optimally charges an entry fee, which extracts speculators' surplus. Observe that a speculator who does not enter the market derives an expected utility equal to -1. Thus, for a given value of μ, the entry fee of the for profit exchange (denoted $C_n^{For}(\mu)$) is chosen so that

$$E\left[U\left(\pi_{in}^{I} - C_n^{For}(\mu) - \phi_n(\mu)\right] = E\left[U\left(\pi_{in}^{O} - C_n^{For}(\mu)\right)\right] = -1. \tag{18}$$

Using equation (14), we deduce that the entry fee is given by

$$C_n^{For}(\mu) = \frac{\ln(E\left[U(\pi_{in}^{O})\right])}{\gamma}. \tag{19}$$

The entry fee decreases with the proportion of insiders since speculators' welfare declines with μ (Proposition 5). At date n, the for profit exchange chooses the proportion of insiders such that it solves

$$\max_{\mu}\ \Pi_n(\mu) = \mu\phi_n(\mu) + C_n^{For}(\mu). \tag{20}$$

We obtain the following result.

Proposition 7 *At any date $n \geq 2$ and for all values of the parameters, rationing access to ticker information is optimal for a for-profit exchange.*

This result follows from the fact that speculators' welfare is not maximized for $\mu = 1$ (Proposition 5). Thus, as the fees are capped by the surplus obtained by speculators, the exchange's profit is maximum by rationing access to ticker information. Rationing access to ticker information can also be optimal even if the exchange derives revenue only from the sale of information (but not necessarily for all parameter values) because the price of information declines with μ.

As $C_n^{For}(\mu)$ decreases with μ, one may then wonder whether full opaqueness ($\mu = 0$) is not optimal for the exchange. This is not the case in general for the following reason. Consider the case in which $\mu = 0$. In this case, the entry fee is maximal.

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[15] The results are unchanged if speculators make this decision at date zero and know when they will enter the market.

However, the fee that a speculator is willing to pay to observe the ticker in real time is also maximal (since $\phi_n(\cdot)$ decreases with μ). The exchange can exploit this high willingness to pay for ticker information only if it sells ticker information to at least a few speculators. Thus, in general, a two-tier market for ticker information, i.e., $0 < \mu < 1$, maximizes the exchange's profit.

[Figure 2 about here.]

To illustrate these points, consider Figure 2. The parameter values are as in Figure 1. As it can be seen from the figure (panel (b)) the expected profit peaks at $\mu^* = 6\%$. The exchange optimally chooses a two-tier market structure as it strikes the optimal balance between its different sources of revenues. Panel (a) of Figure 2 shows that the revenue from the sale of information ($\mu\phi_n(\mu)$) is maximal for $\mu \simeq 20\%$. Thus, even if the exchange could not charge an entry fee, it would still ration access to ticker information because the value of the ticker declines with the proportion of insiders.

The not-for-profit exchange. Now consider the case in which the exchange chooses the proportion of insiders to maximize speculators' welfare. To achieve the desired value of μ, the information fee must be equal to $\phi_n(\mu)$, as previously explained. Moreover the revenue that the exchange derives from the sale of information is redistributed to all speculators. That is:

$$C_n^{Not}(\mu) = -\mu\phi_n(\mu). \tag{21}$$

Thus, insiders and outsiders derive the same expected utility (equation (15)) and the proportion of insiders chosen by the not-for-profit exchange solves:[16]

$$\begin{aligned} &\max_{\mu} \; E\left[U\left(\pi_{in}^{O} - C_n^{Not}(\mu)\right)\right] \\ &u.c. \; C_n^{Not}(\mu) = -\mu\phi_n(\mu). \end{aligned}$$

It is easily seen that the solution to this problem is the Pareto optimum level for the proportion of insiders. Indeed, it yields the largest possible expected utility for insiders and outsiders when a transfer from insiders to outsiders is possible.

Proposition 8 *At any date $n \geq 2$, the proportion of insiders chosen by the not-for-profit exchange is identical to the proportion of insiders chosen by the for profit exchange.*

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[16] As the information fee is chosen so that insiders and outsiders derive the same expected utility, we can choose the maximand of the exchange's problem to be either insiders' expected utility or outsiders' expected utility.

The intuition for this finding is simple. When the for-profit exchange can charge an entry fee and an information fee, it extracts all surplus from each category of investors (insiders and outsiders). Thus, it must choose the proportion of insiders that yields the largest possible expected utility for speculators. Of course, the division of the gains from trade is different when the exchange is for-profit and when it is not-for-profit. In the first case, the exchange leaves no surplus to speculators whereas in the second case speculators leave no surplus to the exchange. The result implies that speculators can all benefit from a two-tier market structure, provided there is a system of redistribution of the revenues from information sale among speculators.

To sum up, rationing access to ticker information reduces the negative externality associated with the dissemination of ticker information. For this reason, providing access to ticker information in real time to *all* speculators ($\mu = 1$) never maximizes gains from trade for speculators. It does not follow that shutting down access to ticker information for *all* speculators ($\mu = 0$) is always optimal. The reason is that ticker information reduces uncertainty on the asset payoff. Thus, other things equal (for a fixed μ), a speculator is strictly better off with ticker information. This surplus can be captured, either by speculators or a for-profit exchange, by disseminating ticker information to only a subset of speculators.

4 Latency

4.1 Latency and the value of the ticker

Until this point, we have assumed that outsiders observe past transaction prices with a delay of one period (in transaction time). We now consider the effect of increasing this delay on the value of the ticker and market liquidity. Namely, we assume that at date n, outsiders observe transaction prices with a lag of $l \geq 2$ periods. Hence at date, $n > l$, outsiders observe $\{p_1, p_2, ..., p_{n-l}\}$ and at date $n \leq l$ outsiders have no information on past transaction prices. We denote the informativeness of the truncated ticker at date n by $\hat{\tau}_n(l) \overset{def}{=} (\text{Var}[v|p^{n-l}, p_n])^{-1}$. In this case, we can generalize Proposition 1 as follows.

Lemma 2 *When $l \geq 2$, in each period, there is a unique rational expectations equi-*

librium. In this equilibrium, the price in each period is given by

$$p_n = A_n(l)v + \sum_{j=0}^{l-1} B_{n,j}(l)u_{n-j} + D_n(l)E[v \mid p^{n-l}], \text{ for } n > l, \tag{22}$$

$$p_n = A_n(l)v + \sum_{j=0}^{n-1} B_{n,j}(l)u_{n-j} + D_n(l)\bar{v}, \text{ for } 1 \leq n \leq l, \tag{23}$$

where $\{A_n(l), B_{n,j}(l), D_n(l)\}$ *are constants characterized in the proof of the proposition and* $D_n(l) = 1 - A_n(l)$*. Moreover,* $A_n(l) > 0$ *iff (a)* $\tau_{\epsilon_n} > 0$ *or (b)* $\tau_{\epsilon_{n-1}} > 0$ *and* $\mu > 0$*. In this equilibrium speculators' trading strategies in period* n *are given by*

$$\begin{aligned} x_1(s_{i1}, p_1) &= \gamma(\tau_1 + \tau_{\epsilon_1})(E[v|s_{i1}, p_1] - p_1), \\ x_n^I(s_{in}, p^n) &= \gamma(\tau_n + \tau_{\epsilon_n})(E[v|s_{in}, p^n] - p_n), \\ x_n^O(s_{i2}, p^{n-l}, p_n) &= \gamma(\hat{\tau}_n + \tau_{\epsilon_n})(E[v|s_{in}, p^{n-l}, p_n] - p_n), \end{aligned} \tag{24}$$

where $\tau_n = \tau_v + \tau_u \sum_{t=1}^{n} a_t^2$ *with* $a_t = \gamma\tau_{\epsilon_t}$*.*

Using this result, we can study the effect of an increase in latency on the value of the real time ticker. We denote this value at date n by $\phi_n(\mu, l)$. Proceeding as in the case in which $l = 2$, we obtain that

$$\phi_n(\mu, l) = \frac{\gamma}{2} \ln\left(\frac{\tau_{\epsilon_n} + \tau_n}{\tau_{\epsilon_n} + \hat{\tau}_n(l)}\right). \tag{25}$$

The informativeness of the real time ticker, τ_n, does not depend on latency. However, an increase in latency makes it more difficult for outsiders to extract information on the signals insiders obtain from the observation of those prices that are not yet publicly disclosed (i.e., the delayed ticker). Thus, intuitively, an increase in latency reduces the precision of the truncated ticker and, for this reason, increases the benefit of observing the ticker in real time.

For instance, suppose that latency is increased from $l = 3$ to $l = 4$. Until date 3, outsiders' information set is unchanged and hence the equilibrium is unchanged. Thus, for $n \leq 3$, $\hat{\tau}_n(4) = \hat{\tau}_n(3)$, which implies $\phi_n(\mu, 3) = \phi_n(\mu, 4)$. At date $n = 4$, however, outsiders observe the first transaction price when $l = 3$ but not when $l = 4$. Thus, $\hat{\tau}_4(4) < \hat{\tau}_4(3)$, which implies that $\phi_4(\mu, 3) < \phi_4(\mu, 4)$. The next proposition establishes formally that the value of the real time ticker increases with latency.

Proposition 9 *The value of the real-time ticker weakly increases with the latency in information dissemination,* l*. More precisely:*

$$\begin{aligned} \phi_n(\mu, l) &< \phi_n(\mu, l+1) \text{ for } n > l, \\ \phi_n(\mu, l) &= \phi_n(\mu, l+1) \text{ for } n \leq l. \end{aligned}$$

The last result has an interesting implication. We measure latency in transaction time. In reality, investors have access to the lagged ticker for free after a fixed amount of time (e.g., 20 minutes). The more active is a security, the larger the number of transactions in a fixed time interval. Hence, latency increases with trading activity when the delay after which the ticker is free is fixed in calendar time. Proposition 9 suggests that the value of the ticker is larger, other things equal, for more actively traded stocks. Thus, when the fee for market data is fixed across stocks, the model implies that the number of subscribers to a real-time data feed should be larger for more actively traded stocks.

4.2 Latency and Liquidity

We now analyze the effect of latency on market liquidity. As usual, we measure market liquidity by the sensitivity of the clearing price to liquidity traders' demand, i.e., by $B_{n,0}$ in our model. Specifically, the smaller is $B_{n,0}$, the greater is market liquidity in period n and the lower are liquidity traders' expected trading losses since[17]

$$E[(p_n - v)u_n] = B_{n,0}/\tau_u.$$

The next corollary shows that an increase in latency reduces the liquidity of the market at each date $n > l$.

Proposition 10 *The liquidity of the market at date* n *weakly decreases with the latency in information dissemination,* l*. More precisely:*

$$\begin{aligned} B_{n,0}(l) &< B_{n,0}(l+1), \text{ for } n > l, \\ B_{n,0}(l) &= B_{n,0}(l+1), \text{ for } n \leq l. \end{aligned}$$

Intuitively, an increase in latency enlarges outsiders' uncertainty on the liquidation value, leading them to require a larger compensation to absorb liquidity traders'

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[17] This expression is obtained using the expression for the clearing price in period n (equation (5))

demand. This finding yields two testable implications. First, stocks experiencing a reduction in latency should become more liquid. Second, for a fixed reduction in latency measured in calendar time, more actively traded stocks should experience a larger improvement in liquidity. Actually, consider two stock A and B. Transactions occur at a rate of two transaction per minute for stocks A and one transaction per minute for stock B. Now consider a reduction in latency for both stocks from twenty minutes to ten minutes. In transaction time, the reduction in latency for stock A is twice that of stock B. Thus, other things equal, the model implies that the liquidity improvement for stock A should be larger than that for stock B.[18]

5 Conclusions

In this paper, we study the effect of disseminating information on past transaction prices in a multi-period rational expectations model. Our model features risk averse speculators who arrive sequentially in the market. Speculators entering the market in a given period have private signals of identical precision but differ in their access to information on past transaction prices (the ticker). Specifically, insiders observe transaction prices in real-time whereas outsiders observe transaction prices with a delay. We endogenize the proportion of insiders by introducing a market for information. Our main findings are as follows.

1. The utility gain of observing the ticker in real time decreases with the number of insiders and increases in the delay with which information on past trades is disseminated for free. Thus, the value of the ticker decreases with the proportion of insiders and increases with latency.

2. Acquisition of ticker information by one speculator exerts a negative externality on other speculators. For this reason, rationing access to ticker information by charging a high price for this information can maximize speculators' surpluses.

3. The informativeness of the ticker does not depend on the proportion of insiders or the delay with which information on trades is disseminated. However, market liquidity declines with this delay.

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[18] Of course, one difficulty for testing this prediction is that in reality transaction rates are endogenous and could depend on latency. Moreover, we assume that the change in latency leaves unchanged the rate of information arrival over time (i.e., the τ_ns').

This version of the paper features liquidity traders with exogenous demand functions. This feature is restrictive as we cannot analyse liquidity traders' welfare. In the next version we plan to consider the case in which investors trade both to exploit their private information (speculative motive) and hedge endowments of the risky security (hedging motive) as in Verrechia (1982). In this case, hedging demands are endogenous. Preliminary analysis of this model indicates that our conclusions are unchanged. In fact, our findings regarding welfare are even stronger because early resolution of uncertainty through price disclosure destroys risk sharing opportunities.[19]

The model suggests interesting venues for future research. First, it is important to study in more detail how price dynamics are affected by the proportion of insiders and latency. We have pointed out that the new information available at a given point in time is not immediately reflected in subsequent prices when some investors are uninformed about past prices. An interesting question is how the proportion of insiders affects the sluggishness in price adjustments to new information and the serial correlation in price changes. Second, a given security often trades in multiple markets. For such a security, transaction prices for trades taking place in different markets are close substitutes.[20] In this context, competing markets' decisions regarding the dissemination of their data are interdependent. It would be interesting to analyze in more details these decisions and how they affect order routing decision.

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[19] This is a manifestation of the so called Hirshleifer effect. Hirshleifer (1971) points out that disclosure of information in asset markets is not necessarily optimal since it may preclude risk sharing between parties.

[20] They can however contain different information and thereby have different values. For instance, Hasbrouck (1995) find that the contribution of NYSE prices to price discovery is higher than regional exchanges' contribution.

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Appendix

Proof of Lemma 1

We prove this proposition in two parts. In part 1 we characterize the equilibrium in any period $n \geq 1$. In part 2, we derive the welfare expressions that appear in the text (equations (13) and (14)), for $n \geq 2$.

Part 1.

Step 1. Informational content of equilibrium prices.
In a symmetric linear equilibrium, speculators' order placement strategies in period $n \geq 2$ can be written as follows:

$$\begin{aligned} x_n^I(s_{in}, p^n) &= a_n^I s_{in} - \varphi_n^I(p^n), & (26) \\ x_n^O(s_{in}, p^{n-2}, p_n) &= a_n^O s_{in} - \varphi_n^O(p^{n-2}, p_n), & (27) \end{aligned}$$

where $\varphi_n^k(p^n)$ is linear in p^n for $k \in \{I, O\}$. In any period n, the clearing condition is

$$\mu x_n^I + (1-\mu)x_n^O + u_n = 0.$$

Thus, using equations (26) and (27), we deduce that at date n

$$a_n v + u_n - \varphi_2^I(p^n) - \varphi_2^O(p^{n-2}, p_n) = 0, \ \forall n \geq 2, \tag{28}$$

with $a_n \overset{def}{=} \mu a_n^I + (1-\mu)a_n^O$. A similar argument shows that

$$a_1 v + u_1 - \varphi(p_1) = 0. \tag{29}$$

Combining equations (28) and (29), we deduce that p^n is observationally equivalent to $z^n = \{z_{1,}z_2, ..., z_n\}$ with $z_n = a_n v + u_n$.

Step 2. Equilibrium in period $n \geq 2$.
Insiders. An insider's demand function in period n, $x_n^I(s_{in}, p^n)$, maximizes

$$E[-\exp\{-(v-p_n)x_n^I/\gamma\}|s_{in}, p^n].$$

We deduce that

$$x_n^I(s_{in}, p^n) = \gamma \frac{E[v - p_n|s_{in}, p^n]}{\text{Var}[v - p_n|s_{in}, p^n]} = \gamma \frac{E[v|s_{in}, p^n] - p_n}{\text{Var}[v|s_{in}, p^n]}.$$

As p^n is observationally equivalent to z^n, we deduce (using well-known properties of normal random variables)

$$\begin{aligned} E[v|s_{in}, p^n] &= E[v|s_{in}, z^n] = (\tau_n + \tau_{\epsilon_n})^{-1}(\tau_n E[v|z^n] + \tau_{\epsilon_n} s_{in}), \\ \mathrm{Var}[v|s_{in}, p^n] &= \mathrm{Var}[v|s_{in}, z^n] = (\tau_n + \tau_{\epsilon_n})^{-1}, \end{aligned}$$

where $\tau_n \overset{def}{=} (\mathrm{Var}[v|p^n])^{-1} = (\mathrm{Var}[v|z^n])^{-1} = \tau_v + \tau_u \sum_{t=1}^{n} a_t^2$. Thus,

$$\begin{aligned} x_n^I(s_{in}, p^n) &= \gamma(\tau_n + \tau_{\epsilon_n})(E[v|s_{in}, p^n] - p_n) \\ &= a_n^I(s_{in} - p_n) + \gamma\tau_n(E[v|p^n] - p_n), \end{aligned} \quad (30)$$

where $a_n^I = \gamma\tau_{\epsilon_n}$.

Outsiders. An outsider's demand function in period n, $x_n^O(s_{in}, p^{n-2}, p_n)$, maximizes:

$$E\left[-\exp\left\{-(v - p_2)x_{in}^O/\gamma\right\} |s_{in}, p^{n-2}, p_n\right].$$

We deduce that

$$x_n^O(s_{in}, p^{n-2}, p_n) = \gamma \frac{E[v - p_n|s_{in}, p^{n-2}, p_n]}{\mathrm{Var}[v - p_n|s_{in}, p^{n-2}, p_n]} = \gamma \frac{E[v|s_{in}, p^{n-2}, p_n] - p_n}{\mathrm{Var}[v - p_n|s_{in}, p^{n-2}, p_n]}.$$

In equilibrium, outsiders correctly anticipate that all prices up to period n are related to the value of the security in the following way

$$p_n = A_n v + B_n u_n + C_n u_{n-1} + D_n E[v \mid p^{n-2}] \text{ for } n \geq 2, \quad (31)$$

$$p_1 = A_1 v + B_1 u_1 + D_1. \quad (32)$$

Let $\hat{z}_n$ be the signal on v that an outsider can obtain from the equilibrium price p_n, given that he observes p^{n-2}. Using equation (31), we obtain that

$$\begin{aligned} \hat{z}_n &= \frac{p_n - D_n E[v \mid p^{n-2}]}{A_n} \\ &= v + \frac{B_n}{A_n} u_n + \frac{C_n}{A_n} u_{n-1}. \end{aligned} \quad (33)$$

Thus, $\{s_{in}, p^{n-2}, p_n\}$ is observationally equivalent to $\{s_{in}, p^{n-2}, \hat{z}_n\}$ and

$$\hat{z}_n | v \sim N(v, A_n^{-2}(B_n^2 + C_n^2)\tau_u^{-1}).$$

Hence, using well known properties of normal random variables, we obtain

$$\begin{aligned} E[v|s_{in}, p^{n-2}, p_n] &= (\hat{\tau}_n + \tau_{\epsilon_n})^{-1}(\hat{\tau}_n E[v|p^{n-2}, p_n] + \tau_{\epsilon_n} s_{in}), \\ \mathrm{Var}[v|s_{in}, p^{n-2}, p_n] &= (\hat{\tau}_n + \tau_{\epsilon_n})^{-1}, \end{aligned}$$

where

$$\hat{\tau}_n \overset{def}{=} (\text{Var}[v|p^{n-2}, p_n])^{-1} = (\text{Var}[v|z^{n-2}, \hat{z}_n])^{-1} = \tau_{n-2} + A_n^2(B_n^2 + C_n^2)^{-1}\tau_u. \tag{34}$$

Thus,

$$\begin{aligned} x_n^O(s_{in}, p^{n-2}, p_n) &= \gamma\left(\hat{\tau}_n + \tau_{\epsilon_n}\right)\left(E[v|s_{in}, p^{n-2}, p_n] - p_n\right) \\ &= a_n^O(s_{in} - p_n) + \gamma\hat{\tau}_n(E[v|p^{n-2}, p_n] - p_n). \end{aligned} \tag{35}$$

with $a_n^O = a_n^I = \gamma\tau_{\epsilon_n}$. Thus, $a_n = \mu a_n^I + (1-\mu)a_n^O = \gamma\tau_{\epsilon_n}$.

Clearing price in period $n \geq 2$**.** The clearing condition in period $n \geq 2$ imposes

$$\mu x_n^I + (1-\mu)x_n^O + u_n = 0.$$

Using equations (30) and (35), we solve for the equilibrium price and we obtain

$$p_n = \frac{1}{K_n}\left(z_n + \mu\gamma\tau_n E[v|p^n] + (1-\mu)\gamma\hat{\tau}_n E[v|p^{n-2}, p_n]\right), \tag{36}$$

where $K_n = a_n + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n)$. Observe that

$$\begin{aligned} E[v|p^{n-2}, p_n] &= E[v|p^{n-2}, \hat{z}_n] = \hat{\tau}_n^{-1}\left(\tau_{n-2}E[v|p^{n-2}] + A_n^2(B_n^2 + C_n^2)^{-1}\tau_u\hat{z}_n\right), \\ E[v|p^n] &= E[v|p^{n-2}, z_{n-1}, z_n] = \tau_n^{-1}\left(\tau_{n-2}E[v|p^{n-2}] + \tau_u\sum_{t=n-1}^{n} a_t z_t\right). \end{aligned}$$

Substituting $E[v|p^{n-2}, p_n]$ and $E[v|p^n]$ by these expressions in equation (36), we can express p_n as a function of v, u_n, u_{n-1}, and $E[v|p^{n-2}]$. In equilibrium, the coefficients on these variables must be identical to those in equation (31). This condition imposes

$$A_n = \frac{(1 + \mu\gamma\tau_u a_n)a_n + \mu\gamma a_{n-1}^2\tau_u + (1-\mu)\gamma A_n^2(B_n^2 + C_n^2)^{-1}\tau_u}{K_n}, \tag{37}$$

$$B_n = \frac{1 + \mu\gamma a_n\tau_u + (1-\mu)\gamma A_n B_n(B_n^2 + C_n^2)^{-1}\tau_u}{K_n}, \tag{38}$$

$$C_n = \frac{\mu\gamma a_{n-1}\tau_u + (1-\mu)\gamma A_n C_n(B_n^2 + C_n^2)^{-1}\tau_u}{K_n}, \tag{39}$$

$$D_n = \frac{\gamma\tau_{n-2}}{K_n}. \tag{40}$$

The three first equations define a system with three unknowns A_n, B_n and C_n. Solving this system of equations, we obtain (after tedious calculations)

$$A_n = \frac{a_n + \mu\gamma(a_{n-1}^2 + a_n^2)\tau_u}{K_n}\left(1 + \frac{(1-\mu)\gamma\tau_u(a_n + \mu\gamma(a_{n-1}^2 + a_n^2)\tau_u)}{(1+\mu\gamma a_n\tau_u)^2 + (\mu\gamma a_{n-1}\tau_u)^2}\right), \tag{41}$$

$$B_n = \frac{1 + \mu\gamma a_n\tau_u}{K_n}\left(1 + \frac{(1-\mu)\gamma\tau_u(a_n + \mu\gamma(a_{n-1}^2 + a_n^2)\tau_u)}{(1+\mu\gamma a_n\tau_u)^2 + (\mu\gamma a_{n-1}\tau_u)^2}\right), \tag{42}$$

$$C_n = \frac{\mu\gamma a_{n-1}\tau_u}{K_n}\left(1 + \frac{(1-\mu)\gamma\tau_u(a_n + \mu\gamma(a_{n-1}^2 + a_n^2)\tau_u)}{(1+\mu\gamma a_n\tau_u)^2 + (\mu\gamma a_{n-1}\tau_u)^2}\right), \tag{43}$$

$$D_n = \frac{\gamma\tau_{n-2}}{K_n}, \tag{44}$$

where $K_n = a_n + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n)$, and

$$\hat{\tau}_n = \tau_{n-2} + A_n^2\left(B_n^2 + C_n^2\right)^{-1}\tau_u \tag{45}$$

$$= \tau_{n-2} + \frac{(a_n(1+\mu\gamma a_n\tau_u) + a_{n-1}(\mu\gamma a_{n-1}\tau_u))^2}{(1+\mu\gamma a_n\tau_u)^2 + (\mu\gamma a_{n-1}\tau_u)^2}\tau_u. \tag{46}$$

Step 3. Equilibrium in period 1. Following the same steps as in period 2, we obtain that in the first period there is a unique linear rational expectations equilibrium with

$$x_1(s_{i1}, p_1) = a_1(s_{i1} - p_1) + \gamma\tau_1(E[v|p_1] - p_1),$$

and

$$p_1 = A_1 v + B_1 u_1 + D_1\bar{v},$$

with $a_1 = \gamma\tau_{\epsilon_1}$, $\tau_1 \overset{def}{=} (\text{Var}[v|p_1])^{-1} = \tau_v + \tau_u a_1^2$ and

$$\begin{aligned} A_1 &= \frac{(1+\gamma\tau_u a_1)a_1}{(a_1 + \gamma\tau_1)}, \\ B_1 &= \frac{(1+\gamma\tau_u a_1)}{(a_1+\gamma\tau_1)}, \\ D_1 &= (1 - A_1). \end{aligned}$$

Part 2.

The expressions for speculators' welfare in equations (13) and (14) derive from Proposition 3.1 in Admati and Pfleiderer (1987). They derive the expected utility of a trader who submit limit orders and who receives a vector of signals. It is easy to check that all the distributional hypotheses necessary for applying their proposition are satisfied in our model. Moreover in our model, the unconditional expected difference between the payoff of the security and the equilibrium price at any date (which is denoted μ in Admati and Pfleiderer (1987)) is nil, that is

$$E[v - p_n] = 0$$

To see this point observe that

$$E[v - p_n] = \bar{v} - (A_n + D_n)\bar{v}.$$

Now, using Equation (37) in the proof of Proposition 1, we have

$$A_n = \frac{a_n + \mu\gamma(\tau_n - \tau_{n-2}) + (1-\mu)\gamma(\hat{\tau}_n - \tau_{n-2})}{K_n} = \frac{K_n - K_n D_n}{K_n}.$$

Thus, $A_n + D_n = 1$, which implies $E[v - p_n] = 0$. Using this observation and Proposition 3.1 of Admati and Pfleiderer (1987), the result is then immediate. QED

Proof of Proposition 1

Part 1. We have shown in the proof of proposition 1 that

$$\tau_n = \tau_v + \tau_u \sum_{t=1}^{n} a_t^2.$$

As a_t does not depend on μ, it is immediate that τ_n does not depend on μ. QED

Part 2. From equation (34) in the proof of Proposition 1, we deduce that

$$\begin{aligned} \hat{\tau}_n &= \tau_{n-2} + \tau_n^m \\ & \tau_{n-2} + \frac{(a_n(1+\mu\gamma a_n\tau_u) + a_{n-1}(\mu\gamma a_{n-1}\tau_u))^2}{(1+\mu\gamma a_n\tau_u)^2 + (\mu\gamma a_{n-1}\tau_u)^2}\tau_u, \end{aligned}$$

where $a_n = \gamma\tau_{\epsilon_n}$. As

$$\frac{\partial\hat{\tau}_n}{\partial\mu} = \frac{2\gamma^2 a_{n-1}^2\tau_u^2(\tau_{\epsilon_n} + \mu(a_{n-1}^2 + a_n^2))}{((1+\mu\gamma\tau_u a_n)^2 + (\mu\gamma\tau_u a_{n-1})^2)^2} > 0,$$

we deduce that $\hat{\tau}_n$ increases with μ.

Last, $\hat{\tau}_n$ can be written as follows

$$\hat{\tau}_n = \tau_{n-2} + \tau_u\left(\frac{(\rho_{n-1}a_{n-1} + \rho_n a_n)^2}{\rho_{n-1}^2 + \rho_n^2}\right),$$

with $\rho_n = (1 + \mu\gamma a_n\tau_u)$ and $\rho_{n-1} = (\mu\gamma a_{n-1}\tau_u)$. It is then direct to show that $\hat{\tau}_n \leq \tau_n$. Moreover the inequality is strict iff $a_{n-1} > 0$, i.e., iff $\tau_{\epsilon_{n-1}} > 0$. QED

Proof of Proposition 2

We have shown in the proof of Lemma 1 that $E\left[v-p_n\right]=0$. Now observe that v, p_n, p_{n-2} are normally distributed. Thus,

$$\operatorname{Var}[v-p_n]=\operatorname{Var}[v-p_n \mid p^{n-2}]+\operatorname{Var}\left[E\left[v-p_n \mid p^{n-2}\right]\right].$$

We also observe that

$$E\left[v-p_n \mid p^{n-2}\right]=E\left[v \mid p^{n-2}\right]-(A_n+D_n)E\left[v \mid p^{n-2}\right].$$

As $A_n+D_n=1$ (see the proof of Lemma 3),

$$E\left[v-p_n \mid p^{n-2}\right]=0.$$

We deduce that

$$\begin{aligned}\operatorname{Var}\left[v-p_n\right] &= \operatorname{Var}\left[v-p_n \mid p^{n-2}\right]\\ &= (1-A_n)^2\tau_{n-2}^{-1}+(B_n^2+C_n^2)\tau_u^{-1}.\end{aligned}$$

Differentiating the above function with respect to μ, we obtain that

$$\frac{\partial \operatorname{Var}[v-p_n]}{\partial \mu}<0, \forall n \geq 2.$$

QED

Proof of proposition 3

Immediate from the arguments in the text. QED

Proof of proposition 4

Let $EU_1=E[U\left(\pi_{in}^I-C^I\right)]|_{\mu=1}$ be speculators' expected utility when $\mu=1$ and let $EU_0=E[U\left(\pi_{in}^O-C^O\right)]|_{\mu=0}$ be speculators' expected utility when $\mu=0$. Using the expressions for speculators' expected utilities, we obtain after some calculations that:

$$\begin{aligned}EU_1 &= -\left(\frac{\gamma^2(\tau_{\epsilon_n}+\tau_{n-2}+a_{n-1}^2\tau_u+a_n^2\tau_u)^{3/2}}{\gamma^2\tau_{n-2}+(1+\gamma a_n\tau_u)^2\tau_u^{-1}+(\gamma a_{n-1}\tau_u)^2\tau_u^{-1}}\right)\exp\left\{\frac{C^I}{\gamma}\right\}\\ EU_0 &= -\left(\frac{\gamma^2(\tau_{\epsilon_n}+\tau_{n-2}+a_n^2\tau_u)^{3/2}}{\gamma^2\tau_{n-2}+(1+\gamma a_n\tau_u)^2\tau_u^{-1}}\right)\exp\left\{\frac{C^O}{\gamma}\right\}.\end{aligned}$$

Calculations show that EU_1 decreases with a_{n-1}. Moreover, for $a_{n-1}=0$ and $C^I=C^O$, $EU_1=EU_0$. Thus, for $a_{n-1}>0$ and $C^I=C^O$, $EU_1<EU_0$ since EU_0 does not depend on a_{n-1}. QED

Proof of proposition 5

To be written

Proof of proposition 6

Immediate from the arguments in the text. QED

Proof of proposition 7

Let $EU_1 = E[U\left(\pi^I_{in} - C^{For}(1) + \phi_n(1)\right)]|_{\mu=1}$ be speculators' expected utility when $\mu = 1$ and let $EU_0 = E[U\left(\pi^O_{in} - C^{For}(0)\right)]_{\mu=0}$ be speculators' expected utility when $\mu = 0$. Equation (18) implies that:

$$\begin{aligned} C^{For}(1) + \phi_n(1) &= \left.\frac{\ln E\left[U\left(\pi^I_{in}\right)\right]}{\gamma}\right|_{\mu=1} \\ C^{For}(0) &= \left.\frac{\ln E\left[U\left(\pi^O_{in}\right)\right]}{\gamma}\right|_{\mu=0}. \end{aligned}$$

Moreover, from Proposition 6 we know that $E[U(\pi^I_{in})]|_{\mu=1} < E[U(\pi^O_{in})]|_{\mu=0}$. Thus, $C^{For}(1) + \phi_n(1) < C(0)$. It follows that the exchange's profit for $\mu = 1$ is always smaller than for $\mu = 0$. QED

Proof of proposition 8

Using equation (14), we rewrite the not-for-profit exchange's objective function as

$$\max_{\mu} - \left(\frac{\mathrm{Var}[v|s_{in}, p^{n-2}, p_n])}{\mathrm{Var}[v - p_n]}\right)^{1/2} \exp\left\{\mu\phi_n(\mu)/\gamma\right\}. \tag{47}$$

This optimization problem is equivalent to

$$\min_{\mu} \frac{1}{2} \ln\left(\frac{\mathrm{Var}[v|s_{in}, p^{n-2}, p_n])}{\mathrm{Var}[v - p_n]}\right) - \mu\phi_n(\mu)/\gamma.$$

Now using equation (19), we deduce that optimization problem (47) is equivalent to

$$\max_{\mu} \ C^{For}_n(\mu) + \mu\phi_n(\mu),$$

which is the optimization problem of the for-profit exchange. QED

Proof of Lemma 2

The proposition can be proved by following exactly the same steps as those followed in the proof of Proposition 1. Thus, we omit the proof for brevity. Details can be obtained upon request. We just provide the expressions for the coefficients in equations (22) and (23). Let $l^* = \min\{l, n\}$ and recall that $a_n = \gamma\tau_{\epsilon_n}$. Then, we have:

$$\begin{aligned}
A_n(l^*) &= \frac{a_n + \mu\gamma(\tau_n - \tau_{n-l^*})}{K_n(l^*)} \left(1 + \frac{(1-\mu)\gamma\tau_u(a_n + \mu\gamma(\tau_n - \tau_{n-l^*}))}{(1+\mu\gamma a_n\tau_u)^2 + \sum_{j=1}^{l^*-1}(\mu\gamma a_{n-j}\tau_u)^2}\right), \\
B_{n,0}(l^*) &= \frac{A_n(l^*)(1+\mu\gamma a_n\tau_u)}{a_n + \mu\gamma(\tau_n - \tau_{n-l^*})}, \\
B_{n,j}(l^*) &= \frac{A_n(l^*)(\mu\gamma a_{n-j}\tau_u)}{a_n + \mu\gamma(\tau_n - \tau_{n-l^*})}, \ \text{ for } 1 \le j \le l^* - 1, \\
D_n(l^*) &= \frac{\gamma\tau_{n-l^*}}{K_n(l^*)},
\end{aligned}$$

with $\tau_n = \tau_v + \tau_u \sum_{t=1}^{n} a_t^2$, and $\tau_0 = \tau_v$. Moreover, $K_n(l^*) = a_n + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n(l^*))$, where

$$\hat{\tau}_n(l^*) = \tau_{n-l^*} + \frac{(a_n + \mu\gamma(\tau_n - \tau_{n-l^*}))^2}{(1+\mu\gamma a_n\tau_u)^2 + \sum_{j=1}^{l^*-1}(\mu\gamma a_{n-j}\tau_u)^2}\tau_u. \tag{48}$$

QED

Proof of proposition 9

Using equation (48) we have that $\hat{\tau}_n(l) = \hat{\tau}_n(l+1)$, for $n \le l$. This implies $\phi_n(\mu, l) = \phi_n(\mu, l+1)$ for $n \le l$. For $n > l$, we deduce from equation (48) that

$$\begin{aligned}
\hat{\tau}_n(l) - \hat{\tau}_n(l+1) &= \left(a_{n-l}^2 + \frac{H^2(l)}{Q(l)} - \frac{H^2(l+1)}{Q(l+1)}\right)\tau_u \qquad (49) \\
&= \left(\frac{a_{n-l}^2(1+\mu\gamma\tau_u a_n)^2}{Q(l)Q(l+1)}\right)\tau_u,
\end{aligned}$$

where $Q(l) \overset{def}{=} (1+\mu\gamma\tau_u)^2 + \sum_{j=1}^{l-1}(\mu\gamma a_{n-j}\tau_u)^2$ and $H(l) \overset{def}{=} a_n + \sum_{j=0}^{l-1}(\mu\gamma\tau_u)a_{n-j}^2$. We therefore have that $\hat{\tau}_n(l) > \hat{\tau}_n(l+1)$ for $n > l$. Thus, $\phi_n(\mu, l+1) > \phi_n(\mu, l)$ if $\tau_{\epsilon_{n-l}} > 0$. QED

Proof of proposition 10

Using the expressions for $A_n(l^*)$ and $B_{n,0}(l^*)$ in the proof of Proposition 2, and writing explicitly the expression for market depth we obtain that

$$B_{n,0}(l) = \begin{cases} \frac{(1+\mu\gamma a_n\tau_u)}{a_n+\gamma(\mu\tau_n+(1-\mu)\hat{\tau}_n(l))}\left(1 + \frac{(1-\mu)\gamma\tau_u(a_n+\mu\gamma(\tau_n-\tau_v))}{(1+\mu\gamma a_n\tau_u)^2+\sum_{j=1}^{n-1}(\mu\gamma a_{n-j}\tau_u)^2}\right), & \text{for } n \le l, \\[2ex] \frac{(1+\mu\gamma a_n\tau_u)}{a_n+\gamma(\mu\tau_n+(1-\mu)\hat{\tau}_n(l))}\left(1 + \frac{(1-\mu)\gamma\tau_u(a_n+\mu\gamma(\tau_n-\tau_{n-l}))}{(1+\mu\gamma a_n\tau_u)^2+\sum_{j=1}^{l-1}(\mu\gamma a_{n-j}\tau_u)^2}\right), & \text{for } n > l. \end{cases}$$

For $n \leq l$, $\hat{\tau}_n(l)$ does not depend on l. Thus, $B_{n,0}(l) = B_{n,0}(l+1)$. For $n > l$, we have

$$B_{n,0}(l) = \frac{(1 + \mu\gamma a\tau_u)}{a + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n(l))}\left(1 + \frac{(1-\mu)\gamma\tau_u H(l)}{Q(l)}\right),$$

where $H(l)$ and $Q(l)$ are defined in the proof of Proposition 9. Calculations show that

$$\frac{H(l)}{Q(l)} > \frac{H(l+1)}{Q(l+1)}$$

This inequality combined with the fact that $\hat{\tau}_n(l+1) < \hat{\tau}_n(l)$ for $n > l$ implies that $B_{n,0}(l) < B_{n,0}(l+1)$. QED

Figure 1: Speculators' welfare is higher in a fully opaque market ($\mu = 0$) compared to a fully transparent one ($\mu = 1$): $E[U(\pi_{i2}^O)]|_{\mu=0} > E[U(\pi_{i2}^I)]|_{\mu=1}$. Parameters' values: $\tau_v = \tau_u = 4$, $\tau_{\epsilon_1} = 1$, $\tau_{\epsilon_2} = 0.3$, and $\gamma = 1$.

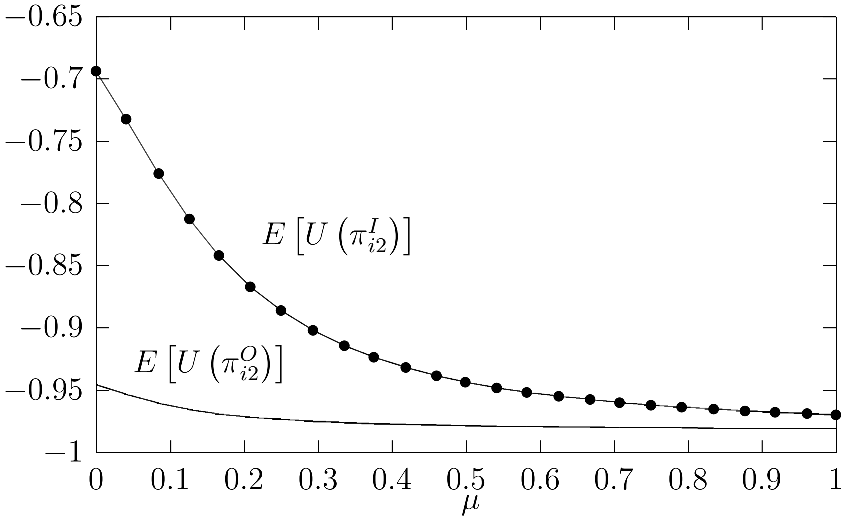
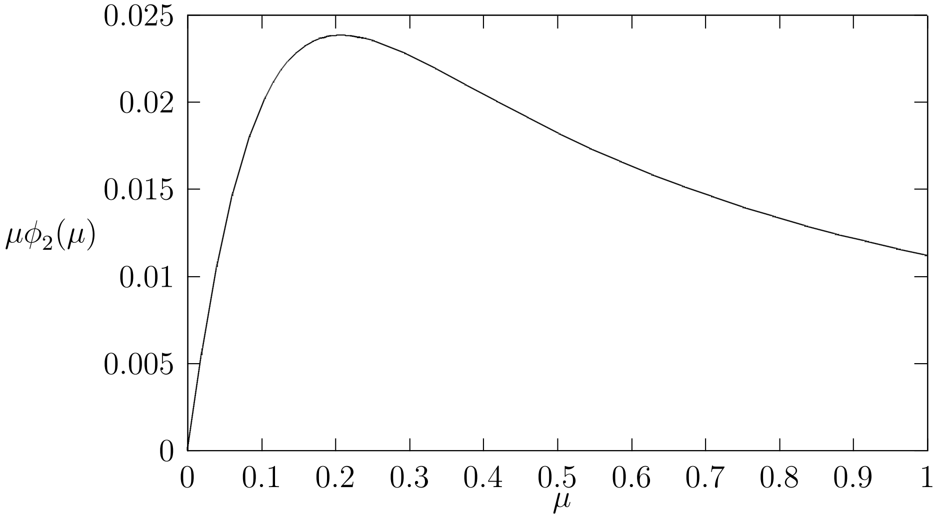
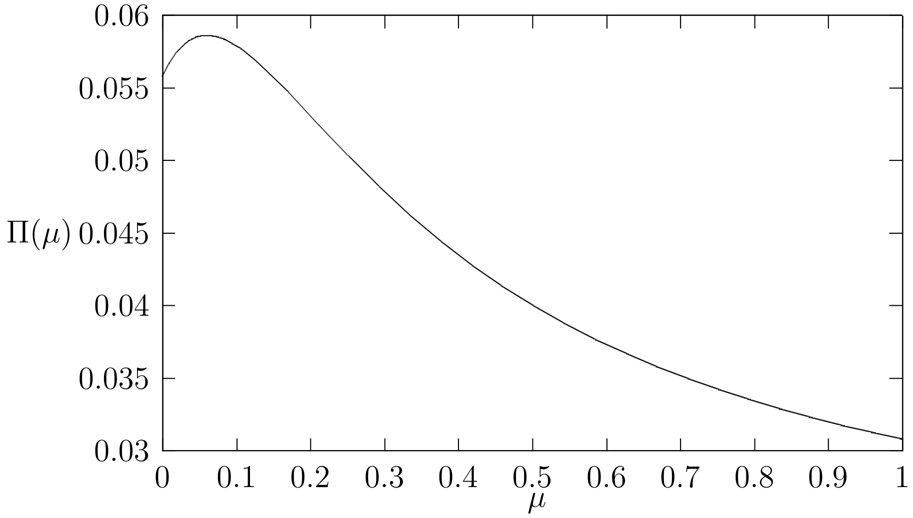


Figure 2: Rationing access to ticker information. Parameters' values: $\tau_v = \tau_u = 4$, $\tau_{\epsilon_1} = 1$, $\tau_{\epsilon_2} = 0.3$, and $\gamma = 1$.



(a) Profit from information sales



(b) Profit from information sales and entry fee