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

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Abstract

We consider a multi-period rational expectations model in which risk-averse investors differ in their information on past transaction prices (the ticker). Some investors (insiders) observe prices in real-time whereas other investors (outsiders) observe prices with a delay. As prices are informative about the asset payoff, insiders get a strictly larger expected utility than outsiders. Yet, information acquisition by one investor exerts a negative externality on other investors. Thus, investors' average welfare is maximal when access to price information is rationed. We show that a market for price information can implement the fraction of insiders that maximizes investors' average welfare. This market features a high price to curb excessive acquisition of ticker information. We also show that informational efficiency is greater when the dissemination of ticker information is broader and more timely.

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

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1 Introduction

Real-time information on transaction prices and quotes is not free in financial markets, and the market for price information is a significant source of revenues to exchanges.[1] For instance, in 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.[2] This situation is controversial and market participants often complain that the price of information is too high. 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. 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]

These debates raise intriguing economic questions. How does the dissemination of price information affect the allocative and informational efficiency of financial markets? Should market data be widely disseminated or can it be efficient to restrict access to real-time information? What is the role of markets for price information? Can it be socially optimal to curb acquisition of market data by charging a high fee for price information?

We study these questions in a multi-period rational expectations model. The model considers the market for a risky security with risk averse investors who possess heterogeneous signals about the payoff of the security. Investors trade to share the risk associated with their initial holdings of the security, and to speculate on their private information. Some investors – the "insiders" – observe the entire history of prices (the "real-time ticker") when they arrive in the market. Other investors – the "outsiders" – observe past prices with a delay (latency).

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[1]Information on past trades is generally available for free 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. Brokers may sometimes give price information for free to their clients. However, they pay a fee to data vendors for this information and presumably pass this cost to their clients by adjusting their brokerage fee.

[2]See Exchange Act Rel N°49, 325 -February, 26, 2004 available at `http://www.sec.gov/rules/proposed/34-49325.htm`. The sale of market data is important for European exchanges as well. For instance, in 2005, the sale of market information accounted for 33% (resp. 10%) of the London Stock Exchange (resp. Euronext) annual revenues. Source: Annual Reports.

[3]For accounts of these debates, see, for instance, "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; 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`, and "TRACE Market Data Fees go to SEC," Securities Industry News, 6/3/2002.

As transaction prices are informative about the asset payoff, insiders have an informational advantage over outsiders, and thus enjoy a higher expected utility. We call the *value of the ticker* the maximum fee that, other things equal, an investor is willing to pay to be an insider. This value depends both on the scope and timeliness of information dissemination. Indeed, insiders' demand depends on their privileged price information, which therefore transpires into clearing prices. Hence, outsiders can partially catch up with insiders' information by conditioning their demands on the clearing price when they trade.[4] Now, the informativeness of the clearing price about the information contained in past prices increases with the proportion of insiders and decreases with latency. Accordingly, the value of the ticker is inversely related to the proportion of insiders and positively related to latency.

We show that there is a conflict between the private and social value of the ticker. Individually, each investor has an incentive to acquire ticker information. However, acquisition of ticker information by one investor exerts a negative externality on all other investors. Indeed, as investors become better informed, their demand is more elastic to the difference between their pay-off forecast and the clearing price. This effect brings prices closer to the asset payoff, reducing the speculative gains that investors derive from market participation. Hedging gains are reduced as well because earlier resolution of uncertainty reduces the scope for risk sharing among investors.[5]

Thus, a too broad dissemination of ticker information can be detrimental to allocative efficiency. In fact, in the model, investors are strictly worse off when ticker information is freely available compared to the situation in which no investor observes ticker information. Yet, completely shutting down the access to ticker information leaves "money on the table" since each investor individually benefits from observing past prices. In fact, in our model, investors' average welfare (i.e., the equally weighted sum of investors' expected utilities) is in general not maximal when the market is fully opaque. Rather, a two-tier market, featuring both insiders and outsiders, maximizes investors' average welfare.

The socially optimal market structure can be achieved by granting privileged access to ticker information only to a limited number of investors. In today's markets,

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[4]This feature distinguishes our approach from Hellwig (1982). Hellwig (1982) considers a multi-period rational expectations model in which some investors form their beliefs about the asset payoff by using the information contained in past prices only.

[5]This is a manifestation of the so called Hirshleifer effect. See, Dow and Rahi (2003) or Medrano and Vives (2004) for an application to models of trading with asymmetric information.

however, exchanges cannot decide who has access to price information.[6] Instead, they can sell this information. We show that the creation of a market for price information can be a way to achieve the socially optimal ticker information dissemination. Indeed, an exchange can control the proportion of investors buying real-time information via the fee it charges (the larger the fee, the smaller the proportion of investors buying information). We first consider the case in which an exchange is not-for profit and redistributes the proceeds from information sales among all investors. In this case, the exchange policy maximizes social welfare and is fair, in the sense that outsiders and insiders obtain the same expected utility (net of their transfers to the exchange).

We then consider the more realistic case of a for-profit, monopolist exchange, which derives revenues from (i) the sale of ticker information and (ii) the sale of trading rights. The exchange finds it optimal to restrict access to ticker information because investors' willingness to pay for both the ticker and trading rights decreases with the proportion of insiders. Moreover, with its tariff, the for-profit exchange extracts all the gains from trade from investors. Hence, it also chooses a pricing policy that maximizes investors' average welfare (gross of their payments to the exchange).

Finally, we analyze how the dissemination of ticker information affects the informational content of prices. We find that a broader and more timely dissemination of price information is associated with more informative prices. In particular, a reduction in latency increases the amount of information available to outsiders and thereby their risk bearing capacity. As a consequence, the equilibrium risk premium is inversely related to latency for each realization of the asset supply. This finding suggests that a reduction in latency should result in a price run-up (smaller risk premia), as found empirically in Easley, Hendershott and Ramadorai (2007).

Our analysis contributes to the literature on financial markets transparency (see, e.g., Biais (1993), Madhavan (1995), Pagano and Roëll (1996)). An important difference with this literature is our focus on investors' welfare and the idea that transparency can be excessive from a social standpoint. Our approach also builds upon the literature on markets for financial information (e.g., Admati and Pfleiderer (1986, 1987, 1990), Fishman and Hagerthy (1995), Cespa (2007)). This literature focuses on the sale of exogenous signals on securities payoffs. As prices aggregate information, they also constitute payoff-relevant signals. However, their precision is endogenous as it depends on investors' demands and market organization. That is, this precision

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[6]In the U.S., stock exchanges must make their data available since 1975 according to the so called "Quote Rule." Yet, they can charge a price for disseminating their market data.

cannot be directly controlled by the information seller. Moreover, access to price information can be delayed, a feature that has not been considered in the literature on information sales. Last, price information is usually sold by exchanges (directly or through data vendors).[7] Exchanges also derive revenues from trading. Thus, they are not pure information sellers and they care about the effect of disseminating price information on market participation. For all these reasons, markets for price information deserve a specific analysis.

Research on this topic is surprisingly scarce given the importance of prices as a conduit for information in economics. Mulherin et al. (1992) offer an historical account of how exchanges established their property rights over market data.[8] Boulatov and Dierker (2007) in a paper that is more related to ours, formally analyze the sale of price information. In their model, however, traders cannot condition their demand on the contemporaneous clearing price. Hence, they seek price information to reduce their uncertainty on execution prices ("execution risk"). In the present article, execution risk is not a concern since traders submit price contingent orders. Rather, price information is valuable because past prices are informative about the asset payoff. Moreover, differently from Boulatov and Dierker (2007), our main focus is on the welfare effects of price information dissemination. The presence of noise traders with exogenous demands precludes a welfare analysis in Boulatov and Dierker (2007).

The paper is organized as follows. We describe the model in Section 2. In Section 3, we derive the equilibrium of the model. Section 4 analyzes the effects of a change in the proportion of insiders and latency on price discovery. Section 5 analyzes how investors' welfare depends on the distribution of price information among investors and introduces a market for price information in the model. Section 6 summarizes the main findings of the article. We collect proofs that are not in the text in the Appendix.

2 Model

We consider the market for a risky asset with payoff $v \sim N(0, \tau_v^{-1})$. Trades in this market take place at dates $1, 2, \ldots, N$. At date $N + 1$, the asset payoff is realized. In each period, a continuum of investors (indexed by $i \in [0, 1]$) arrives in the market.

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[7]See Lee (2000), Chapter 6, for a detailed description of the market for price information and pricing policies followed by exchanges. For a description of this market in the U.S., see "Report of the advisory committee on market information: a blueprint for responsible change," SEC, 2001.

[8]See also Pirrong (2002) for related research.

They invest in the risky security and in a riskless security with a zero return and then leave the market. As investors stay in the market for only one period, they are not informed about the terms of past transactions when they enter the market. For this reason, they have a motive for buying information on past transaction prices.

As in Hellwig (1980) or Verrechia (1982), an investor arriving at date n is endowed with e_{in} shares of the risky security and a private signal s_{in} about the payoff of the security. We assume that

$$e_{in} = e_n + \eta_{in}, \tag{1}$$

and

$$s_{in} = v + \epsilon_{in}, \tag{2}$$

where $\eta_{in} \sim N(0, \tau_{\eta_n}^{-1})$, $\epsilon_{in} \sim N(0, \tau_{\epsilon_n}^{-1})$ and $e_n \sim N(0, \tau_e^{-1})$. Investors in a given period have private signals of equal precision but this precision can vary across periods. We say that "fresh" information is available at date n if investors entering the market at this date have private information (that is, if $\tau_{\epsilon_n} > 0$). Error terms (the $\eta s'$ and $\epsilon s'$) are independent across agents, across periods, and from v and e_n. The $e_n s'$ are i.i.d. and independent from the asset payoff, v. We also assume that error terms across agents cancel out (i.e., $\int_0^1 s_{in} di = v$, and $\int_0^1 e_{in} di = e_n$, a.s.). Thus, the aggregate (per capita) endowment in period n is e_n.

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 (the "ticker"):

$$p^n = \{p_t\}_{t=0}^n, \text{ with } p_0 = E[v] = 0. \tag{3}$$

Investors differ in their access to ticker information. Investors with type I (the *insiders*) observe the ticker in real-time while investors 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^*} where $l^* = \min\{n, l\}$:

$$p^{n-l^*} = \begin{cases} \{p_1, p_2, \ldots, p_{n-l}\}, & \text{if } n > l, \\ p_0, & \text{if } n \leq l. \end{cases} \tag{4}$$

We refer to p^n as the "real-time ticker" and to p^{n-l^*} as the "lagged ticker." The "delayed ticker" is the set of prices unobserved by outsiders (i.e., $p^n - p^{n-l^*}$). The fraction of insiders is denoted by μ. In the first period, the distinction between insiders and outsiders is moot since there are no prior transactions (and hence no past prices

to observe). This period can be seen as the first trading round following the overnight closure in real markets. Figure 1 below describes the timing of the model.

[**Insert Figure 1 about here**]

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

$$E[U(\pi_{in})|s_{in}, e_{in}, \Omega_n^k] = E[-\exp\{-\gamma^{-1}\pi_{in}\}|s_{in}, e_{in}, \Omega_n^k], \qquad (5)$$

where $\pi_{in} = (v - p_n)x_{in} + p_n e_{in}$ and Ω_n^k is the price information available at date n to an investor with type $k \in \{I, O\}$. In period n, insiders and outsiders submit orders contingent on the price at date n (limit orders). The clearing price in each period aggregates investors' private signals and provides an additional signal about the asset payoff. As investors submit price contingent demand functions, they can all act as if they were observing the contemporaneous clearing price and account for the information contained in this price. Thus, in period $n \geq 2$, we have $\Omega_n^I = \{p^n\}$ and $\Omega_n^O = \{p^{n-l^*}, p_n\}$. We denote the demand function of an insider by $x_n^I(s_{in}, e_{in}, p^n)$ and that of an outsider by $x_n^O(s_{in}, e_{in}, p^{n-l^*}, p_n)$. In each period, the clearing price, p_n, is such that the demand for the security is equal to its supply, i.e.,

$$\int_0^\mu x_n^I(s_{in}, e_{in}, p^n)di + \int_\mu^1 x_n^O(s_{in}, e_{in}, p^{n-l^*}, p_n)di = e_n, \quad \forall n. \qquad (6)$$

Parameters μ and l control the level of market transparency. When the proportion of insiders increases, the market is more transparent as more investors observe the ticker in real-time. When l becomes smaller, market transparency increases since outsiders observe past transaction prices more quickly. We refer to l as the *latency in information dissemination* and to μ as the *scope in information dissemination*.

3 Equilibrium prices with heterogeneous ticker information

In this section, we study the equilibrium of the security market in each period. We focus on rational expectations equilibria in which investors' demand functions are linear in their private signals and prices. In this case, the clearing price in equilibrium is itself a linear function of the asset payoff and the aggregate endowment. We refer to $\tau_n(\mu, l) \overset{def}{=} (\text{Var}[v|p^n])^{-1}$ as the informativeness of the real-time ticker at date n and

to $\hat{\tau}_n(\mu, l) \stackrel{def}{=} (\text{Var}[v|p^{n-l^*}, p_n])^{-1}$ – the precision of outsiders' forecast conditional on their price observations at date n – as the informativeness of the "truncated" ticker. The next lemma provides a characterization of the unique linear rational expectations equilibrium in each period.

Lemma 1 *In any period n, there is a unique linear rational expectations equilibrium. In this equilibrium, the price is given by*

$$p_n = A_n v - \sum_{j=0}^{l^*-1} B_{n,j} e_{n-j} + D_n E[v \mid p^{n-l^*}], \tag{7}$$

where $A_n, \{B_{n,j}\}_{j=0}^{l^*-1}, D_n$ are positive constants characterized in the proof of the lemma. Moreover, investors' demand functions are given by

$$x_n^I(s_{in}, e_{in}, p^n) = \gamma(\tau_n + \tau_{\epsilon_n})(E[v|s_{in}, e_{in}, p^n] - p_n), \tag{8}$$

$$x_n^O(s_{in}, e_{in}, p^{n-l^*}, p_n) = \gamma(\hat{\tau}_n + \tau_{\epsilon_n})(E[v|s_{in}, e_{in}, p^{n-l^*}, p_n] - p_n), \tag{9}$$

where $\tau_n + \tau_{\epsilon_n} \equiv \text{Var}[v|p^n, s_{in}]^{-1}$, and $\hat{\tau}_n + \tau_{\epsilon_n} \equiv \text{Var}[v|p_n, p^{n-l^*} s_{in}]^{-1}$.

An investor's demand is proportional to the difference between her forecast of the asset payoff and the clearing price, scaled by the precision of her forecast (e.g., $\tau_n + \tau_{\epsilon_n}$ for an insider). As shown below, an insider holds a more precise forecast of the asset pay-off compared to an outsider. Hence, her demand is more elastic to difference between her forecast and the clearing price, and, other things equal, her position in the risky asset is larger.

To interpret the expression for the equilibrium price, we focus on the case in which $l = 2$ (the same interpretation applies for $l > 2$). In this case, equation (7) becomes

$$p_n = A_n v - B_{n,0} e_n - B_{n,1} e_{n-1} + D_n E[v \mid p^{n-2}], \text{ for } n \geq 2. \tag{10}$$

To gain more intuition, we now consider some particular cases. For the discussion, we define $z_n \stackrel{def}{=} a_n v - e_n$, and $a_n \stackrel{def}{=} \gamma \tau_{\epsilon_n}$.

Case 1. *No fresh information is available at date $n - 1$ and at date n (for $n \geq 3$).* In this case, $A_n = 0$, $B_{n,0} = (\gamma \tau_{n-2})^{-1}$, $B_{n,1} = 0$, and $D_n = 1$ (see the expressions for these coefficients in the appendix). Thus, the equilibrium price at date n is

$$p_n = E[v \mid p^{n-2}] - (\gamma \tau_{n-2})^{-1} e_n. \tag{11}$$

As investors entering the market at dates n and $n-1$ do not possess fresh information, the clearing price at date n cannot reflect information above and beyond that contained in the lagged ticker, p^{n-2}. Thus, the clearing price is equal to the expected value of the security conditional on the lagged ticker adjusted by a risk premium. The size of the risk premium is smaller when investors are more risk tolerant (γ large) or when the uncertainty on the asset payoff 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 $\tau_{\epsilon_{n-1}} > 0$).* In this case, the transaction price at date $n-1$ contains new information on the asset payoff ($A_{n-1} \neq 0$). Specifically, we show in the proof of Lemma 1 that the observation of the price at date $n-1$ conveys a signal $z_{n-1} = a_{n-1}v - e_{n-1}$ on the asset payoff. Moreover, the equilibrium price at date n can be written as follows

$$p_n = E[v \mid p^{n-2}] + A_n a_{n-1}^{-1} \left(z_{n-1} - E \left[z_{n-1} \mid p^{n-2} \right] \right) - B_{n,0} e_n. \tag{12}$$

If $\mu = 0$, we have $A_n = 0$ and the expression for the equilibrium price at date n is identical to the expression derived in Case 1 (equation (11)). Indeed, in this case, no investor observes the last transaction price. Thus, the information contained in this price (z_{n-1}) cannot transpire into the price at date n.

In contrast, if $\mu > 0$ some investors at date n observe the last transaction price and trade on the information it contains. Thus, this information "percolates" into the price at date n and the latter is informative ($A_n > 0$), even though there is no fresh information at date n. Specifically, equation (12) shows that an outsider can extract a signal $\hat{z}_n$, from the clearing price at date n:

$$\hat{z}_n = \alpha_1 z_{n-1} - \alpha_0 e_n = \alpha_1 z_{n-1} + \alpha_0 z_n, \tag{13}$$

with $\alpha_0 \overset{def}{=} A_n^{-1} B_{n,0}$ and $\alpha_1 \overset{def}{=} a_{n-1}^{-1}$. This signal does not perfectly reveal insiders' information (z_{n-1}) as it also depends on the supply of the risky security at date n (e_n). Thus, at date n, outsiders obtain information ($\hat{z}_n$) from the clearing price but this information is not as precise as insiders' information. For this reason, being an insider is valuable in our set-up. ∎

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 investors' private signals at this date and for this reason $A_n > 0$. On the other hand, no investor observes the price realized at date $n-1$. Hence $B_{n,1} = 0$. Thus, the equilibrium price at date n can be written as follows:

$$p_n = E \left[v \mid p^{n-2} \right] + A_n a_n^{-1} \left(z_n - E \left[z_n \mid p^{n-2} \right] \right). \tag{14}$$

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In this case, all investors obtain the same signal, z_n, from the price at date n. Thus, investors' estimates of the asset payoff have identical precision. Together, Cases 2 and 3 show that insiders' informational edge exclusively comes from their ability to observe transaction prices more quickly than outsiders. ∎

In the rest of the paper, we shall assume that fresh information is available at all dates ($\tau_{\epsilon_n} > 0, \forall n$). This assumption simplifies the presentation of some results without affecting the findings. In this case, the price at date n contains information on the asset payoff (i.e., $A_n > 0$) because *(a)* investors' demand depends on their private signals (as in Case 3), and *(b)* insiders' demand depends on the signals $\{z_{n-j}\}_{j=1}^{j=l^*-1}$ that they extract from the prices yet unobserved by outsiders at date n (as in Case 2). We show in the proof of Lemma 1 that outsiders extract from the clearing price a signal:

$$\hat{z}_n = \sum_{j=0}^{l^*-1} \alpha_j z_{n-j} = v - \sum_{j=0}^{l^*-1} \frac{B_{n,j}}{A_n} e_{n-j}, \tag{15}$$

where the $\alpha s'$ are positive coefficients. As shown below (Proposition 1), this signal provides a less precise estimate of the asset payoff than the signals $\{z_{n-j}\}_{j=1}^{j=l^*-1}$ obtained from the delayed ticker by insiders. In other words, the current clearing price is not a sufficient statistic for the entire price history. Thus, observing past prices has value even though investors can condition their demand on the contemporaneous clearing price.[9] We analyze the determinants of this value in Section 5.2 below.

4 Price discovery and risk premium with heterogeneous ticker information

We now study how the scope in information dissemination (μ) and latency (l) affect the informativeness of the price history. We use two measures of price informativeness: *(i)* $\hat{\tau}_n(\mu, l) = (\text{Var}[v|p^{n-l^*}, p_n])^{-1}$, the informativeness of the "truncated ticker" and *(ii)* $\tau_n(\mu, l) = (\text{Var}[v|p^n])^{-1}$, the informativeness of the real-time ticker. The first (resp. second) measure takes the point of view of outsiders (resp. insiders) since it measures the residual uncertainty on the asset payoff conditional on the prices that outsiders (resp. insiders) observe.

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[9]Other authors (Brown and Jennings (1989) and Grundy and McNichols (1989)) have considered multi-period rational expectations models in which clearing prices are not a sufficient statistic for past prices. In contrast, Brennan and Cao (1996) and Vives (1995) develop multi-period models in which the clearing price in each period is a sufficient statistic for the entire price history.

Let $\tau_n^m(\mu, l) \stackrel{def}{=} (\mathrm{Var}[\hat{z}_n|v])^{-1}$. The next proposition shows that τ_n^m is the contribution of the nth clearing price to the informativeness of the truncated ticker. For this reason, we refer to τ_n^m as the informativeness of the nth clearing price for outsiders.[10]

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

1. *The informativeness of the real-time ticker, τ_n, is independent of latency and the scope in information dissemination. It is given by*

$$\tau_n(\mu, l) = \tau_v + \tau_e \sum_{t=1}^{n} a_t^2, \ \text{with} \ a_t = \gamma \tau_{\epsilon_t}. \tag{16}$$

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

$$\hat{\tau}_n(\mu, l) = \tau_{n-l*} + \tau_n^m(\mu, l). \tag{17}$$

It increases in the scope of information dissemination and (weakly) decreases with latency. Moreover, it is strictly smaller than the informativeness of the real-time ticker (i.e., $\hat{\tau}_n < \tau_n$).

In equilibrium, an investor's demand can be written as

$$x_n^k(s_{in}, e_{in}, \Omega_n^k) = (\gamma \tau_{\epsilon_n})s_{in} - \varphi_n^k(\Omega_n^k), \tag{18}$$

where φ_n^k is a linear function of the prices observed by an investor with type $k \in \{I, O\}$. Thus, the sensitivity of investors' demand to their private signals $(\gamma \tau_{\epsilon_n})$ is identical for outsiders and insiders. Accordingly, the sensitivity of the nth 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 (first part of the proposition). Yet, the informativeness of a truncated record of prices, $\{p_n, p^{n-l*}\}$, increases with the fraction of insiders (second part of the proposition). The explanation for these seemingly incompatible findings is as follows.

As explained in the previous section, the nth clearing price is informative about the signals $\{z_{n-j}\}_{j=1}^{l*-1}$ obtained by insiders from the delayed ticker (the prices yet unobserved by outsiders). This information is useless for an insider, as he directly

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[10]Strictly speaking, this is the informativeness of the nth clearing price from the point of view of outsiders *after* accounting for the information contained in the lagged ticker.

observes the zs', but not for an outsider. For this reason, the precision of an outsider's forecast at date n is larger than if he could not condition his forecast on the contemporaneous clearing price ($\hat{\tau}_n > \tau_{n-l^*}$). Yet, insiders' forecast is more precise than outsiders' ($\hat{\tau}_n < \tau_n$) because the clearing price at date n is not a sufficient statistic for the delayed ticker

As the proportion of insiders increases, the price at date n aggregates better insiders' information on the delayed ticker. For this reason, the informativeness of the truncated ticker increases in μ. In contrast, as latency increases, it becomes more difficult for outsiders to extract information on the signals obtained by insiders from the delayed ticker (since the number of price signals possessed by insiders increases). Thus, $\tau_n^m(\mu, l)$ decreases with l (for $n > l$).[11] Moreover, an increase in latency implies that outsiders have access to a shorter and, therefore less informative, price history. Hence, the informativeness of the truncated ticker decreases with latency.

The mean squared deviation between the payoff of the security and the clearing price (the average "pricing error" at date n) is a measure the quality of price discovery. Using the law of iterated expectations and the fact that $E[v] = 0$, it is immediate from equation (7) that

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

Thus, the average pricing error at date n is equal to $\text{Var}[v - p_n]$.[12]

Proposition 2 *At any date $n \geq 2$, the average pricing error ($\text{Var}[v - p_n]$), decreases with the proportion of insiders.*

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

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

Thus, an increase in the proportion of insiders widens the proportion of investors with a relatively high elasticity of demand to the perceived risk premium. Simultaneously,

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[11] When $n < l$, $\hat{\tau}_n(\mu, l)$ does not depend on l. In particular, an increase in l in this case leaves unchanged the number of prices unobserved by an outsider, that is, the number of signals possessed by insiders that outsiders attempt to recover from the observation of the nth clearing price. Thus, for $n < l$, $\tau_n^m(\mu, l)$ does not depend on l.

[12] It is also the case that $E[v - p_n] = 0$ if $E[v] \neq 0$ because $A_n + D_n = 1$.

it increases the precision of outsiders' estimate at date n, $\hat{\tau}_n$. These two effects combine to make investors' aggregate demand more elastic to the perceived risk premium. As a consequence, the absolute difference between the clearing price and the payoff of the security narrows when there are more insiders.

We have not been able to study analytically the effect of an increase in latency on the average pricing error. However, extensive numerical simulations indicate that an increase in latency has a positive impact on the average pricing error at each date $n \geq 2$, as illustrated in Figure 2 (compare for instance the pricing error when $n = 15$ for $l = 10$ and $l = 20$).

[Insert Figure 2 about here]

In each trading round, investors receive new information which is then reflected into subsequent prices through trades by insiders and outsiders. For this reason, the pricing error decreases over time (i.e., n). Interestingly, Figure 2 shows that the speed at which the pricing error decays with n increases sharply when outsiders start obtaining information on past prices, that is, when $l < n$. Intuitively, in this case, the information contained in past prices is better reflected into current prices because all investors (insiders plus outsiders) trade on this information. This effect dramatically accelerates the speed of learning about the asset payoff compared to the case in which outsiders trade in the "dark" ($n \leq l$). This observation suggests that the time at which ticker information becomes available for free in the trading day should coincide with a discontinuity in the speed of price discovery in financial markets.

Interestingly, changes in latency also affect the price level of the security. To see this, let $R_n(e_n) \stackrel{def}{=} E[(v - p_n)I(e_n) \mid e_n]$ be the average risk premium at date n when the net supply is e_n. Variable $I(e_n)$ is an indicator variable equal to $+1$ when $e_n \geq 0$ and -1 when $e_n < 0$. This definition guarantees that the average risk premium is positive even when e_n is negative (in which case investors have a short position in the aggregate). Using Lemma 1 and the law of iterated expectations, it is immediate that:

$$R_n(e_n) = E[v - p_n \mid e_n] = B_{n,0}(l)I(e_n)e_n. \tag{19}$$

where $B_{n,0}(l)$ is the value of coefficient $B_{n,0}$ when latency is l. We obtain the following result.

Proposition 3 *For each realization of the asset supply at date n, the average risk premium weakly increases with the latency in information dissemination, l.*

An increase in latency reduces the precision of the outsiders' asset payoff forecast. As a consequence, outsiders require a larger compensation to hold a given position (long or short) in the risky security, implying that the average risk premium increases in latency. In other words, a reduction in latency should be associated with an increase in stock prices, other things equal. This prediction is consistent with empirical findings in Easley et al. (2007).

To sum up, we find that restricting the dissemination of ticker information impairs price discovery.[13] Indeed, an increase in the proportion of insiders improves the informativeness of the truncated ticker and reduces the dispersion of pricing errors. Moreover, an increase in latency reduces the informativeness of the truncated ticker. For this reason, an increase in latency decreases the risk bearing capacity of the market, and increases the equilibrium risk premium.

5 Dissemination of the ticker and welfare

5.1 The ticker externality

We now consider the effect of broadening the dissemination of ticker information on investors' welfare. As in Dow and Rahi (2003), we measure investors' welfare by the certainty equivalent of their ex-ante expected utility (i.e., before they learn their signals and their endowment).[14] At date n, the certainty equivalent is the maximal fee that an investor would be willing to pay to enter the market. We denote it by $C_n^k(\mu, l)$ for an investor with type k and call it the *investor's payoff*.

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[13]This possibility is often discussed in regulatory controversies about the pricing of market data. For instance, 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`

[14]The conclusions are identical if we work directly with investors' expected utilities. Expressions for the certainty equivalent are easier to interpret.

When $\gamma^2 \tau_e \tau_v > 1$, we obtain the following expressions for investors' payoffs:

$$C_n^I(\mu, l) = \frac{\gamma}{2} \left[\underbrace{\ln \left(\frac{\text{Var}[v - p_n]}{\text{Var}[v | s_{in}, p^n]} \right)}_{\text{Speculative component}} + \underbrace{\ln \left(\frac{\gamma^2 \tau_e - \text{Var}[v | v - p_n]}{\gamma^2 \tau_e - \text{Var}[v]} \right)}_{\text{Hedging Component}} \right], \qquad (20)$$

$$C_n^O(\mu, l) = \frac{\gamma}{2} \left[\underbrace{\ln \left(\frac{\text{Var}[v - p_n]}{\text{Var}[v | s_{in}, p^{n-l^*}]} \right)}_{\text{Speculative component}} + \underbrace{\ln \left(\frac{\gamma^2 \tau_e - \text{Var}[v | v - p_n]}{\gamma^2 \tau_e - \text{Var}[v]} \right)}_{\text{Hedging Component}} \right]. \qquad (21)$$

The condition $\gamma^2 \tau_e \tau_v > 1$ guarantees that investors' ex-ante expected utility is well defined.[15] The derivation of these expressions requires tedious calculations but is standard (see for instance Dow and Rahi (2003)). We thus omit these calculations for brevity.[16]

An investor's payoff is the sum of two components that we call respectively the speculative component and the hedging component. These two components reflect the two benefits that an investor derives from market participation. First, market participation enables the investor to share the risk associated with his endowment of the security. This benefit is captured by the hedging component of investors' payoffs. Second, market participation enables the investor to buy (resp. sell) the security at a discount (resp. premium) when other investors are on average net sellers (resp. net buyers), i.e., when $e_n < 0$ (resp. $e_n > 0$). This benefit is captured by the speculative component of investors' payoffs. According to (20) and (21) this component increases with the pricing error, $\text{Var}[v - p_n]$ because large pricing errors mean that the investor can buy (resp. sell) the asset at large discount (resp. premium) on average. It also increases with the precision of the investor's information, as risk averse investors are willing to bear more risk when they face less uncertainty on the asset payoff.[17]

The hedging component is identical for insiders and outsiders. In contrast, the speculative component is higher for insiders since their forecast of the asset payoff is more precise. Thus, in our model, ticker information is valuable only for speculative purposes, and *not* for hedging. Using equations (20) and (21), it is immediate that

$$C_n^I(\mu, l) - C_n^O(\mu, l) = \ln \left(\frac{\text{Var}[v | s_{in}, p^{n-l^*}]}{\text{Var}[v | s_{in}, p^n]} \right) = \ln \left(\frac{\tau_{\epsilon_n} + \tau_n(\mu, l)}{\tau_{\epsilon_n} + \hat{\tau}_n(\mu, l)} \right) > 0. \qquad (22)$$

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[15] If it is not satisfied, the expression for investors' ex-ante expected utility diverges to $-\infty$.

[16] They can be obtained from the authors upon request.

[17] If an investor had a zero endowment in the security with certainty, the hedging component would be zero and the speculative component would be unchanged.

We deduce the following result.

Proposition 4 *At any date $n \geq 2$, an insider's ex-ante expected utility is strictly larger than an outsider's expected utility.*

Thus, individually, investors benefit from observing the ticker in real-time. However, the next proposition shows that the regime in which **no** investor observes the ticker in real-time always Pareto dominates the regime in which **all** investors observe the ticker in real-time.

Proposition 5 *At any date $n \geq 2$, investors' welfare when the market is fully opaque ($\mu = 0$) is larger than when the market is fully transparent ($\mu = 1$), i.e., $C_n^I(1, l) < C_n^O(0, l)$.*

At first glance, this result is counterintuitive. Indeed, when $\mu = 1$, investors have a more precise estimate of the asset payoff than when $\mu = 0$ because past transaction prices are informative. Hence, they bear less risk, which positively affects their expected utility. There are two counterbalancing effects, however. First, an increase in the proportion of insiders drives prices "closer" to the payoff of the security (Proposition 2). This effect reduces the speculative value of market participation. Second, an increase in the proportion of insiders implies that each clearing price becomes more informative for outsiders, as explained in the previous section. Earlier resolution of uncertainty reduces the scope for risk sharing and thereby the hedging component of investors' payoff (formally, $\text{Var}[v \mid v - p_n]$ increases in μ). This effect corresponds to the so called "Hirshleifer effect" discussed in Dow and Rahi (2003) for instance.[18] In equilibrium, these two effects dominate and investors' welfare is smaller when $\mu = 1$ than when $\mu = 0$.

[**Insert Figure 3 about here**]

Figure 3 illustrates this result for specific values of the parameters. For these values, an investor's payoff is about 0.41 when $\mu = 0$ and about 0.37 when $\mu = 1$.

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[18]Hirshleifer (1971) point out that disclosure of information can be socially harmful since it destroys insurance opportunities (one cannot insure against a risk whose realization is known). Several authors (e.g., Diamond (1985), Marin and Rahi (2000), Dow and Rahi (2003) or Medrano and Vives (2004)) have observed that a similar effect prevails when asset prices reveal information on asset payoffs. Early resolution of uncertainty implies that the innovation $v - p_n$ is less informative, i.e., $\text{Var}[v \mid v - p_n]$ is larger. Thus, the Hirshleifer effect is measured by $\text{Var}[v \mid v - p_n]$ in the model.

However, at $\mu = 0$, an investor could increase her payoff to 0.52 by acquiring ticker information. Thus, if ticker information is available for free, the situation in which $\mu = 0$ is not sustainable. In the absence of coordination, each investor uses ticker information. Eventually, investors end up with a lower expected utility than if they could commit not to use ticker information at all.

Figure 2 also shows that investors' payoffs decline with the proportion of insiders, whether they are insiders or outsiders. This result also holds true for all parameter values as shown in the next proposition.

Proposition 6 *At any date $n \geq 2$ investors' welfare declines with the proportion of insiders.*

Acquisition of ticker information by one investor exerts a *negative externality* on other investors because it reduces the speculative value of market participation and the scope for risk sharing. Taken together, Proposition 5 and Proposition 6 suggest that restricting access to ticker information can be socially optimal. To analyze this point, we use the equally weighted sum of all investors' payoffs, denoted $W_n(\mu, l)$, as a measure of social welfare:

$$W_n(\mu, l) \stackrel{def}{=} \mu C_n^I(\mu, l) + (1 - \mu)C_n^O(\mu, l). \tag{23}$$

We denote by μ_n^*, the proportion of insiders that maximizes $W_n(\mu, l)$. This proportion is a Pareto optimum. Indeed, if a proportion μ_n^* of investors are insiders, there is no other distribution of price information among investors arriving at date n that makes all of them better off (even if side payments between investors are possible). We obtain the following result.

Proposition 7 *In each period, the proportion of insiders that maximizes investors' average welfare, μ_n^*, is strictly smaller than one.*

Proof: We know from Proposition 5 that $C_n^I(1, l) < C_n^O(0, l)$. Thus, $W_n(1, l) < W_n(0, l)$. It follows that $\mu_n^* < 1$.∎

Thus, some degree of opaqueness maximizes investors' average welfare. Yet, full opaqueness does not in general maximize investors' average payoff. Indeed, at $\mu = 0$, the welfare gain of getting price information $(C_n^I(0, l) - C_n^O(0, l))$ is large (in fact it is maximal; see Proposition 8 below). But this welfare gain can be realized only by allowing some investors to get ticker information.

5.2 The market for price information and welfare

We now endogenize the proportion of insiders by introducing a market for ticker information in which investors freely decide whether to buy ticker information. We show that the price set in this market is a tool to implement the socially optimal proportion of insiders. Moreover, we identify sufficient conditions under which a for-profit exchange prices ticker information in such a way that investors' average welfare, $W_n(\mu, l)$, is maximized.

At the beginning of each period, before receiving their private signals, investors decide *(i)* whether to participate to the market and *(ii)* whether to purchase ticker information. We assume that the cost of disseminating information on past transaction prices does not depend on the proportion of investors buying information. To simplify notations, we set this cost equal to zero. We denote the price of ticker information at date n by ϕ_n. An investor entering the market at date n becomes an insider if she pays this fee. Otherwise she is an outsider. We denote the proportion of investors buying ticker information by $\mu^e(l, \phi_n)$.

Let $\overline{\phi}_n(\mu, l)$ be the *maximum* fee that an investor entering the market at date n is willing to pay to observe the ticker in real-time. We call this fee the *value of the real-time ticker*. Analytically, its expression is given by the difference between the payoff of an insider and the payoff of an outsider:

$$\overline{\phi}_n(\mu, l) = C_n^I(\mu, l) - C_n^O(\mu, l). \tag{24}$$

Using equation (22), we obtain

$$\overline{\phi}_n(\mu, l) = \frac{\gamma}{2} \ln \left(\frac{\tau_{\epsilon_n} + \tau_n(\mu, l)}{\tau_{\epsilon_n} + \hat{\tau}_n(\mu, l)} \right) = \frac{\gamma}{2} \ln \left(1 + \frac{\tau_n(\mu, l) - \hat{\tau}_n(\mu, l)}{\tau_{\epsilon_n} + \hat{\tau}_n(\mu, l)} \right) > 0. \tag{25}$$

The value of the real-time ticker at date n is strictly positive because it is more informative than the "default option," that is, the truncated ticker ($\tau_n > \hat{\tau}_n$). Moreover, this value increases when the gap between the informativeness of the real-time ticker and the informativeness of the truncated ticker widens. Proposition 1 implies that this gap is reduced when the proportion of insiders increases or when latency is reduced. Thus, we obtain the following result.

Proposition 8 *For a fixed latency, the value of the real-time ticker at any date $n \geq 2$ decreases with the proportion of insiders. Moreover, for a fixed proportion of insiders, the value of the real-time ticker weakly increases with the latency in*

information dissemination, l. More precisely:

$$\overline{\phi}_n(\mu, l) \quad < \quad \overline{\phi}_n(\mu, l+1) \text{ for } n > l,$$

$$\overline{\phi}_n(\mu, l) \quad = \quad \overline{\phi}_n(\mu, l+1) \text{ for } n \leq l.$$

At date n, an investor buys ticker information if the price of the ticker is strictly less than the value of the ticker ($\phi_n < \overline{\phi}_n(\mu, l)$). She does not buy information if $\phi_n > \overline{\phi}_n(\mu, l)$. Finally, she is indifferent between buying ticker information or not if $\phi_n = \overline{\phi}_n(\mu, l)$. Consequently, as the value of the ticker declines with μ, for each price of the ticker, there is a unique equilibrium proportion of insiders $\mu^e(l, \phi_n)$, which is given by

$$\mu^e(l, \phi_n) = \begin{cases} 1 & \text{if } \phi_n \leq \overline{\phi}_n(1, l), \\ \mu & \text{if } \phi_n = \overline{\phi}_n(\mu, l), \\ 0 & \text{if } \phi_n \geq \overline{\phi}_n(0, l). \end{cases} \tag{26}$$

Figure 4 below shows how the equilibrium proportion of insiders is determined. As $\overline{\phi}_n(\mu, l)$ decreases with μ, the equilibrium proportion of insiders decreases with the price of ticker information (to see this, consider an upward shift in ϕ_{10} in Figure 4).

[Insert Figure 4 about here]

The not-for-profit exchange. We now study how market organizers set the price of ticker information. As a benchmark, we consider the case in which the market for price information is organized by a not-for profit exchange whose objective is to maximize investors' average welfare under a balanced budget constraint. This exchange can achieve its objective by setting a price:

$$\phi_n^* = \overline{\phi}_n(\mu_n^*, l), \tag{27}$$

for ticker information at date n. Indeed, at this price a fraction μ_n^* of investors, which is precisely the fraction that maximizes investors' average welfare, decides to buy price information. The balanced budget constraint is satisfied by redistributing the proceeds from information sale among investors (e.g., by paying a "dividend" to each investor).[19] The (per capita) proceeds from information sales in equilibrium are:

$$\Pi_n^{NFP} = \mu_n^* \phi_n^* = \mu_n^* \overline{\phi}_n(\mu_n^*, l) \tag{28}$$

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[19]The exchange can cover other costs by charging a fixed entry fee. This fee does not affect the decision to buy information or not. See the analysis for the for-profit exchange.

Thus, outsiders' net payoff after receiving their "dividend" from the exchange is:

$$C_n^O(\mu_n^*, l) + \mu_n^* \overline{\phi}_n(\mu_n^*, l) = C_n^I(\mu_n^*, l) - (1 - \mu_n^*)\overline{\phi}_n(\mu_n^*, l). \tag{29}$$

The right-hand side of the previous equation follows from the definition of $\overline{\phi}_n(\mu_n^*, l)$, and captures insiders' net payoff since each insider pays a fee $\overline{\phi}_n(\mu_n^*, l)$, and receives a dividend $\mu_n^* \overline{\phi}_n(\mu_n^*, l)$. Thus, the price set by the not-for profit exchange is "fair" since it equalizes insiders and outsiders' payoffs net of the transfers paid to or received from the exchange.

The for-profit exchange. We now study the case in which the market for price information is organized by a for-profit exchange.[20] The for-profit exchange charges two fees: a fee for distributing ticker information (ϕ_n), and an entry fee (E_n), which gives the right to trade. In this way, we account for the fact that exchanges derive revenues from market participation. We refer to (ϕ_n, E_n) as being the exchange's tariff. The for-profit exchange chooses its tariff to maximize its profit. Given this tariff, the proportion of insiders is $\mu^e(l, \phi_n)$ as explained previously.

As the exchange is a monopolist, it chooses its tariff to extract investors' surplus. Thus, the optimal tariff of the exchange is such that[21]

$$\begin{aligned}
\phi_n^* &= \overline{\phi}_n(\mu^e(l, \phi_n^*), l), \\
E_n^* &= C_n^O(\mu^e(l, \phi_n^*), l).
\end{aligned}$$

The entry fee is completely determined by the fee for ticker information since this fee determines the equilibrium proportion of insiders. Hence, the objective function of the for-profit exchange is

$$\max_{\phi_n^*} \; \mu^e(l, \phi_n^*)\overline{\phi}_n(\mu^e(l, \phi_n^*), l) + C_n^O(\mu^e(l, \phi_n^*), l), \tag{30}$$

As there is a one-to-one relationship between the equilibrium proportion of insiders and the fee charged for ticker information, the solution of this problem can be found by first solving

$$\max_{\mu} \; \mu \overline{\phi}_n(\mu, l) + C_n^O(\mu, l). \tag{31}$$

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[20] Major exchanges (e.g., NYSE-Euronext, Nasdaq, London Stock Exchange, Chicago Mercantile Exchange) are now for-profit. See Aggarwal and Dahiya (2006) for a survey of exchanges' governances around the world.

[21] In our setting, investors' payoffs do not depend on the proportion of investors entering the market. Thus, charging an entry fee larger than outsiders' payoffs cannot be optimal for the exchange. Indeed, this strategy cannot raise the total revenues obtained from insiders (since these are capped by insiders' payoff) and it results in a loss of revenues on outsiders (since they decide to stay put).

Indeed, if μ_n^{**} is the solution of this optimization problem then $\phi_n^* = \overline{\phi}_n(\mu_n^{**}, l)$ is the optimal price of the ticker at date n for the exchange.

The for-profit exchange faces the following trade-off. On the one hand, by increasing the proportion of insiders, it gets a larger revenue from information sale ($\mu \overline{\phi}_n(\mu, l)$). However, to achieve such an increase, the exchange must lower (i) the price for ticker information (since $\partial \overline{\phi}_n(\mu, l)/\partial \mu < 0$) and (ii) the entry fee since investors' gain from market participation decreases with the proportion of insiders ($\partial C_n^O(\mu, l)/\partial \mu < 0$). Using the definition of $\overline{\phi}_n(\mu, l)$, we can rewrite equation (31) as:

$$\max_{\mu} \; \mu C_n^I(\mu, l) + (1 - \mu)C_n^O(\mu, l) = W_n(\mu, l). \tag{32}$$

The following result is then immediate.

Proposition 9 *At any date $n \geq 2$ and for all values of the parameters, the for-profit exchange chooses its tariff so that the fraction of investors buying ticker information maximizes investors' average welfare (that is, $\mu_n^{**} = \mu_n^*$). Thus, rationing access to ticker information is optimal for a for-profit exchange.*

Proposition 9 establishes that a two-tier market structure can emerge as a result of the optimal pricing decisions of a for-profit exchange. Indeed, restricting access to price information is a way to maintain a high price for the ticker and to increase the value of market participation. Under our assumptions, it turns out that this two-tier market structure also maximizes welfare. The for-profit exchange, however, seizes all the gains from trade with its price structure. Thus, investors prefer the case in which the proceeds from information sale are redistributed.

[Insert Figure 5 about here]

Figure 5. illustrates Proposition 9 for specific parameter values (the same as those in Figure 3 and $n = 2$). For these parameters, the exchange's expected profit peaks at relatively low proportion of insiders ($\mu_2^{**} \simeq 11\%$).

Latency and the price of ticker information. Previous results are established for a fixed, arbitrary, level of latency. We now study the effect of a change in latency on the price of ticker information and the corresponding proportion of insiders. The next corollary first considers the effect of an increase in latency on the proportion of insiders for a fixed price of the ticker.

Corollary 1 *For a fixed price of the ticker at date n, ϕ_n, the equilibrium proportion of insiders at this date weakly increases with latency.*

When $n > l$, other things equal, an increase in latency shifts upwards the value of the ticker (Proposition 8). Therefore, for a fixed price of the ticker, this increases the proportion of investors buying information in equilibrium. Figure 4 illustrates this result. For the parameter values used in Figure 4, an increase in latency from $l = 2$ to $l = 4$ generates an increase in the proportion of insiders from $\mu^e \approx 12\%$ to $\mu^e \approx 65\%$.

The effect of latency on the proportion of insiders is more complex when we allow the exchange to react to an increase in latency by adjusting the price of the ticker. Indeed, as the value of the ticker increases, the exchange has an incentive to raise the price of the ticker. Thus, the net effect of a change in latency on the proportion of insiders is ambiguous when the exchange controls the price of the ticker. However, in numerical simulations, we always find that an increase in latency results in a smaller proportion of insiders, after accounting for the impact of latency on the fees charged by the exchange (we have not been able to obtain analytical results in this case).
Discussion. The main point of this section is that a high price for ticker information (larger than the cost of disseminating information) can be socially desirable. Indeed, it is a way to curb excessive acquisition of ticker information.

Another finding is that, under some conditions, a for-profit exchange sets the price for ticker information that maximizes social welfare. It is worth stressing that these conditions are unlikely to be satisfied in reality for several reasons.

First, we assume that the for-profit exchange can charge different fees for investors arriving at different dates. In practice, this form of price discrimination is not observed. Second, in reality, exchanges sell information to investors directly, as in our model, but also indirectly through data vendors (e.g., Bloomberg or Reuters).[22] Vertical relationships between exchanges and data vendors may introduce distortions in the pricing of ticker information. In particular, data vendors do not earn revenues from the sale of trading rights. Thus, they have no incentives to internalize, in their pricing decisions, the effect of the sale of ticker information on the value of trading rights. Last, a given security often trades in multiple markets. For such a security,

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[22] In U.S. equity markets, trades for a given stock can take place in various competing markets. But revenues from market data are collected by a unique agency. This agency redistributes market data revenues to the markets generating these revenues according to various rules. Caglio and Mayhew (2008) show empirically that the specification of these redistribution schemes affects exchanges' pricing policies and investors' trading strategies.

transaction prices for trades taking place in different markets are close substitutes.[23] In this context, the decisions of competing markets regarding the dissemination of their data are interdependent. Unbridled competition between markets for the same security could result in a low price for ticker information, leading to excessive dissemination of ticker information from a welfare standpoint. For instance, Chi-X is a trading platform on which investors can trade European blue chips listed on Euronext and the London Stock Exchange. Chi-X has chosen to disseminate for free information on trades and quotes in its system to attract order flow from its competitors. In contrast, Euronext and the London Stock Exchange charge a fee for this information.

6   Conclusions

In this article, we study the effect of disseminating information on past transaction prices in a multi-period rational expectations model. Our model features risk averse investors who arrive sequentially in the market. Investors 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 (latency). We endogenize the proportion of insiders by introducing a market for information. Our main findings are as follows.

1. There is a conflict between the private value of ticker information and its social value. Insiders have a higher expected utility as they have a more precise forecast of the asset payoff. However, acquisition of ticker information by one investor exerts a negative externality on other investors because it reduces both the speculative and hedging gains from market participation. Thus, excessive transparency can be welfare reducing.

2. A market for price information is a mechanism to implement the socially optimal level of transparency. A high fee for ticker information (larger than the information distribution cost) in this market should not necessarily be construed as a symptom of market inefficiency. In fact, the socially optimal fee is high to curb excessive acquisition of ticker information.

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[23]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 the contribution of regional exchanges.

3. The effects of the dissemination of ticker information on allocative and informational efficiency are distinct. Indeed, an increase in the proportion of insiders or a reduction in latency reduces pricing errors and thereby improves price discovery. Thus, in the model, informational efficiency is maximal when all investors observe the ticker in real-time. This situation, however, does not maximize investors' welfare.

The model suggests several directions for future research. For instance, we have shown that the new information available at a given point in time percolates through subsequent prices before it becomes known to all investors. It would be interesting to study more closely this process and its implication for the dynamics of returns (e.g., their serial correlation). Moreover, the analysis shows that the information provided on past trades can affect the level of prices. A more detailed analysis of this result could relate the cost of capital to the scope of information dissemination on past trades. Last, as mentioned in the previous section, it would be interesting to study how competition among exchanges or relationships between data vendors and exchanges affect the pricing of ticker information.

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Appendix

Proof of Lemma 1

Step 1. Informational content of equilibrium prices.

In a symmetric linear equilibrium, investors' order placement strategies in period $n \geq 1$ can be written as follows:

$$x_n^I(s_{in}, e_{in}, p^n) = a_n^I s_{in} - \varphi_n^I(p^n), \tag{33}$$

$$x_n^O(s_{in}, e_{in}, p^{n-2}, p_n) = a_n^O s_{in} - \varphi_n^O(p^{n-l^*}, p_n), \tag{34}$$

where $\varphi_n^k(.)$ is a linear function of the clearing price at date n and the past prices observed by an investor with type $k \in \{I, O\}$ ($\varphi_1^I(.) = \varphi_1^O(.)$ since price information is identical for insiders and outsiders at date 1). In any period n, the clearing condition is

$$\int_0^\mu x_{in}^I di + \int_\mu^1 x_{in}^O di = e_n.$$

Thus, using equations (33) and (34), we deduce that at date n

$$a_n v - \varphi_n^I(p^n) - \varphi_n^O(p^{n-l^*}, p_n) = e_n, \quad \forall n \geq 2, \tag{35}$$

with $a_n \stackrel{def}{=} \mu a_n^I + (1 - \mu)a_n^O$. We deduce that p^n is observationally equivalent to $z^n = \{z_1, z_2, \ldots, z_n\}$ with $z_n = a_n v - e_n$.

Step 2. Equilibrium in period n.

Insiders. An insider's demand function in period n, $x_n^I(s_{in}, e_{in}, p^n)$, maximizes

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

We deduce that

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

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

$$E[v|s_{in}, e_{in}, p^n] = E[v|s_{in}, e_{in}, z^n] = (\tau_n(\mu, l) + \tau_{\epsilon_n})^{-1}(\tau_n E[v|z^n] + \tau_{\epsilon_n} s_{in}),$$

$$\text{Var}[v|s_{in}, e_{in}, p^n] = \text{Var}[v|s_{in}, e_{in}, z^n] = (\tau_n(\mu, l) + \tau_{\epsilon_n})^{-1},$$

where

$$\tau_n(\mu, l) \stackrel{def}{=} (\text{Var}[v|p^n])^{-1} = (\text{Var}[v|z^n])^{-1} = \tau_v + \tau_e \sum_{t=1}^n a_t^2. \tag{36}$$

Thus,

$$
\begin{aligned}
x_n^I(s_{in}, e_{in}, p^n) &= \gamma(\tau_n + \tau_{\epsilon_n})(E[v|s_{in}, e_{in}, p^n] - p_n) \\
&= a_n^I(s_{in} - p_n) + \gamma\tau_n(E[v|p^n] - p_n),
\end{aligned} \tag{37}
$$

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

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

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

We deduce that

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

In equilibrium, outsiders correctly anticipate that the clearing price at each date is given by

$$
p_n = A_n v - \sum_{j=0}^{l^*-1} B_{n,j} e_{n-j} + D_n E[v \mid p^{n-l^*}], \text{ for } n \geq 1. \tag{38}
$$

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-l^*}. Using equation (38), we obtain that

$$
\begin{aligned}
\hat{z}_n &= \frac{p_n - D_n E[v \mid p^{n-l^*}]}{A_n} \\
&= v - \sum_{j=0}^{l^*-1} \frac{B_{n,j}}{A_n} e_{n-j} \tag{39} \\
&= \sum_{j=0}^{l^*-1} \alpha_j z_{n-j}, \tag{40}
\end{aligned}
$$

with

$$
\alpha_0 = (1 + \mu\gamma\tau_e)(a_n(1 + \mu\gamma\tau_e) + \mu\gamma\tau_e(\sum_{j=1}^{l^*-1} a_{n-j}))^{-1},
$$

and

$$
\alpha_j = (\mu\gamma\tau_e)(a_n(1 + \mu\gamma\tau_e) + \mu\gamma\tau_e(\sum_{j=1}^{l^*-1} a_{n-j}))^{-1}.
$$

Thus, $\{s_{in}, p^{n-l^*}, p_n\}$ is observationally equivalent to $\{s_{in}, p^{n-l^*}, \hat{z}_n\}$. Moreover, equation (39) implies

$$
\hat{z}_n|v \sim N\left(v, A_n^{-2}\left(\sum_{j=0}^{l^*-1} B_{n,j}^2\right)\tau_e^{-1}\right).
$$

Let $\Gamma \stackrel{def}{=} A_n^2 (\sum_{j=0}^{l^*-1} B_{n,j}^2)^{-1}$. Using well known properties of normal random variables, we obtain

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

where

$$
\hat{\tau}_n(\mu, l) \stackrel{def}{=} (\mathrm{Var}[v|p^{n-l^*}, p_n])^{-1} = (\mathrm{Var}[v|z^{n-l^*}, \hat{z}_n])^{-1} = \tau_{n-l^*}(\mu, l) + \Gamma\tau_e. \qquad (41)
$$

In the rest of the proofs, we sometimes omit arguments μ and l in $\hat{\tau}_n(\mu, l)$ and $\tau_n(\mu, l)$ for brevity. Thus,

$$
\begin{aligned}
x_n^O(s_{in}, e_{in}, p^{n-l^*}, p_n) &= \gamma(\hat{\tau}_n + \tau_{\epsilon_n})(E[v|s_{in}, p^{n-l^*}, p_n] - p_n) \\
&= a_n^O(s_{in} - p_n) + \gamma\hat{\tau}_n(E[v|p^{n-l^*}, p_n] - p_n). \qquad (42)
\end{aligned}
$$

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

Clearing price in period n. The clearing condition in period n imposes

$$
\int_0^\mu x_{in}^I di + \int_\mu^1 x_{in}^O di = e_n.
$$

Using equations (37) and (42), we solve for the equilibrium price and we obtain

$$
p_n = \frac{1}{K_n}\left(z_n + \mu\gamma\tau_n E[v|p^n] + (1-\mu)\gamma\hat{\tau}_n E[v|p^{n-l^*}, p_n]\right), \qquad (43)
$$

where

$$
K_n = a_n + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n), \qquad (44)
$$

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

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

Substituting $E[v|p^{n-l^*}, p_n]$ and $E[v|p^n]$ by these expressions in equation (43), we can express p_n as a function of v, $\{e_{n-j}\}_{j=0}^{l^*-1}$, and $E[v|p^{n-l^*}]$. In equilibrium, the coefficients on these variables must be identical to those in equation (38). This condition

imposes

$$A_n = \frac{\left(a_n + \mu\gamma\tau_e \sum_{t=n-(l^*-1)}^{n} a_t^2\right) + (1-\mu)\gamma\Gamma\tau_e}{K_n}, \tag{45}$$

$$B_{n,0} = \frac{1 + \mu\gamma a_n \tau_e + (1-\mu)\gamma\tau_e\Gamma B_{n,0}A_n^{-1}}{K_n}, \tag{46}$$

$$B_{n,j} = \frac{\mu\gamma a_{n-j}\tau_e + (1-\mu)\gamma\tau_e\Gamma B_{n,j}A_n^{-1}}{K_n}, \quad \forall j \in \{1, \ldots, l^* - 1\}, \tag{47}$$

$$D_n = \frac{\gamma\tau_{n-l^*}}{K_n}. \tag{48}$$

Equations (45), (46), (47) form a system with $l^* + 1$ unknowns: A_n and $\{B_{n,j}\}_{j=0}^{j=l^*-1}$. Solving this system of equations, we obtain

$$A_n = \frac{a_n + \mu\gamma(\tau_n - \tau_{n-l^*})}{K_n}\left(1 + \frac{(1-\mu)\gamma\tau_e(a_n + \mu\gamma(\tau_n - \tau_{n-l^*}))}{(1 + \mu\gamma a_n\tau_e)^2 + \sum_{j=1}^{l^*-1}(\mu\gamma a_{n-j}\tau_e)^2}\right), \tag{49}$$

$$B_{n,0} = \frac{A_n(1 + \mu\gamma a_n\tau_e)}{a_n + \mu\gamma(\tau_n - \tau_{n-l^*})}, \tag{50}$$

$$B_{n,j} = \frac{A_n(\mu\gamma a_{n-j}\tau_e)}{a_n + \mu\gamma(\tau_n - \tau_{n-l^*})}, \quad \text{for } 1 \leq j \leq l^* - 1, \tag{51}$$

$$D_n = \frac{\gamma\tau_{n-l^*}}{K_n}. \tag{52}$$

We deduce from these expressions and equation (41) that

$$\hat{\tau}_n(\mu, l) = \tau_{n-l^*} + \frac{(a_n + \mu\gamma(\tau_n - \tau_{n-l^*}))^2}{(1 + \mu\gamma a_n\tau_e)^2 + \sum_{j=1}^{l^*-1}(\mu\gamma a_{n-j}\tau_e)^2}\tau_e. \tag{53}$$

This achieves the characterization of the equilibrium in each period in closed-form. QED

Proof of Proposition 1

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

$$\tau_n(\mu, l) = \tau_v + \tau_e \sum_{t=1}^{n} a_t^2.$$

where $a_t = \gamma\tau_{\epsilon_t}$ (see equation (36)). As a_t does not depend on μ and l, it is immediate that τ_n does not depend on these parameters.

Part 2. From equation (53) in the proof of Lemma 1, we deduce that

$$\hat{\tau}_n(\mu, l) = \tau_{n-l^*} + \tau_n^m(\mu, l), \tag{54}$$

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with

$$\tau_n^m(\mu, l) \stackrel{def}{=} \frac{(a_n + \mu\gamma(\tau_n - \tau_{n-l^*}))^2}{(1 + \mu\gamma a_n \tau_e)^2 + \sum_{j=1}^{l^*-1}(\mu\gamma a_{n-j}\tau_e)^2}\tau_e. \tag{55}$$

As

$$\frac{\partial \tau_n^m(\mu, l)}{\partial \mu} = \frac{2\gamma\tau_e(\tau_{n-1} - \tau_{n-l^*})(a_n(1 + \gamma\mu\tau_e a_n) + \mu\gamma(\tau_{n-1} - \tau_{n-l^*}))}{((1 + \gamma\mu\tau_e a_n)^2 + (\mu\gamma)^2\tau_e(\tau_{n-1} - \tau_{n-l^*}))^2} > 0,$$

we deduce that $\hat{\tau}_n(\mu, l)$ increases with μ.

We now show that $\hat{\tau}_n(\mu, l)$ decreases in l. Using equation (53), we have that $\hat{\tau}_n(\mu, l) = \hat{\tau}_n(\mu, l + 1)$, for $n \leq l$. For $n > l$, we deduce from equation (53) that

$$\begin{aligned} \hat{\tau}_n(\mu, l) - \hat{\tau}_n(\mu, l + 1) &= \left(a_{n-l}^2 + \frac{G_n^2(\mu, l)}{Q_n(\mu, l)} - \frac{G_n^2(\mu, l + 1)}{Q_n(\mu, l + 1)}\right)\tau_e \tag{56} \\ &= \left(\frac{a_{n-l}^2(1 + \mu\gamma\tau_e a_n)^2}{Q_n(\mu, l)Q_n(\mu, l + 1)}\right)\tau_e, \end{aligned}$$

where $Q_n(\mu, l) \stackrel{def}{=} (1+\mu\gamma\tau_e)^2+\sum_{j=1}^{l-1}(\mu\gamma a_{n-j}\tau_e)^2$ and $G_n(\mu, l) \stackrel{def}{=} a_n+\sum_{j=0}^{l-1}(\mu\gamma\tau_e)a_{n-j}^2$. We therefore have that $\hat{\tau}_n(\mu, l) > \hat{\tau}_n(\mu, l + 1)$ for $n > l$.

Last, $\hat{\tau}_n(\mu, l)$ can be written as follows

$$\hat{\tau}_n(\mu, l) = \tau_{n-l^*} + \tau_e \left(\frac{(\sum_{j=0}^{l^*-1}\rho_{n-j}a_{n-j})^2}{\sum_{j=0}^{l^*-1}\rho_{n-j}^2}\right),$$

with $\rho_n = (1 + \mu\gamma a_n\tau_e)$ and $\rho_{n-j} = (\mu\gamma a_{n-j}\tau_e)$ for $j \geq 1$. It is then direct to show that $\hat{\tau}_n < \tau_n$ since $a_{n-j} > 0$.   QED

Proof of Proposition 2

As v and p_n are normally distributed for all n, we have

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

Using the expression of the clearing price given in Lemma 1, we obtain

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

Now, equations (45), (48) and the definition of K_n in the proof of Lemma 1 yields

$$\begin{aligned} A_n &= \frac{(a_n + \mu\gamma\tau_e \sum_{t=n-(l^*-1)}^{n} a_t^2) + (1 - \mu)\gamma(\hat{\tau}_n - \tau_{n-l^*})}{K_n} \\ &= \frac{K_n - K_n D_n}{K_n} \\ &= 1 - D_n. \end{aligned}$$

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Thus, $A_n + D_n = 1$. We deduce that

$$E\left[v - p_n \mid p^{n-l^*}\right] = 0, \tag{57}$$

which yields

$$
\begin{aligned}
\text{Var}[v - p_n] &= \text{Var}\left[v - p_n \mid p^{n-l^*}\right] \\
&= (1 - A_n)^2 \tau_{n-l^*}^{-1} + \left(\sum_{j=0}^{l^*-1} B_{n,j}^2\right) \tau_e^{-1} \\
&= (1 - A_n)^2 \tau_{n-l^*}^{-1} + A_n^2 (\hat{\tau}_n - \tau_{n-l^*})^{-1}, \tag{58}
\end{aligned}
$$

where the last equation follows from equation (41) in the proof of Lemma 1. We can now differentiate the R.H.S of equation (58) with respect to μ to show that $\text{Var}[v - p_n]$ decreases with μ. We omit details of the calculations for brevity. They can be obtained upon request. QED

Proof of Proposition 3

Using the expressions for A_n and $B_{n,0}$ in the proof of Lemma 1, we obtain that

$$
B_{n,0}(l) = \begin{cases}
\frac{(1+\mu\gamma a_n \tau_e)}{a_n + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n)} \left(1 + \frac{(1-\mu)\gamma\tau_e(a_n + \mu\gamma(\tau_n - \tau_v))}{(1+\mu\gamma a_n \tau_e)^2 + \sum_{j=1}^{n-1}(\mu\gamma a_{n-j}\tau_e)^2}\right), & \text{for } n \leq l, \\[4mm]
\frac{(1+\mu\gamma a_n \tau_e)}{a_n + \gamma(\mu\tau_n + (1-\mu)\hat{\tau}_n)} \left(1 + \frac{(1-\mu)\gamma\tau_e(a_n + \mu\gamma(\tau_n - \tau_{n-l}))}{(1+\mu\gamma a_n \tau_e)^2 + \sum_{j=1}^{l-1}(\mu\gamma a_{n-j}\tau_e)^2}\right), & \text{for } n > l.
\end{cases}
$$

For $n \leq l$, $\hat{\tau}_n$ does not depend on l (see equation (54)). Thus, $B_{n,0}(l) = B_{n,0}(l+1)$. For $n > l$, we have

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

where $G_n(\mu, l)$ and $Q_n(\mu, l)$ are defined in the proof of Proposition 1. Calculations show that

$$\frac{G_n(\mu, l)}{Q_n(\mu, l)} > \frac{G_n(\mu, l+1)}{Q_n(\mu, l+1)}.$$

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

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

Proposition 3 follows from equation (19). QED

Proof of Proposition 4

Immediate from the arguments in the text. QED

Proof of Proposition 5

We prove that $C_n^I(1,l) < C_n^O(0,l)$. To this end, we define $S_n^k(\mu,l)$ and $H_n(\mu,l)$ such that:

$$S_n^k(\mu,l) = \ln\left(\frac{\text{Var}[v-p_n]}{\text{Var}[v|s_{in},p^n]}\right), \tag{59}$$

$$H_n(\mu,l) = \ln\left(\frac{\tau_e - \gamma^{-2}\text{Var}[v\mid v-p_n]}{\tau_e}\right). \tag{60}$$

That is, $S_n^k(\mu,l)$ and $H_n(\mu,l)$ are respectively the *speculative component* and the *hedging component* of the payoff for an investor with type k. Clearly if *(i)* $S_n^I(1,l) < S_n^O(0,l)$ and *(ii)* $H_n(1,l) < H_n(0,l)$ then $C_n^I(1,l) < C_n^O(0,l)$. We prove that these two conditions hold true.

First, consider $S_n^I(\mu,l)$. Using equation (58) in the proof of Proposition 2 and the expressions for the coefficients A_n and $B_{n,j}$ in the proof of Lemma 1, we obtain after some algebra

$$S_n^I(1,l) = \ln\left(\frac{\gamma^2\tau_{n-l^*} + \tau_e^{-1}((1+\gamma a_n\tau_e)^2 + \sum_{j=1}^{l^*-1}(\gamma a_{n-j}\tau_e)^2)}{\gamma^2(\tau_{\epsilon_n} + \tau_n(1,l))^{3/2}}\right),$$

$$S_n^O(0,l) = \ln\left(\frac{\gamma^2\tau_{n-l^*} + \tau_e^{-1}(1+\gamma a_n\tau_e)^2}{\gamma^2(\tau_{\epsilon_n} + \widehat{\tau}_n(0,l))^{3/2}}\right).$$

Observe that $S_n^I(1,l) = S_n^O(0,l)$ iff $\tau_{\epsilon_{n-j}} = 0$, $\forall j \in \{1,\ldots,l^*-1\}$ since in this case $a_{n-j} = 0$, $\forall j \in \{1,\ldots,l^*-1\}$ and $\tau_n(1,l) = \widehat{\tau}_n(0,l)$. Now, it is easily checked that $S_n^I(1,l)$ decreases in a_{n-j}, for $j \in \{1,\ldots,l^*-1\}$. This implies that it decreases with $\tau_{\epsilon_{n-j}}$ since $a_{n-j} = \gamma\tau_{\epsilon_{n-j}}$. Moreover, $S_n^I(0,l)$ does not depend on a_{n-j}, $\forall j \in \{1,\ldots,l^*-1\}$. As $\tau_{\epsilon_{n-j}} > 0$, we deduce that $S_n^I(1,l) < S_n^O(0,l)$.

Now, consider $H_n(\mu,l)$. As v and $v-p_n$ are normally distributed:

$$\text{Var}[v\mid v-p_n] = \text{Var}[v] - \frac{\text{Cov}^2[v,v-p_n]}{\text{Var}[v-p_n]}. \tag{61}$$

Moreover, we have

$$\text{Cov}[v,v-p_n] = E\left[\text{Cov}[v,v-p_n\mid\Omega_{n-l^*}]\right] + \text{Cov}\left[E\left[v\mid\Omega_{n-l^*}\right], E\left[v-p_n\mid\Omega_{n-l^*}\right]\right], \tag{62}$$

where $\Omega_{n-l^*} = p^{n-l^*}$. We have $E[v - p_n \mid \Omega_{n-l^*}] = 0$ (see equation (2) in the proof of Proposition 2). Thus, using the expression for the equilibrium price:

$$\text{Cov}[v, v - p_n] = \text{Cov}[v, v - p_n \mid \Omega_{n-l^*}] = D_n \tau_{n-l^*}^{-1}.$$

Hence, using (61) and the expression for D_n, we deduce that

$$\text{Var}[v \mid v - p_n] = \tau_v^{-1} - \frac{\gamma^2}{K_n^2 \text{Var}[v - p_n]}. \tag{63}$$

Using the definition of K_n and equation (58) in the proof of Proposition 2, we obtain that

$$K_n^2 \text{Var}[v - p_n] = \begin{cases} \gamma^2 \tau_{n-l^*} + \tau_e^{-1}(1 + \gamma a_n \tau_e)^2, & \text{if } \mu = 0, \\ \gamma^2 \tau_{n-l^*} + \tau_e^{-1}((1 + \gamma a_n \tau_e)^2 + \sum_{j=1}^{j=l^*-1}(\gamma a_{n-j} \tau_e)^2), & \text{if } \mu = 1. \end{cases}$$

It is then immediate, using equations (60) and (63) that $H_n(1, l) < H_n(0, l)$.

QED

Proof of Proposition 6

Observe that:

$$\begin{aligned} C_n^k(\mu, l) &= \frac{\gamma}{2} \left[\ln \left(\left(\frac{\text{Var}[v - p_n]}{\text{Var}[v \mid \Omega_n^k]} \right) \left(\frac{\gamma^2 \tau_e - \text{Var}[v \mid v - p_n]}{\gamma^2 \tau_e - \text{Var}[v]} \right) \right) \right] \\ &= \frac{\gamma}{2} \left[\ln \left(\left(\frac{\text{Var}[v - p_n]}{\text{Var}[v \mid \Omega_n^k]} \right) \left(1 + \left(\frac{1}{\gamma^2 \tau_e - \text{Var}[v]} \right) \left(\frac{\gamma^2}{K_n^2 \text{Var}[v - p_n]} \right) \right) \right) \right] \end{aligned}$$

where the second equality follows from equation (63) in the proof of Proposition 5. Thus,

$$C_n^k(\mu, l) = \frac{\gamma}{2} \left[\ln \left(\frac{\text{Var}[v - p_n]}{\text{Var}[v \mid \Omega_n^k]} + \left(\frac{1}{\gamma^2 \tau_e - \text{Var}[v]} \right) \left(\frac{\gamma^2}{K_n^2 \text{Var}[v \mid \Omega_n^k]} \right) \right) \right] \tag{64}$$

Consider insiders first $(C_n^I(\mu, l))$. For insiders, $\text{Var}[v \mid \Omega_n^I]$ does not depend on μ since τ_n does not depend on μ. Using equation (44) in the proof of Lemma 1, it is immediate that K_n increases with μ. Next, we know from Proposition 2 that $\text{Var}[v - p_n]$ decreases with μ. We deduce from these observations and equation (64) that

$$\frac{\partial C_n^I(\mu, l)}{\partial \mu} > 0.$$

For outsiders, the argument is more complex because $\text{Var}[v \mid \Omega_n^O]$ decrease with μ (the precision of outsiders' forecasts improves when the proportion of insiders enlarges). However, calculations show that

$$\frac{\partial C_n^O(\mu, l)}{\partial \mu} > 0.$$

We omit these calculations for brevity. They can be obtained upon request.   QED

Proof of Proposition 8

Immediate from the arguments in the text.   QED

Proof of Proposition 9

Immediate from the arguments in the text.   QED

Proof of Corollary 1

Immediate from the arguments in the text.   QED

Figure 1: The timeline

$t = n-1$	$t = n$	$t = n+1$	$t = n+2$

$\vdots$

Date n speculators arrive with signals s_{in} and endowments e_{in}

- Insiders observe $\{p_1, p_2, \ldots, p_{n-1}\}$

- Outsiders observe $\{p_1, p_2, \ldots, p_{n-l^*}\}$

- Speculators submit orders contingent on their information and on p_n: x_{in}^I, x_{in}^O

- Clearing price p_n is realized.

Date $n+1$ speculators arrive with signals s_{in+1} and endowments e_{in+1}

- Insiders observe $\{p_1, p_2, \ldots, p_n\}$

- Outsiders observe $\{p_1, p_2, \ldots, p_{n+1-l^*}\}$

- Speculators submit orders contingent on their information and on p_{n+1}: x_{in+1}^I, x_{in+1}^O
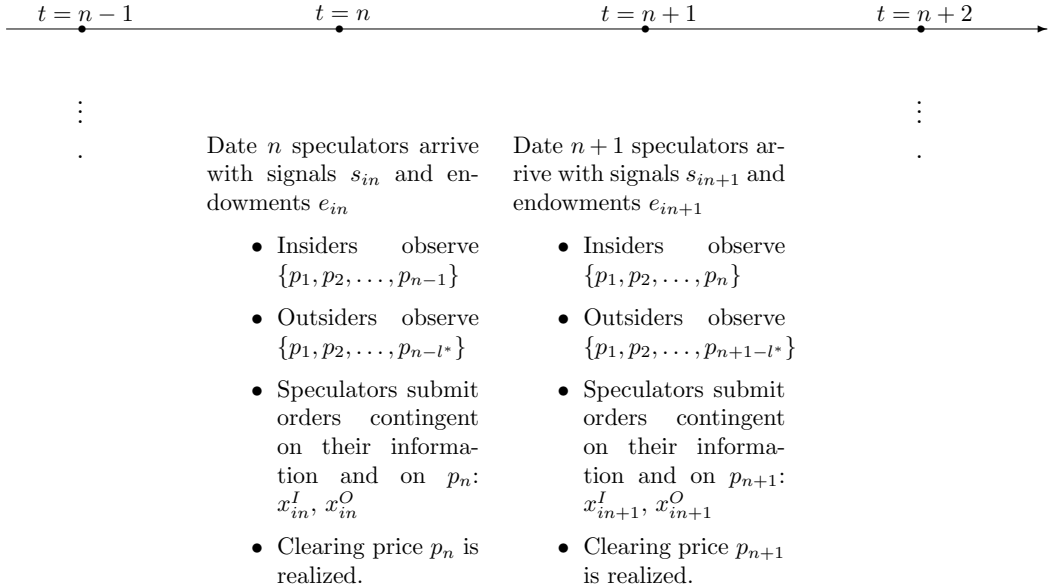
- Clearing price p_{n+1} is realized.

$\vdots$

Figure 2: Variance of the pricing error $\mathrm{Var}[v - p_n]$ as a function of latency. Parameter values: $\tau_v = 2$, $\tau_e = 1$, $\tau_{\epsilon_n} = 1$, for $n = 1, 2, \ldots, N$, $\gamma = 1$, $\mu = 0.01$, $N = 50$, and $l \in \{10, 20, 30, 40, 50\}$.
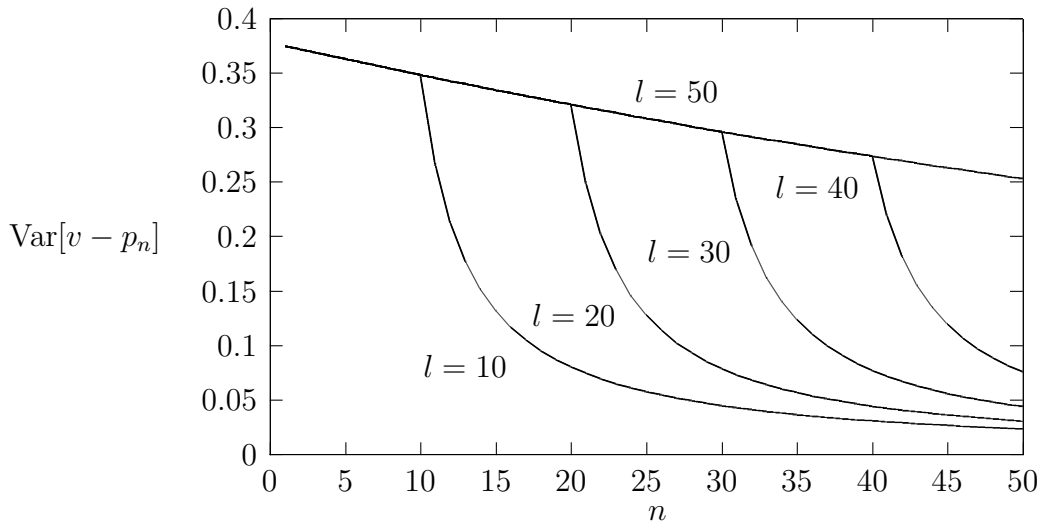
Figure 3: Speculators' welfare is higher in a fully opaque market ($\mu = 0$) compared to a fully transparent one ($\mu = 1$): $C_2^O(0,2) > C_2^I(1,2)$. Parameters' values: $\tau_v = 2$, $\tau_e = 1$, $\tau_{\epsilon_1} = \tau_{\epsilon_2} = 1$, $\gamma = 1$, and $n = 2$.
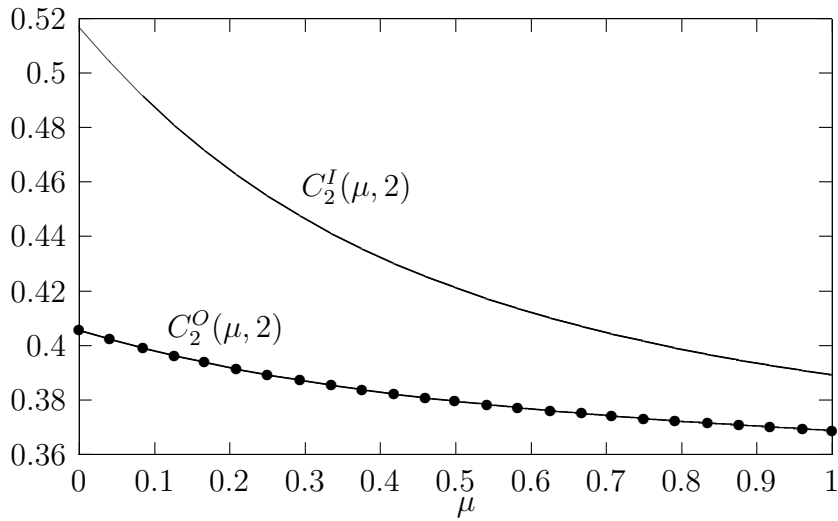
Figure 4: Value of the ticker for two levels of latency when $n > l$. Parameters' values: $\tau_v = 2$, $\tau_e = 1$, $\gamma = 1$, $l \in \{2, 4\}$, and $\tau_{\epsilon_n} = 1$ for $n = 1, 2, \ldots, 50$.
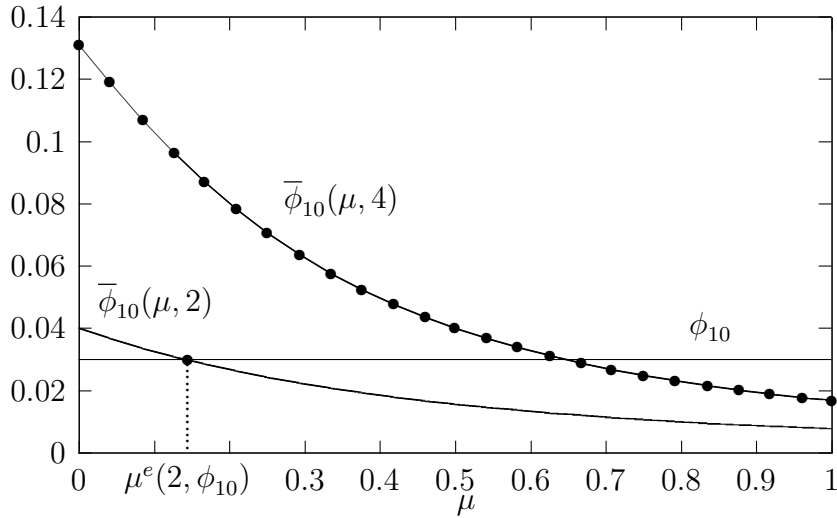
Figure 5: Profit from ticker sale and entry fee: The Exchange optimally segments the market ($\mu^* \approx 0.11$). Parameters' values: $\tau_v = 2$, $\tau_e = 1$, $\tau_{\epsilon_1} = \tau_{\epsilon_2} = 1$, $\gamma = 1$, and $n = 2$.

$\Pi_2(\mu, 2)$