Information Leakage and Market Efficiency

Markus K. Brunnermeier
Princeton University

This article analyzes the effects of information leakage on trading behavior and market efficiency. A trader who receives a noisy signal about a forthcoming public announcement can exploit it twice. First, when he receives it, and second, after the public announcement since he knows best the extent to which his information is already reflected in the pre-announcement price. Given his information he expects the price to overshoot and intends to partially revert his trade. While information leakage makes the price process more informative in the short-run, it reduces its informativeness in the long-run. The analysis supports Securities and Exchange Commission's Regulation Fair Disclosure.

In a perfect world, all investors would receive information pertinent to the value of the stock immediately and simultaneously. In reality, however, some agents like corporate insiders and their favored analysts can receive signals about this information before it is disclosed to the general public. The focus of our analysis is to determine (i) the optimal trading strategy of an early-informed agent and (ii) the implications of this trading behavior for the informational efficiency of the stock market. This knowledge can facilitate the design and evaluation of trading regulations by the Securities and Exchange Commission (SEC).

Our model generates several novel insights on insider trading by enriching the information structure typically employed in the prior literature. In our analysis, a trader receives an early imprecise signal about a forthcoming news announcement — possibly in the form of a rumor. The new element is that the stock price reflects unrelated *long-run* private information held by other traders as well as the early-informed trader's *short-run* signal. Given this generalized information structure, we find that the early-informed agent's trading strategy exhibits three features: (1) he trades based on his private information twice, once before the public

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An earlier version of this article was circulated under the title "Buy on Rumors — Sell on News." I benefited from suggestions from Maureen O'Hara and an anonymous referee. I am also grateful for helpful discussions with Sudipto Bhattacharya, Margaret Bray, Smita Brunnermeier, Thomas de Garidel, Clemens Grafe, Dominik Hotz, 'Pete' Kyle, John Moore, Marcelo Pinheiro, Rohit Rahi, Ailsa Roell, Dimitri Vayanos and Wei Xiong. Seminar participants at Boston University, Duke, ECARE Brussels, Harvard University, London School of Economics, McGill, NYU, Pompeu Fabra, Princeton University, Tel-Aviv University, University College London, UCLA, and UNC as well as participants of the CEPR Summer Symposium in Gerzensee provided further useful comments. I acknowledge financial support from the National Science Foundation (SES-0214445). Responsibility for errors and omissions of course rests with me. Address correspondence to: Princeton University, Department of Economics, Bendheim Center for Finance, 26 Prospect Avenue, Princeton, NJ 08540-5296, Tel. (609) 258 4050, or e-mail: markus@princeton.edu, http://www.princeton.edu/~markus.

The Review of Financial Studies Vol. 18, No. 2
doi:10.1093/rfs/hhi015 Advance Access publication February 10, 2005

announcement and a second time after it; (2) he builds up a position which he intends to unwind partially after the public announcement because he predicts that the market will overreact to the news; and (3) his trading prior to the announcement makes it more difficult for other market participants to learn from past price movements. The analysis also shows that this trading behavior reduces the long-run informativeness of prices, and hence, provides an argument in favor of Regulation Fair Disclosure (FD). Regulation FD prohibits companies from revealing information early to certain analysts or traders before they are made public.

Not only is this trading behavior interesting from a theoretical viewpoint, it also matches with events documented in the press. For example, the *New York Times* had the following to say about the price movement of BJ Services, an oil and gas company, prior to a negative public earnings announcement in August 1993:

> Sell on the rumor, buy on the news.[1] That's Wall Street's advice for individual investors. But the pros have a different refrain: sell when company officials tell you the news, buy when they tell everyone else. . . .

The article notes that the company disclosed some information to selected analysts prior to the official announcement of weak earnings. These analysts and their clients sold aggressively and the stock price tumbled. After the actual earnings announcement, these analysts bought back shares, thereby stabilizing the stock price.

The intuition behind the early-informed agent's trading strategy is as follows. Traders employ technical analysis after the public announcement to determine the extent to which the news is already "priced in." As in Treynor and Ferguson (1985), they try to learn this information from past price movements. In contrast to the prior literature on technical analysis, such as Brown and Jennings (1989) and Grundy and McNichols (1989), in our model the public announcement does not affect all traders symmetrically. The early-informed trader's technical analysis is more informative than the other traders' analyses since he knows the exact extent to which he has moved the past price. This provides him an additional informational advantage even after the public announcement. This is in spite of the fact that the public announcement is more precise than his original private signal. Paradoxically, it is the imprecision of the early-informed trader's signal that induces the uninformed market participants to make an error in their technical analyses, thereby giving him an informational advantage even after the public announcement. A similar result can also

[1] Note that the saying becomes "buy on rumors — sell on news" if one refers to a positive rumor (news).

be obtained in a setup in which the precision of the information leakage or even whether occurred or not is not commonly known. Blume, Easley, and O'Hara (1994) analyze a setting where the precision of traders' signals is unknown and demonstrate that traders can also infer valuable information from past volume data.[2]

In addition to showing that an analyst with short-run information can exploit his information twice, we demonstrate that he expects to partially reverse his trade after the public announcement. That is, after receiving a positive (negative) imprecise signal, the early-informed trader buys (sells) stocks that he expects to sell (buy) at the time of the public announcement. In other words, he follows the well-known trading strategy: "Buy on rumors — sell on news." This trade reversal relies on the fact that, given his information, he expects that the market will overreact to the news announcement. Hirshleifer, Subrahmanyam, and Titman (1994) also generate *trade reversals* wherein risk-averse insiders unwind part of their risky position as soon as their private information is revealed to a larger group of traders. In their model a trade reversal occurs because of traders' risk aversion, while in our setting all traders are risk-neutral.

In Kyle (1985) the insider holds back his order size to avoid revealing too much of his information to the market maker. This incentive of the early-informed trader is reduced in our setting since more aggressive trading causes his signal's imprecision to have a larger impact on the current price. This, in turn, makes it harder for other market participants to infer relevant information from past prices after the public announcement. Put more bluntly, by trading more aggressively, he "throws sand in the eyes" of the others. This is costly in the short-run, but it boosts his future and overall expected capital gains.[3] Numerical simulations reveal that even though the short-term-information trader expects to unwind a sizable fraction of his trade after the public announcement, he makes most of his profit prior to the news announcement. Hence, he trades only slightly more aggressively than a myopic trader would do.

This article also examines the effect of early selective disclosure on market efficiency. The empirical literature in finance distinguishes between the weak, semi-strong, and strong form of market efficiency depending on whether agents can make excess profits from the knowledge of past prices, public information, and private information, respectively. While in our model prices are weak-form efficient, in the sense that

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[2] While in our model traders do not infer information from trading volume, the analysis would not change if they could observe past net order flow in addition to past prices.

[3] In this respect, our model is related to the signaling jamming models in the industrial organization literature [Fudenberg and Tirole (1986)]. Similarly, Huddart, Hughes, and Levine (2001) show that an insider whose order size is made public applies a mixed strategy in order to make it more difficult for the market maker to infer *his* information. In contrast, in our model mixed strategies can be ruled out and aggressive trading makes it more difficult for other traders to learn *somebody else's* information from the past price movements. Section 4.2 further contrasts both models.

knowledge of past prices *alone* does not provide additional value, knowledge of (endogenous) past prices combined with (possibly "outdated") private information does. In this sense, it is profitable to conduct technical analysis. Unlike past prices, all other public information is exogenous in our model. Due to the presence of a risk-neutral market maker, prices follow a martingale process conditional on public information and are semi-strong efficient. However, from the viewpoint of a short-run-information trader, the price on average overshoots at the time of the news announcement. Markets are not strong-form efficient in our model. To measure the degree of information revelation by prices, we propose two concepts: "informational efficiency" and "informativeness." While the former refers to the informational content of the price relative to the pooled information in the economy, the latter measures how informative the price process is in absolute terms. This makes it the more relevant measure for regulatory purposes. Our analysis shows that an information leak makes the price process less informationally efficient both before and after the general public announcement. We also find that there is a short-term gain in informativeness prior to the public announcement, but it comes at the cost of less informative prices in the long-run. The previous literature ignores long-run impact since it uses a less general information structure.

Our analysis also has important policy implications. On October 23, 2000 the SEC introduced Regulation Fair Disclosure (FD) to combat the selective disclosure that occurs when companies release information to selected securities analysts or institutional investors before disclosing it to the general public. Regulation FD forces companies to make material information — that merits a public announcement — public simultaneously to all investors. If the information leaks unintentionally, firms are forced to reveal it to all investors within 24 hours. Our analysis shows that to the extent that Regulation FD prevents information leakage, it enhances long-run informational efficiency (and informativeness). However, if it precludes or delays public news announcements about short-run matters altogether it is counter-productive.[4] Which of the two effects dominates is an empirical question. Section 3.3 briefly surveys the empirical evidence and discusses additional facets of Regulation FD.

As mentioned above, our model predicts that selective disclosure hurts the long-run informativeness of the price process, but makes prices more informative in the short-run. As pointed out in Leland (1992), less

[4] Opponents of Regulation FD assert that companies will release less information for fear of litigation. This so-called *chilling effect* also provides CEOs an excuse to hide information. Proponents highlight its positive incentive implications. Without Regulation FD, analysts have a desire to remain in good standing with a company in order to receive advanced private briefings. Therefore, they have an incentive to "schmooze" rather than to conduct sound fundamental analysis about the company's prospects. They are also very reluctant to disclose negative information. This "schmooze effect" makes the price process less informative and undermines the monitoring role of analysts.

informative prices postpone uncertainty resolution and increase future volatility. This makes it more costly for firms to raise capital. Since most information leaks occur only a few days prior to official news announcements and capital is seldom raised within this short period, the long-run disadvantage most likely outweighs any short-run gain emphasized in Leland (1992). Therefore, we draw the opposite conclusions to Leland (1992). Other normative papers in the literature also address the question of how insider trading affects the information revelation role of prices. Fishman and Hagerty (1992) endogenize the information acquisition process. In their model, trading by corporate insiders discourages analysts from collecting information, which can lead to less informative prices. In Ausubel (1990), insider trading reduces the initial ex ante investment by the traders and can lead to a Pareto-inferior outcome. In all these models, there is only one trading round. Hence, informational efficiency after the public announcement cannot be analyzed in these models. Our article contributes to the literature by analyzing the long-run impact of insider trading on the informational efficiency of prices and by highlighting a dynamic trade-off between short- and long-run informativeness of prices.

The remainder of the article is organized as follows. Section 1 outlines the model setup. Section 2 shows that an early-informed trader still has an informational advantage at the time of the public announcement and that he expects to unwind a large fraction of his trade after the public announcement for strategic reasons. The impact of information leakage on market efficiency is outlined in Section 3. Section 4 extends the analysis to a setting with multiple short-term-information traders and discusses the generality of the results. Concluding remarks are presented in Section 5.

1. Model Setup

There are two assets in the economy: a risky stock and a risk-free bond. For simplicity, we normalize the interest rate of the bond to zero. Market participants include risk-neutral informed traders (also referred to as analysts), liquidity traders, and a market maker. The informed traders' sole motive for trading is to exploit their superior information about the fundamental value of the stock. Liquidity traders buy or sell shares for reasons exogenous to the model. Their demand typically stems from information that is not of common interest, such as from their need to hedge against endowment shocks or private investment opportunities in an incomplete market setting.[5] A single competitive risk-neutral market maker observes the aggregate order flow and sets the price. Traders submit their market orders to the market maker in two consecutive

[5] See Brunnermeier (2001) or O'Hara (1995) for a detailed discussion of the different reasons why liquidity traders trade, and for a discussion on the distinction between information of common versus private interest.

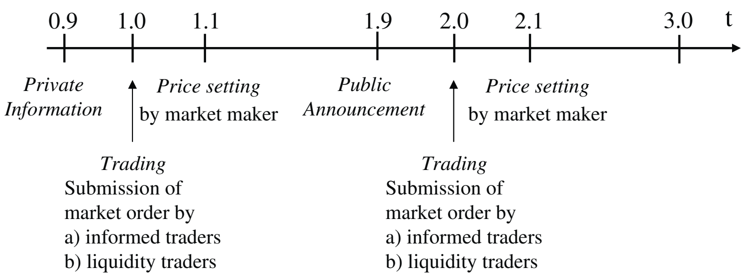

Figure 1
Timeline

trading rounds taking into account the price impact of their orders. The market maker sets the price in each round after observing the aggregate order flow and trades the market clearing quantities. As in Kyle (1985), the market maker is assumed to set semi-strong informationally efficient prices; thus his expected profit is zero. The underlying Bertrand competition with potential rival market makers is not explicitly modeled in this analysis. The trading game differs from Kyle (1985), Admati and Pfleiderer (1988), and Foster and Viswanathan (1994, 1996) since one trader receives short-lived information about a forthcoming announcement, while the remaining analysts collect different pieces of long-run fundamental information.

Analysts receive private information before trading begins in $t=1$. The public announcement occurs prior to trading in $t=2$. The timeline in Figure 1 illustrates the sequence of moves.

Public announcements about earnings, a major contract with a new client, a legal allegation, a new CEO, macroeconomic news, etc. can have a significant impact on the market value of a stock. However, such announcements reflect only part of the relevant information pertinent to the value of the stock. In order to gain a complete picture of the long-run future prospects of a company, one has to study its business model and gather a lot of information unrelated to the announcement. The ideal role of analysts is to collect this long-run information, analyze it, and translate it into the stock market value.[6] The liquidation value of the stock in our model is the sum of two random variables: $v=s+l$. The random variable s refers to the *short-run* information which will be publicly announced at $t=2$, while l reflects the *long-run* information about the company not related to the forthcoming public announcement. In our model l is only made public at the end of the trading game at $t=3$. This long-run

[6] Note that Regulation FD does not prevent analysts from soliciting information that does not merit a public announcement. These pieces of information are more like mosaics that allow a skilled analyst to form a more informative picture about the long-run prospects of a company's business model than a tip-off prior to a forthcoming news announcement.

Table 1
Information structure

Player	Period $t=1$	$t=2$	$t=3$
Market maker	X_1	s, p_1, X_2	l, p_2
Trader S	$s+\varepsilon$	s, p_1	l, p_2
Trader L_1 … Trader L_i … Trader L_I	$\frac{1}{I}l_i$	s, p_1	l, p_2

information l is dispersed among many traders in the economy. In particular, we assume that each long-run-information trader L_i of I traders receives a signal $(1/I)l_i$, where all l_is are independent. The sum of all $(1/I)l_i$ is l. The variance of each individual l_i is set equal to I, so that the variance of l is normalized to 1, that is, $\mathrm{var}\left[(1/I)\sum_{i=1}^{I} l_i\right] = 1$.

In addition to the long-run-information traders, there is also a trader or analyst S who "schmoozes" the CEO and tries to receive an early signal about the forthcoming information in $t=2$. The company leaks a noisy signal of next period's public news $s+\varepsilon$, possibly in the form of a rumor, to the short-run-information analyst prior to trading round $t=1$. Liquidity traders do not receive any information and their aggregate trading activity is summarized by the random variables u_1 in period one and u_2 in period two.

Table 1 presents the information each agent receives in each period, where $X_1 = x_1^S + \sum_{i=1}^{I} x_1^{L_i} + u_1$ is the aggregate order flow in $t=1$ and $X_2 = x_2^S + \sum_{i=1}^{I} x_2^{L_i} + u_2$ is the order flow in $t=2$. The short-run-information trader and each long-run-information trader submits his market order (x_t^S and $x_t^{L_i}$, respectively) to the market maker in each trading round. The random variables s, l, ε, u_1, and u_2 are independently normally distributed with mean zero. Let $\Sigma = \mathrm{var}[s]$, $\sigma_{u1}^2 = \mathrm{var}[u_1]$, $\sigma_{u2}^2 = \mathrm{var}[u_2]$, and $\sigma_\varepsilon^2 = \mathrm{var}[\varepsilon]$.

This information structure is common knowledge among all market participants, that is, we assume that everybody knows that there is a short-run-information trader S who has received some noisy information about a forthcoming public announcement. However, they do not know the content of his short-run information.[7] As will become apparent later,

[7] This problem can also be captured in a model with higher order uncertainty, that is, information leakage occurs only with a certain probability. In that case, the short-run-information trader S receives two pieces of information. In addition to the actual signal, he knows whether some information has leaked or not. The short-run-information trader's informational advantage at the time of the public announcement in $t=2$ stems from his knowledge of whether he had received an early signal or not. Such models are not pursued in this article because they are very intractable if no restrictions are placed on the trading size. Models with "event uncertainty" as by Easley and O'Hara (1987, 1992) within a Glosten and Milgrom (1985) framework share some of these features.

asymmetric information about long- and short-run information is essential for our results on trading patterns and informational efficiency. In a setting without long-run information, the past price p_1 would not carry any information after s is announced.

In period two, each trader knows not only his signal, the price p_1 and the public information s but also his order size in $t=1$. The risk-neutral market maker sets the execution price p_t after observing the aggregate net order flow. The price is semi-strong, informationally efficient, that is, the price is the best estimate given the market maker's information $p_1 = E[v|X_1]$ and $p_2 = E[v|X_1, s, X_2]$. Any different price would lead to an expected loss or an expected profit for the market maker. The latter is ruled out because the market maker faces Bertrand competition from potential rival market makers.

A sequentially rational Bayesian Nash equilibrium of this trading game is given by a strategy profile $\{x_1^{S,*}, x_2^{S,*}, \{x_1^{L_i,*}(\cdot), x_2^{L_i,*}(\cdot)\}_{i=\{1,\dots,I\}}, p_1^*(\cdot), p_2^*(\cdot)\}$, such that

1. $x_2^{S,*} \in \arg\max_{x_2^S} E\left[x_2^S(v-p_2)|s+\varepsilon, x_1^S, p_1, s\right]$
   $x_2^{L_i,*} \in \arg\max_{x_2^{L_i}} E\left[x_2^{L_i}(v-p_2)|\frac{1}{I}l_i, x_1^{L_i}, p_1, s\right], \qquad \forall i \in \{1,\dots,I\},$
2. $x_1^{S,*} \in \arg\max_{x_1^S} E\left[x_1^S(v-p_1) + x_2^{S,*}(v-p_2)|s+\varepsilon\right]$
   $x_1^{L_i,*} \in \arg\max_{x_1^{L_i}} E\left[x_1^{L_i}(v-p_1) + x_2^{L_i,*}(v-p_2)|\frac{1}{I}l_i\right], \quad \forall i \in \{1,\dots,I\},$
3. $p_1^* = E[v|X_1^*]$ and $p_2^* = E[v|X_1^*, s, X_2^*]$,

where the conditional expectations are derived using Bayes' rule to ensure that the beliefs are consistent with the equilibrium strategy.

2. Trading Patterns in Case of Information Leakage

In this section we analyze the trading behavior induced by the information structure described above. After deriving the linear Bayesian Nash equilibrium, we take a closer look at the trading patterns of the trader who receives some early information about a forthcoming public announcement. In Section 3, we contrast this equilibrium with the situation where trader S does not receive any insider information and hence does not trade in either of the trading rounds.

2.1 Linear sequential equilibrium

Proposition 1 characterizes a sequentially rational Bayesian equilibrium in linear pure strategies. It has the elegant feature that each trader's demand is the product of his trading intensity (or aggressiveness) and the difference between the trader's and market maker's expectations about the value of the stock, namely the trader's informational advantage. Linear strategies have the advantage that all random variables remain normally distributed. In addition, the pricing rules are linear as a consequence of the Projection theorem. In equilibrium, the market maker's pricing rule is $p_1 = \lambda_1 X_1$ in period one and $p_2 = s + E[l|X_1, s] + \lambda_2\{X_2 - E[X_2|X_1, s]\}$ in period two. As in Kyle (1985), λ_t reflects the price impact of an increase in market order by one unit. This price impact restricts the trader's optimal order size. Kyle (1985) interprets the reciprocal of λ_t as market depth. If the market is very liquid, that is, λ_t is very low, then an increase in the trader's demand has only a small impact on the stock price. The equilibrium is derived in Appendix A.1 for any number of long-run-information traders. For expositional clarity, Proposition 1 and the following results focus on the equilibrium for the limiting case where I goes to infinity. Needless to say, this corresponds to the case in which information about l is dispersed among infinitely many traders.

Proposition 1. *A symmetric sequentially rational Bayesian Nash equilibrium in which all pure trading strategies are of the linear form*

$$x_1^S = \beta_1^S(s+\varepsilon), \qquad x_1^{L_i} = \beta_1^L\left(\frac{1}{I}l_i\right),$$
$$x_2^S = \alpha^S T + \beta_2^S\left(l + \frac{1}{\beta_1^L}u_1\right), \quad x_2^{L_i} = \alpha^L T + \beta_2^L\left(\frac{1}{I}l_i\right),$$

and the market maker's pricing rule is of the linear form

$$\begin{aligned} p_1 &= E[v|X_1] = \lambda_1 X_1, \\ p_2 &= E[v|X_1, s, X_2] \\ &= s + \frac{(\beta_1^L)^2}{(\beta_1^L)^2 + (\beta_1^S)^2\sigma_\varepsilon^2 + \sigma_{u1}^2} T + \lambda_2\{X_2 - E[X_2|X_1, s]\}, \end{aligned}$$

with $T = (p_1/\lambda_1 - \beta_1^S s)/\beta_1^L$, is determined by the following system of equations:

$$\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma + \sigma_\varepsilon^2}\left[1 - \frac{\lambda_2}{\lambda_1}\left(\frac{\alpha^S}{\beta_1^L}\right)^2 \frac{\sigma_\varepsilon^2}{\Sigma + \sigma_\varepsilon^2}\right]^{-1},$$

$$\beta_1^L = \left[2\lambda_1 + \frac{1}{(\beta_1^L)^2 + (\beta_1^S)^2\sigma_\varepsilon^2 + \sigma_{u1}^2}\beta_2^L\right]^{-1},$$

$$\alpha^S = -\frac{1}{2\lambda_2}\frac{1}{2C}\frac{(\beta_1^L)^2}{(\beta_1^L)^2 + (\beta_1^S)^2\sigma_\varepsilon^2 + \sigma_{u1}^2}, \quad \alpha^L \to 0,$$

$$\beta_2^S = \frac{1}{2\lambda_2}\frac{1}{2C}\frac{(\beta_1^L)^2}{(\beta_1^L)^2 + \sigma_{u1}^2}, \quad \beta_2^L = \frac{1}{2\lambda_2}\frac{2C-1}{C},$$

$$\lambda_1 = \frac{\beta_1^L + \beta_1^S \Sigma}{(\beta_1^S)^2(\Sigma + \sigma_\varepsilon^2) + (\beta_1^L)^2 + \sigma_{u1}^2},$$
$$\lambda_2 = \frac{(\beta_2^L + \beta_2^S)\operatorname{var}[l|T]}{(\beta_2^L + \beta_2^S)^2 \operatorname{var}[l|T] + (\beta_2^S/\beta_1^L)^2 \operatorname{var}[u_1|T] + \sigma_{u2}^2},$$
$$C = \frac{3/4(\beta_1^L)^2 + \sigma_{u1}^2}{(\beta_1^L)^2 + \sigma_{u1}^2} - \frac{1}{4}\frac{(\beta_1^L)^2}{(\beta_1^L)^2 + (\beta_1^S)^2\sigma_\varepsilon^2 + \sigma_{u1}^2},$$

if the second-order conditions

$$\lambda_1 \geq \lambda_2 \left(\frac{\alpha^S}{\beta_1^L}\right)^2, \quad \lambda_1 \geq \frac{1}{4\lambda_2}\frac{(\beta_1^L)^2}{\left[(\beta_1^L)^2 + (\beta_1^S)^2\sigma_\varepsilon^2 + \sigma_{u1}^2\right]^2} \quad \textit{and} \quad \lambda_2 > 0$$

are satisfied.

The interested reader is referred to the appendix for a complete proof of the proposition. The proof makes use of backward induction. In order to solve the continuation game in $t = 2$, the information structure prior to trading in $t = 2$ has to be derived. For this purpose, let us propose an arbitrary action rule profile, $\{\beta_1^S, \beta_1^L, \lambda_1\}$, for $t = 1$, which is mutual knowledge and is considered to be an equilibrium profile by all agents. In $t = 2$ all market participants can derive the aggregate order flow $X_1 = \beta_1^S(s + \varepsilon) + \beta_1^L l + u_1$ from price p_1. After learning s, the information which can be inferred from the past price by using technical analysis (the price signal) is given by

$$T = \frac{p_1/\lambda_1 - \beta_1^S s}{\beta_1^L} = l + \frac{\beta_1^S}{\beta_1^L}\varepsilon + \frac{1}{\beta_1^L}u_1.$$

Even if a trader deviates in $t = 1$, other market participants still assume that he has played his equilibrium strategy. This is because the liquidity traders' order size u_1 is normally distributed and thus any aggregate order flow from $-\infty$ to $+\infty$ can arise in equilibrium. This makes it unnecessary to specify off-equilibrium beliefs as the market maker and the other traders do not see an order flow that could not be observed in equilibrium. In $t = 2$, traders face a generalized static Kyle-trading-game with the usual trade-off. On the one hand, a risk-neutral trader wants to trade very aggressively in order to exploit the gap between his estimate of the fundamental value of the stock and the price of the stock. On the other hand, very aggressive trading moves the price at which his order will be executed toward his estimate of the asset's value since it allows the market maker to infer more of the trader's information from the aggregate order flow. This latter price impact reduces the value-price gap from which the trader can profit and restrains the traders from trading very aggressively.

Using backward induction one has to check whether a single player wants to deviate in $t=1$ from the proposed action rule profile, $\{\beta_1^S, \beta_1^L, \lambda_1\}$. Trading in $t=1$ affects not only the capital gains in $t=1$ but also the future prospects for trading in $t=2$. Any deviation in $t=1$ alters the price p_1. Since other market participants infer wrong information from p_1, their trading and price setting in $t=2$ is also affected. An equilibrium is reached if no trader wants to deviate from the proposed action rule profile in $t=1$. In other words, the sequentially rational Bayesian Nash equilibrium is given by the fixed point described in Proposition 1.

Proposition 1 also presents three inequality conditions. They result from the second-order conditions in the traders' maximization problems. They guarantee that the quadratic objective functions for each period have a maximum rather than a minimum. In economic terms, they require that the market is sufficiently liquid/deep in trading round one relative to trading round two. These inequality restrictions rule out the case where it is optimal to trade an unbounded amount in $t=1$, move the price, and make an infinitely large capital gain in $t=2$.

2.2 Exploiting information twice due to technical analysis

Information about the fundamental value of the stock as well as information about other traders' demand affects the traders' optimal order size. In period two, traders can infer some information from the past price, p_1. Brown and Jennings (1989) call this inference "technical analysis". If a trader's prediction of the stock's liquidation value is more precise than the market maker's prediction, then the trader has an informational advantage. Lemma 1 states that the short-run-information trader still has an informational advantage in period two over the market maker as well as over all long-run-information traders. The short-run-information trader can, therefore, exploit his private information twice. First, when he receives his signal, and second, at the time of the public announcement. This is surprising since one might think that the public announcement of s is a sufficient statistic for the short-run-information trader's private information $s+\varepsilon$.

Lemma 1. *The short-run-information trader retains an informational advantage in period two in spite of the public announcement in this period. Technical analysis is more informative about the value of the stock for the short-run-information trader than for any other market participant.*

Since all traders trade conditionally on their signal in period one, the price p_1 reflects not only the signal about l but also the signal $s+\varepsilon$. In period two all market participants try to infer information in $t=2$ from the past price p_1. However, only the short-run-information trader knows the exact extent to which the past price, p_1, already reflects the new public information, s. That is, while the other market participants can only separate the impact of s on p_1, the short-run-information trader can also deduce the impact of the error term ε on p_1.

In general, technical analysis serves two purposes. First, traders try to infer more about the fundamental value of the stock, $v=s+l$, from the past price. After s is announced, the remaining uncertainty about the fundamental value concerns only the long-run information l. Second, they use the past price to forecast the forecasts of others. Knowing others' estimates is useful for predicting their market orders in $t=2$. This in turn allows traders to estimate the execution price p_2 more precisely.

When conducting technical analysis, the market maker and all long-run-information traders are aware that price p_1 is affected by the error term ε. The price $p_1=\lambda_1 X_1$ depends on the individual demand of the short-run-information trader S, x_1^S, and thus on the signal $s+\varepsilon$. The short-run-information trader's informational advantage in $t=2$ is his knowledge of the error ε. He can infer ε from the difference between his signal in $t=1$ and the public announcement in $t=2$. If the short-run-information trader would have abstained from trading in $t=1$, the public announcement s would be a sufficient statistic for the short-run-information trader's private information, $s+\varepsilon$. However, since he traded in $t=1$, all long-run-information traders and the market maker would like to know the extent to which his trading activities changed the price, p_1. Knowledge, not only of s but also of ε, would allow them to infer even more information from the price, p_1. Hence, the public announcement in $t = 2$ is not a sufficient statistic for $s+\varepsilon$ for interpreting the past price, p_1.

The short-run-information trader also applies technical analysis in order to infer more information about the fundamental value of the stock, more specifically about l. This information is also valuable for predicting the aggregate net demand of all long-run-information traders in $t=2$. The additional information about the value of the stock provided by technical analysis is higher for the short-run-information trader than for the market maker and for long-run-information traders. Since the short-run-information trader knows his own demand, he can infer

$$\frac{1}{\beta_1^L}\left(\frac{p_1}{\lambda_1}-x_1^S\right)=l+\frac{1}{\beta_1^L}u_1.$$

All long-run-information traders conduct technical analysis in order to infer each other's l^i-signal from p_1. They — as well as the market maker — can only infer $(l+(1/\beta_1^L)u_1)+(\beta_1^S/\beta_1^L)\varepsilon$. This is the short-run-information trader's price signal perturbed by the additional error term, ε. Therefore, the short-run-information trader's informational advantage is due to the term, $(\beta_1^S/\beta_1^L)\varepsilon$, which increases with his trading intensity, β_1^S, and decreases with the trading intensity of long-run-information traders,

β_1^L. Intuitively, if the short-run-information trader trades more aggressively in $t=1$, his signal's imprecision has a higher impact on the price, p_1.

2.3 Trade reversals

The short-run-information trader expects an information advantage that induces him to unwind part of his acquired position in period two. Proposition 2 shows that he trades slightly more aggressively than a myopic trader in order to enhance his information advantage after the public announcement.

Proposition 2. *The short-term-information trader S expects to revert* $-\alpha^S(\beta_1^S/\beta_1^L)(\sigma_\varepsilon^2/(\Sigma+\sigma_\varepsilon^2))(s+\varepsilon)$ *of his trades after the public announcement. His order size in* $t=1$, $\beta_1^S(s+\varepsilon)$, *exceeds the order of a short-term-information trader who cannot re-trade after the public announcement by*

$$\left[\frac{\lambda_1}{\lambda_2}\left(\frac{\beta_1^L}{\alpha^S}\right)^2\frac{\Sigma+\sigma_\varepsilon^2}{\sigma_\varepsilon^2}-1\right]^{-1}(s+\varepsilon)$$

shares. All coefficients in front of $(s+\varepsilon)$ *are strictly positive.*

The best way to see why a short-run-information trader expects to unwind a fraction of his pre-announcement trade is to note that a positive (negative) signal for trader S has two implications. First, he buys (sells) shares in the first trading round and second, he expects that ε is positive (negative), that is, $E[\varepsilon|s+\varepsilon]=\text{var}[\varepsilon](\text{var}[s]+\text{var}[\varepsilon])^{-1}(s+\varepsilon)>(<)0$. Other market participants' technical analysis in $t=2$ is based on $T=l+(\beta_1^S/\beta_1^L)\varepsilon+(1/\beta_1^L)u_1$. That is, if ε is positive (negative), the market maker and the long-run-information traders overestimate (underestimate) the long-run value l in period two. Since the short-run-information trader can infer ε in period two, he expects to make money by correcting the market maker's overoptimism (pessimism). In short, he expects to sell (buy) shares in period two. Therefore, the short-run-information trader expects to trade in the opposite direction in period two. "On average," he partially unwinds his position in period two. This is solely due to informational reasons since the short-run-information trader expects the price to overshoot in $t=2$. Given, however, the information of the market maker or of any other outsider who only observes the past prices and the public announcement, the price follows a Martingale process, that is, it neither overshoots nor undershoots.

The short-term-information trader also has an incentive to trade slightly more aggressively than is myopically optimal. His trading worsens the other market participants' ability to infer each others' information from the past price in period two, while he retains his full ability to conduct technical analysis. More specifically, by trading excessively in $t=1$, the short-run-information trader confounds the other market participants' price signal T in $t=2$. The reason is that the imprecision of the short-run-information trader's signal ε has a larger impact on p_1 if he trades more aggressively. Consequently, the larger the β_1^S, the less the price signal $T = l + (\beta_1^S/\beta_1^L)\varepsilon + (1/\beta_1^L)u_1$ reveals about the value l. This increases trader S's informational advantage in $t=2$ with respect to the market maker and long-run-information traders. It makes each long-run-information trader's forecast about the short-run-information trader's forecast of l worse. Recall that all traders also conduct technical analysis to forecast the others' market orders in order to better predict the execution price p_2. The short-run-information trader's market order in $t=2$ is based on his information, $l + (1/\beta_1^L)u_1$ and T. Long-run-information traders also do not know $(1/\beta_1^L)u_1$, the short-run-information trader's error in predicting the fundamental value l. The usefulness of the price signal T in predicting $(1/\beta_1^L)u_1$ also decreases as β_1^S increases. In short, if the short-run-information trader trades more aggressively in period one, he makes it not only more difficult for others to infer information about the value l, but also worsens others' forecasts about his forecast. Hence, more aggressive trading in period one increases the short-run-information trader's expected future capital gains. This aggressive trading is a novel form of stock price manipulation by an informed trader because it worsens other market participants' ability to conduct technical analysis and, unlike in the existing literature, it does not conceal his own information. Nevertheless, the manipulative component of the trade is relatively small and he does not apply a contrarian trading strategy. In other words, if the short-run-information trader receives a positive (negative) signal, all trading objectives induce the trader to take a long (short) position in the stock in $t = 1$ and to unwind it only partially in $t = 2$.

Figure 2 shows the short-run-information trader's trading behavior as we vary the precision of his signal from $\sigma_\varepsilon^2 = 0$ to $\sigma_\varepsilon^2 = 10$. All other variance terms are set equal to one. The solid line in Figure 2 shows the fraction of the short-run-information trader's trading in $t=1$ that he expects to unwind in the trading round after the forthcoming public announcement. The fraction is the same, independent of whether expectations are taken conditional on knowing $s+\varepsilon$, or unconditionally. The dashed line displays the fraction of his trading in $t=1$, which goes beyond the trading of a myopic short-term-information trader.

Obviously, for $\sigma_\varepsilon^2 = 0$ the expected trade reversal is zero and the short-run-information trader's order size coincides with that of a trader who cannot re-trade after the public announcement. Recall that it is the expected knowledge of the ε-term which induces the trade reversal. As the imprecision of the short-run-information trader's signal increases, so does the fraction of trading which he expects to unwind. For $\sigma_\varepsilon^2 = 10$, the short-run-information trader expects to unwind more than 25% of his

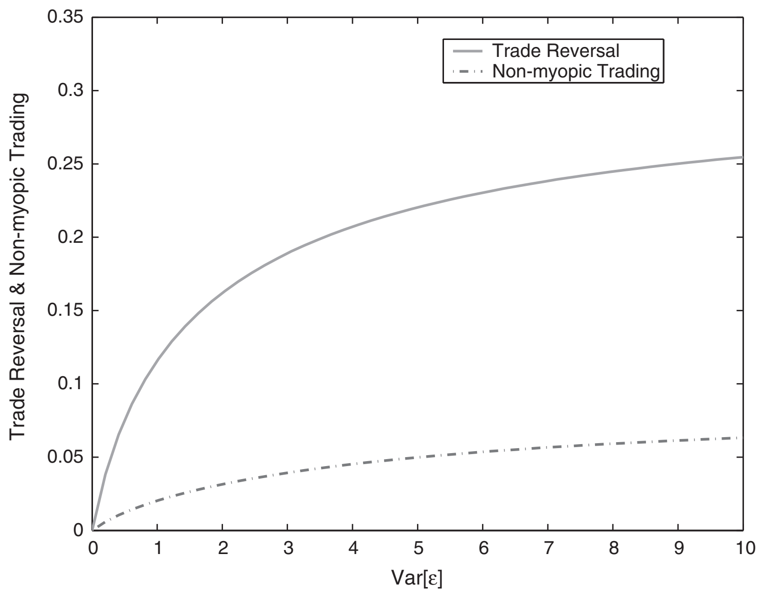

Figure 2
Fraction of trade reversal and non-myopic trading for different levels of var[ε]

pre-announcement trades. As σ_ε^2 goes to infinity the short-term-information trader's trade size shrinks to zero and so does the expected size of the trade reversal. Further numerical analysis shows that the expected trade reversal increases with the variance of noise trading in $t=2$, σ_{u2}^2. Since the amount of noise trading is typically larger after a public announcement than prior to it, the amount of trade reversal depicted in Figure 2 is a conservative estimate. The pre-announcement trade of a short-term-information trader is declining in σ_ε^2, while the trade reversal is hump-shaped and peaks around $\sigma_\varepsilon^2 = 2$.

Finally, note that while in our setting trade reversals are purely driven by strategic reasons, Hirshleifer, Subrahmanyam, and Titman (1994) appeal to traders' risk aversion and thus provide a very distinct explanation. In their setting, early-informed risk-averse traders are willing to take on a riskier position in order to profit from their superior private information. After a larger group of traders receives the same information one period later, they partially unwind their position to reduce their risk exposure. In their model, no trade reversal would occur without risk aversion, while in our setting the short-run-information trader expects to unwind a large fraction of his trade even though he is risk-neutral. His speculation is driven by informational reasons. It is easy to visualize a generalized setting with risk-averse traders in which these traders speculate due to both risk aversion and informational reasons.

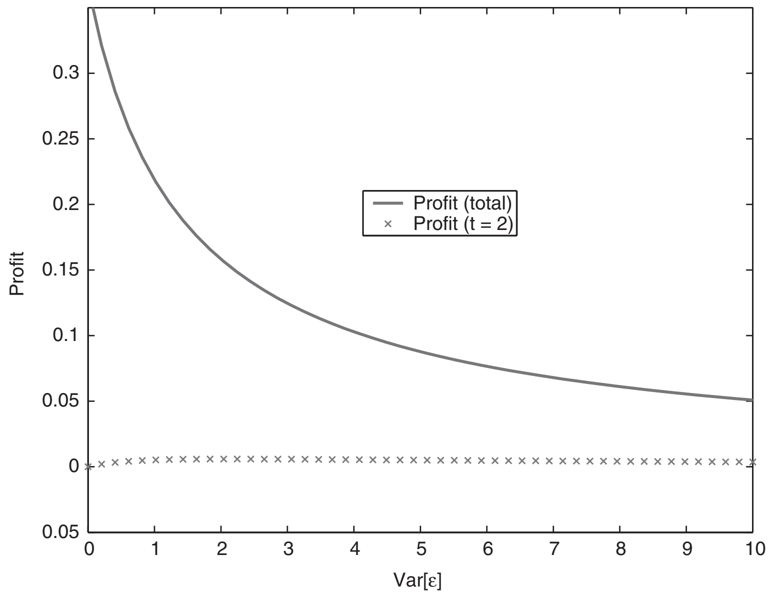

Figure 3
Trader *S*'s profit for different var[ε]

Even though the short-term-information trader expects to unload a substantial fraction of the acquired position after the public announcement, the bulk of the short-term-information trader's ex ante expected profit results from his trading prior to the public announcement. Figure 3 shows that the short-run-information trader's ex ante overall expected capital gains are monotonically decreasing in σ_ε^2. We set all other variance terms equal to one. This finding is also robust for other parameter values.

The x-marked line reflects the expected profits in the second trading round. They are small relative to the total profit in both trading rounds and hump-shaped with zero second-period profit for $\sigma_\varepsilon^2 = 0$ and $\sigma_\varepsilon^2 = \infty$. The short-term-information trader's relative profits in $t = 2$ need not be so small in a setting where he receives the short-term information only with a certain probability (or the precision of the leaked information is only known to him). Introducing this form of higher order uncertainty gives the short-term-information insider a bigger informational advantage after the public announcement. This is because he is the only one who knows whether he has received early information and whether he has moved the price or not. Ideally, one would like to incorporate this higher order uncertainty in the model. This would lead to larger quantitative effects but makes the model less tractable.

3 Market Efficiency — An Argument in Favor of Regulation FD

On October 23, 2000 the SEC imposed Regulation FD to prevent selective disclosure and private briefings to preferred analysts. Regulation FD requires companies to release any intentional disclosure of material non-public information simultaneously to the public. Any unintentional selective disclosure has to be made public promptly within 24 hours.

In this section, we analyze how information leakage to some traders affects market efficiency. Informed (insider) trading that results from selective disclosure typically leads to higher trading costs. As a consequence, allocative efficiency is reduced. On the other hand, information leakage might also lead to faster price adjustment to the true asset value, thereby enhancing the informational efficiency of the market.

To analyze the impact of selective disclosure on market efficiency, we contrast the benchmark setting where trader S receives no signal prior to the public announcement[8] with the information structure in which the short-run-information trader receives valuable information $s + \varepsilon$ prior to the official public announcement of s at $t = 2$. The next subsection illustrates a dynamic trade-off: While information leakage can make prices more informative in the very short-run, it reduces informational efficiency in the long-run. Section 3.2 contrasts the trading costs in both settings. Our analysis carefully sets out one core argument in favor of Regulation FD. Additional implications for market efficiency are discussed in Section 3.3.

3.1 Informational efficiency and informativeness

The empirical literature distinguishes between weak, semi-strong, and strong forms of market informational efficiency. A market is said to be weak (semi-strong, strong)-form efficient if the knowledge of past prices (public and private information, respectively) does not allow one to achieve excess trading profits. Equilibrium prices are weak-form efficient in our model since the risk-neutral market maker conducts technical analysis in equilibrium. Hence, the knowledge of past prices *alone* does not provide additional value. Markets are also semi-strong efficient in our setting since the risk-neutral market maker incorporates all (exogenous) public information. However, knowledge of (endogenous) past prices combined with (possibly "outdated") private information does. It is therefore profitable for informed traders to conduct technical analysis.

A market is strong-form informationally efficient if the price is a sufficient statistic for all the information dispersed among all market participants. In this case, the market mechanism perfectly aggregates all

[8] Receiving no signal prior to the public announcement is identical to assuming the limiting case where σ_ε^2 goes to infinity.

information available in the economy, and the price reveals the sufficient statistic to everybody. In general, if traders trade for informational as well as non-informational reasons, the price is not informationally efficient. This is also the case in our setting where some traders try to exploit their superior information and others trade for liquidity reasons. Nevertheless, one can distinguish between more and less informationally efficient markets. A measure of informational efficiency should reflect the degree to which information dispersed among many traders can be inferred from the price (process) together with other public information. Note that informational efficiency is relative to the information dispersed in the market and it does not necessarily imply that the price is informative. For example, in a setting without asymmetric information, the informationally efficient price does not reveal any additional information at all.

Even though informational efficiency is a commonly used concept in the empirical finance literature, it is less useful for addressing regulatory issues. Policy makers such as the SEC should care more about how informative the price process is in absolute terms. The more information the price reveals, the higher should be the measure. Our second measure "*informativeness*" does exactly that. It reports the reciprocal of the residual uncertainty after all public information including the price process is observed. Before providing more intuition for both measures, let us first define them formally. For this purpose, we denote by $\mathcal{I}_t^{\text{public}}$ the set of all public information (including past prices) that is known to all market participants and by $\mathcal{I}_t^{\text{pooled}}$ the information set that pools all public and private information up to time t.

Definition 1 *(Informativeness). The reciprocal of the conditional variance* $\text{var}[v|\mathcal{I}_t^{public}]$ *measures how informative the price (process) and the public information are at time t.*

The conditional variance $\text{var}[v|\mathcal{I}_t^{\text{public}}]$ is the risk an uninformed trader faces when trading the stock and it is zero only if all public information, including the price process, allows one to perfectly predict the liquidation value of the stock.[9]

Informational efficiency is relative to the pool of all information $\mathcal{I}_t^{\text{pooled}}$.

Definition 2 *(Informational efficiency). The reciprocal of the variance* $\text{var}\left[E[v|\mathcal{I}_t^{pooled}]|\mathcal{I}_t^{public}\right]$ *conditional on the public information,* $\mathcal{I}_t^{public}$, and the pool of private information up to time t measures the degree of informational efficiency at time t.

[9] Note that all public information at the beginning of the trading game is incorporated in the common priors.

To gain intuition for this measure, let us first consider $E[v|\mathcal{I}_t^{\text{pooled}}]$, the best forecast of the fundamental value of the stock, v, given the pool of all available information in the economy at a certain point in time. If the price (process) is informationally efficient, then $E[v|\mathcal{I}_t^{\text{public}}] = E[v|\mathcal{I}_t^{\text{pooled}}]$, that is, the price(s) and other public information up to this time yield the same forecast as the pool of all information. Moreover, the variance $\text{var}\left[E[v|\mathcal{I}_t^{\text{pooled}}]|\mathcal{I}_t^{\text{public}}\right]$ of this forecast conditional on prices and other public information is zero. For less informationally efficient markets, this conditional variance is higher. This makes the reciprocal of the conditional variance, that is, the precision, a natural measure of the degree of informational efficiency.

Equipped with these two measures, we can now analyze how the leakage of information $s+\varepsilon$ affects informational efficiency and informativeness of the price (process) at different points in time. We study informativeness and informational efficiency at the time after the first trading round, after the public announcement of s, and after the second trading round. Note that the two information measures only differ before the public announcement. After the public announcement in $t=2$, s is commonly known and the pooled information of all long-run-information traders includes l. This implies that the best forecast $E[v|\mathcal{I}_t^{\text{pooled}}]$ given the pooled information is v. Furthermore, the conditional variance stems solely from the uncertainty about l.

For the analytical results, in this section we assume that long-run-information traders submit myopically optimal market orders. This simplifies the analysis a great deal and, as the numerical simulations for which we do not make this assumption show, does not distort the main intuition.

Proposition 3. *In $t=1$, information leakage makes the price p_1 more informative but less informationally efficient in the short-run. After the public announcement in $t=2$, the price p_1 and price process $\{p_1, p_2\}$ is less informative and less informationally efficient, assuming that the* short-run insider *expects a positive profit from his trading prior to the public announcement.*

Leakage of information about a forthcoming announcement makes the price p_1 in $t=1$ more informative. The short-run-information trader trades on his information $s+\varepsilon$, and thus, price p_1 reveals information not only about l but also about s. The short-run-information trader's market activity increases informed trading relative to liquidity trading. This allows the market maker as well as the public to infer more information from the aggregate order flow X_1. The numerical results captured in Figure 4 confirm this finding. The price is more informative prior to the public announcement if some information leaked (depicted by the line in Figure 4) compared to a setting where no information leaked (denoted by the x-marked line). The distance between the two lines vanishes as the

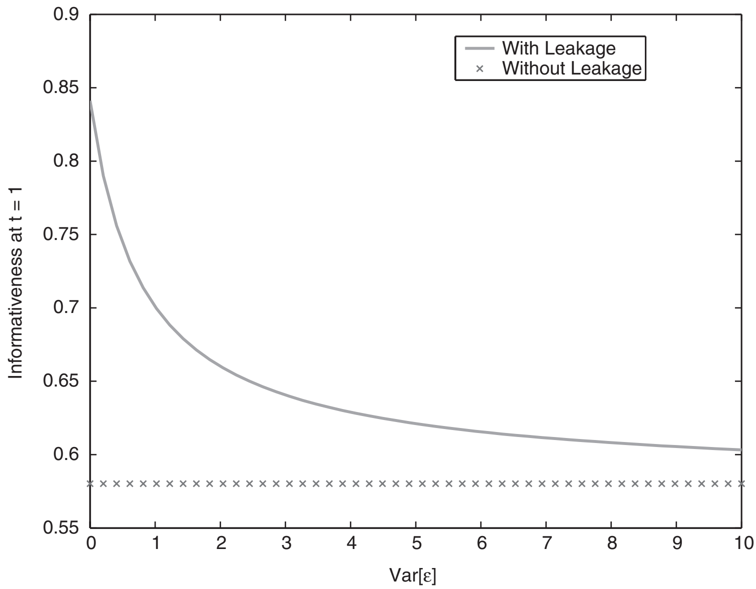

Figure 4
Informativeness of p_1 at $t = 1$, 1/var[$v|p_1$]

short-term-information trader's signal $s + \varepsilon$ becomes less precise. All other variance terms are set equal to one for the numerical results.

On the other hand, information leakage makes the market less informationally efficient in $t = 1$. If information leaks, not only l but also $s + \varepsilon$ is known to somebody in the marketplace. That is, $E[v|\mathcal{I}_t^{\text{pooled}}]$ becomes $E[v|\ell, s + \varepsilon] = l + \Sigma(\Sigma + \sigma_\varepsilon^2)^{-1}(s + \varepsilon)$ instead of $E[v|l] = l$. In addition, p_1 reveals less about l since *long-term traders* trade less aggressively. To see this, note that if *the short-term trader* receives a signal, he also trades for informational reasons and tries to disguise his trades behind the noise trading. This reduces market liquidity (λ_1 is higher) and his trading crowds out some of the *long-term trader's* informed trading. This "crowding out" effect lowers β_1^L. Both effects together yield the result that information leakage reduces informational efficiency for p_1.

Both informativeness and informational efficiency are lower after the news announcement in $t = 2$ if some information has leaked prior to it. There are two reasons for this. First, due to the "crowding out" effect β_1^L is lower, and hence, the price signal $T = l + (\beta_1^S/\beta_1^L)\varepsilon + (1/\beta_1^L)u_1$ is less precise. Second, the price signal is also perturbed by the ε-error term ("noise effect"). Figure 5 shows that informativeness after the public announcement is higher after Regulation FD is imposed, compared to a setting with information leakage. As before, all other variance terms are

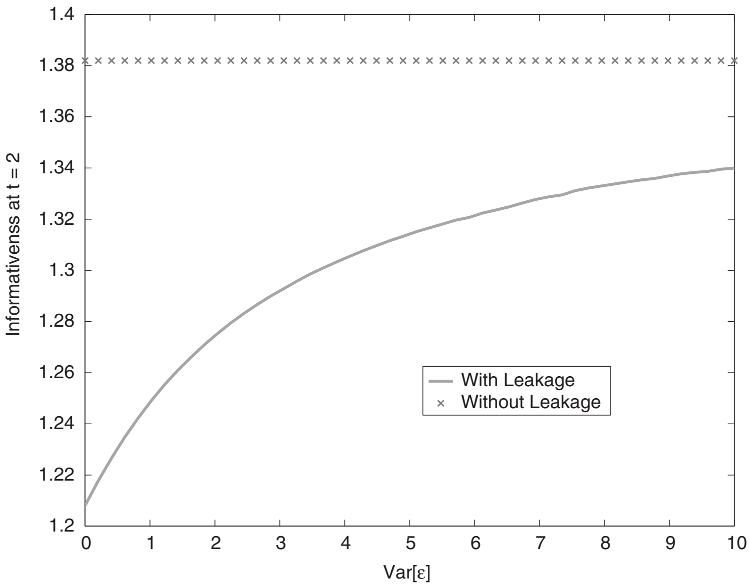

Figure 5
Informativeness of p_1 at $t = 2$, 1/var[$v|p_1, s$]

set equal to unity for the simulation. The informational efficiency of the price process $\{p_1, p_2\}$ after trading in $t = 2$ exhibits a similar pattern.

Figure 5 also shows that the negative long-run effect of information leakage on informativeness weakens as the leaked information becomes less precise. Indeed, precise leaks ($\sigma_\varepsilon^2 = 0$) are the worst in our setting. This is despite the fact that, for the special case $\sigma_\varepsilon^2 = 0$, there is no "noise effect" and the short-term-information trader only trades prior to the public announcement. The reason is that as σ_ε^2 increases, *the short-term insider* trades less aggressively in $t = 1$ which reduces "crowding out." This reduction dominates the initial rise in the "noise effect" as σ_ε^2 increases. This is the case since both the insider's profit in $t = 2$ and the "noise effect" is relatively small in our model. This need not be the case in a more general, but less tractable, setting in which the precision of the leaked signal (or knowledge of whether the information has leaked at all) is only known to the short-term-information trader. In such a setting, the short-term-information trader has an even larger informational advantage at $t = 2$ and the (past) price signal T is even less informative to other traders.

In summary, Regulation FD increases informational efficiency at each point in time. Even though it makes the price process less informative in the very short-run (prior to the public announcement), prices are more informative in the long-run.

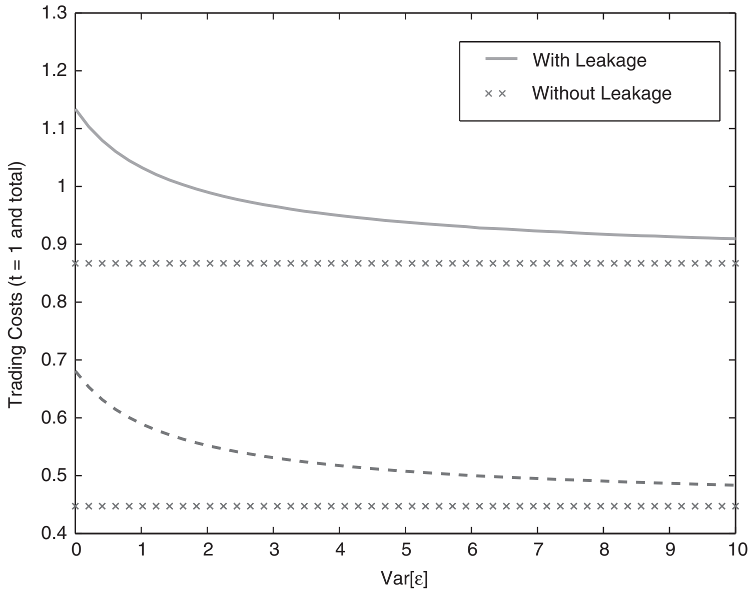

Figure 6
Trading Costs — total and $t = 1$

3.2 Trading costs

Information leakage leads to insider trading, which raises trading costs for liquidity traders. Our analysis shows that this is the case for trading prior to and also after the public announcement. Figure 6 contrasts trading costs with and without information leakage. Total trading costs are declining with the imprecision of the information leakage (depicted by the top decreasing line). Figure 6 also shows trading costs for liquidity trades in $t = 1$ only. The dotted curve is for the case of information leakage and the lower x-marked horizontal line for the case of no information leakage.

Note that the trading costs coincide with aggregate capital gains of short-term and long-term-information traders in our setting. Since all agents are risk-neutral, they face a zero-sum game.

In our model setup, the amount of liquidity trading in each trading round is exogenously fixed. In a more general setting where risk-averse liquidity traders trade to hedge their endowment shocks, higher trading costs reduce overall trading. This reduces the amount of risk sharing, and hence, reduces allocative efficiency. Furthermore, liquidity traders will try to delay some of their trades until after the public announcement.

3.3 The many facets of Regulation FD

The finding that information leakage lowers informational efficiency and increases trading costs provides a compelling argument in favor of

Regulation FD. However, to fully evaluate the implication of Regulation FD, one has to amend our analysis. In particular, in our model the timing and quality of the public announcement are exogenously fixed. Opponents of Regulation FD argue that Regulation FD delays and worsens information dissemination for multiple reasons. Fear of litigation and of legal fees causes a “chilling effect” which might make managers reluctant to make private or public announcements. Furthermore, CEOs might sometimes hide behind Regulation FD to delay the announcement of negative news. While managers might be willing to reveal certain information, like technical advances and possible future patents, to some expert analysts, they are reluctant to make it public. This is especially the case if competing firms could benefit from this information. A delay of a public announcement lowers the informativeness of prices. For example, if the short-run information s in our model is only released at $t = 3$, the informativeness prior to trading at $t = 2$ remains at the low level of 0.58 (like in the case of no information leakage shown in Figure 4). In contrast, if s is made public in $t = 2$, the informativeness after the public announcement is between 1.2 and 1.39 (see Figure 5) even when some of the information leaks already prior to trading in $t = 1$.

Regulation FD also reduces an analyst’s incentives for eliciting information and active monitoring. The reward for an expert analyst to ask pertinent questions is reduced since he does not gain an information advantage relative to other investors. On the other hand, Regulation FD also lowers the “schmoozing” effect. Ideally, analysts should conduct analysis about the long-run prospects and strategies of companies. However, prior to Regulation FD, analysts devoted a lot of effort to cultivating good relationships with management in order to receive tips about future earnings announcements. In return, management expected favorable stock recommendations. Due to Regulation FD, firms can no longer threaten to cut certain analysts off from future information releases. This should improve analysts’ forecasts and make them less biased.

Whether these incentive effects outweigh the effects derived in our theoretical model is an empirical question. Eleswarapu, Thompson, and Venkataraman (2002) empirically document that Regulation FD lowers trading costs overall. This is especially true for illiquid firms. Helfin, Subrahmanyman, and Zhang (2003) report that stock prices adjust more quickly and that firms increase the frequency of voluntary disclosure. However, Štraser (2002) argues that this regulation did not positively affect the overall quality of information released. Bailey et al. (2003) show that trading volume increased around earnings releases, but that there was no increase in price volatility due to Regulation FD. They and Agrawal and Chadha (2002) also document that analysts’ forecasts became more dispersed. The latter article also shows that analysts’ performance ranking became more stable, which should make it easier to differentiate good from bad analysts.

Finally, proponents of Regulation FD argue that technological changes, like the internet and video- and tele-conferencing, make alternative channels of information dissemination more efficient, and hence, they diminish the importance of the role of analysts as information disseminators.

4. Extensions and Discussion

Assuming a more realistic information structure, the previous two sections explain the optimal trading strategy of a trader who receives a signal about a forthcoming public announcement and analyze the market inefficiencies associated with this information leakage. This section addresses the generality of our results and checks for robustness. We also suggest possible remedies to alleviate the inefficiencies. In the first subsection, we point out that the market inefficiencies are due to market incompleteness. Given that the trade reversal is driven by the imprecision of the early informed trader's signal, in the second subsection we ask whether he would like to add his own noise term. The third subsection generalizes the setting and shows that our results also hold in a setting where information leaks to multiple traders.

4.1 Completing the market

The inefficiency highlighted in this article arises from market incompleteness. It vanishes if one splits the asset with payoff $v = s + l$ into two, such that the payoffs s and l can be traded separately. Most simply, consider the setting where the first asset's payoff only depends on the public announcement s in $t = 1$ and the second asset's payoff is l. Trader S with short-term information $s + \varepsilon$ will only be active in the first market, $\mathcal{S}$, while the long-term-information traders only trade in the second market, $\mathcal{L}$. At $t = 2$, s is revealed to the public and the price of asset S is set equal to its final payoff s. Neither the market maker nor other strategic traders conduct any technical analysis to infer additional information from past prices. Trader S has no informational advantage in the second trading round about l and he does not trade after the public announcement. Hence, there is no trade reversal. All L traders are active in market $\mathcal{L}$. In short, since s and l are independently distributed, market $\mathcal{S}$ is simply a one-period Kyle setting, while market $\mathcal{L}$ resembles a two-period multiple-insider Kyle model. Information leakage of $s + \varepsilon$ to trader S does not affect the revelation of information about l at all. It makes the price in market $\mathcal{S}$ more informative without any negative effects on the long-run informational efficiency. In other words, the dynamic trade-off discussed in Section 3.1 does not arise with two separate assets.

Theoretically, one can eliminate the inefficiencies by completing the market. Nevertheless, it is quite unrealistic to assume that in practice one can trade on next week's earnings announcement and all other news separately. The asset structure and information structure assumed in the main part of the article seem more reasonable.

4.2 Precise signal and absence of mixed strategy equilibria

It is apparent from Figures 5 and 6 that the inefficiencies disappear as the leaked signal becomes less precise. In the limit as $\sigma_\varepsilon^2 \to \infty$, it coincides with the case of no information leakage.

For the opposite extreme, $\sigma_\varepsilon^2 = 0$, where the short-information signal is perfect, ε does not affect p_1. Consequently, the short-run-information trader also has no informational advantages and does not trade in the second period. In addition to market incompleteness, the noise term ε is crucial for trade reversal. Two interesting questions come to mind: (i) What is the optimal level of imprecision for the short-run-information trader? (ii) Is it possible for the short-run-information trader to generate the imprecision himself in equilibrium by trading above or below his optimal level in period one?

The first question is simply answered by Figure 3 in Section 2.3. Even though the second-period profit is hump-shaped with a maximum around $\sigma_\varepsilon^2 = 1$, the overall profit of trader S is declining in σ_ε^2. Hence, trader S strictly prefers a more precise signal.

With regard to the second question, consider a short-term-information trader who observes s in $t = 1$ and adds to his order size $\tilde{\alpha}_1^S s$ the noise component $\tilde{\beta}_1^S \xi$, that is, his order is $x_1^S = \tilde{\alpha}_1^S s + \tilde{\beta}_1^S \xi$. He follows a "linear" mixed (or behavioral) strategy.[10] In order to preserve normality for all random variables, assume $\xi \sim \mathcal{N}(0, 1)$. The additional random component $\tilde{\beta}_1^S \xi$ in trading round one makes the market more liquid in $t = 1$, but less liquid in $t = 2$. The second-period effect occurs because the short-run-information trader trades in $t = 2$ on information generated by $\tilde{\beta}_1^S \xi$. Analogous to the analysis in Section 2, in $t = 2$ all other traders learn $T = l + (\tilde{\beta}_1^S / \tilde{\beta}_1^L)\xi + (1/\tilde{\beta}_1^L) u_1$ from the past price p_1, while trader S can infer $T = l + (1/\tilde{\beta}_1^L) u_1$ because he knows ξ.

Note that this error term differs from the ε-error term in the previous sections in two respects. First, the short-run-information trader knows ξ already in $t = 1$, whereas he learns the precise value of ε only at the time of the public announcement. Second, if the short-run-information trader wants to increase the importance of the ε-error term in the previous

[10] Pagano and Röell (1993) conjecture a mixed strategy equilibrium in a model that analyzes front-running by brokers. Investors submit their orders to the broker who forwards it to the market maker. Prior to trading the broker observes the aggregate order flows for the next two trading rounds. Hence, he has more information than the market maker in the first trading period. At this round of trading, he front-runs by adding his own (possibly random) orders.

sections, he has to trade more aggressively on $s+\varepsilon$, thereby revealing more of his signal. In contrast, by trading on an unrelated random noise term ξ, he reveals less about his signal s. Overall, he faces a trade-off: He acts like a noise trader in $t=1$ incurring trading costs on the one hand, but he increases his informational advantage in $t=2$ on the other hand.

For a mixed strategy to sustain in equilibrium, the short-run-information trader has to be indifferent between any realized pure strategy, that is, between any realization of ξ. Since the random variable ξ can lead to any demand with positive probability, he has to be indifferent between any $\tilde{x}_1^S$ in equilibrium. This requires that the marginal trading costs in $t=1$ exactly offset the expected marginal gains in $t=2$. More formally, the short-run-information trader's objective function consists of two quadratic parts: the expected capital gains in $t=1$, and the expected value function for capital gains in $t=2$. The sum of both quadratic functions has to reduce to a constant in equilibrium to ensure that trader S is indifferent between all realizations of ξ. This is only the case if the short-run-information trader's second-order condition binds, that is, $\tilde{\lambda}_1=\tilde{\lambda}_2(\tilde{\alpha}^S/\tilde{\beta}_1^L)^2$. This necessary condition together with the second-order condition of the long-run-information traders allow us to rule out mixed strategy equilibria.

Proposition 4. *There does not exist a linear mixed strategy equilibrium.*

The non-existence of a linear mixed strategy equilibrium is in sharp contrast to Huddart, Hughes, and Levine (2001). The *single* insider in Huddart, Hughes, and Levine (2001) employs a mixed strategy since his order size is made public after his order is executed.[11] Similar to our setting without the ε-error term, the insider forgoes all future profit opportunities if he employs a pure trading strategy. In Huddart, Hughes, and Levine (2001), the incentive for the single insider to deviate from any pure strategy is extremely high since the market would be infinitely deep in $t=2$, that is, $\lambda_2=0$. So, any tiny deviation in $t=1$ would yield an infinite profit in the future trading rounds. Therefore only a mixed strategy equilibrium exists in Huddart, Hughes, and Levine (2001). In contrast, in our model the market is not infinitely deep in $t=2$ since there are *multiple* informed traders. The trading activities of long-run-information traders destroy the incentive to apply a mixed strategy in $t=1$.[12]

4.3 Multiple traders with short-term information

Completing the market eliminates the trade reversal and inefficiencies studied in this article. The former effect also vanishes when the

[11] See also Fishman and Hagerty (1995).

[12] Vitale (2000) shows that a mixed-strategy equilibrium can exist if one excludes long-run-information traders from trading after the public announcement.

forthcoming public announcement leaks without noise. In this subsection we ask whether the main results of this article still hold if information is leaked to many traders or analysts. More specifically, we consider the setting where J traders receive the signal $s+\varepsilon$. Proposition 5 in the appendix, generalizes Proposition 1 of Section 2 to this case.[13]

As in a multi-insider Kyle setting, competition among short-term-information traders increases their total size, $J\beta_1^S(s+\varepsilon)$. Hence, the error ε has a larger impact on p_1, thereby increasing the informational advantage of S traders in $t=2$. As a consequence, each short-term-information trader expects to unwind a substantial fraction of his trade. The total trade reversal remains large even as their number J goes to infinity.

On the other hand, each individual trader S's incentive to trade aggressively in $t=1$ to enhance trading profit in the second trading round becomes even smaller. The formal analysis shows that in the limit as the number of short-term-information traders J converges to infinity, this incentive totally vanishes and the J traders act like myopic competitive insiders, that is,

$$\lim_{J\to\infty} J\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}.$$

The reason is twofold. All short-run-information traders try to free-ride on the aggressive trading of the other short-term-information traders. Furthermore, a larger number of short-run-information traders enhances competition and shrinks profits in the second trading round.

The large trade reversal suggests that the dynamic trade-off between short-run improvement of price informativeness and the long-run worsening of the informational efficiency also extends to this setting with multiple S-traders. Indeed, this is the case. The proof in Appendix A.6 replicates all analytical market efficiency results of Section 3 for this more general setting.

In summary, competitive forces among short-term-information traders do not eliminate the large aggregate trade reversal, but lower each individual short-run-information trader's trading intensity. Our conclusion on the impact of information leakage on market efficiency is robust to this generalization.

5. Concluding Remarks

It is well understood that insider trading typically reduces risk sharing and allocative efficiency. One of the main messages of this article is that insider trading also reduces informational efficiency of prices in the long-run. Therefore, it provides strong support for the new Regulation FD. By introducing multiple trading rounds and a more realistic signal structure,

[13] We did not include the formal proof in the article, but it is available from the author on request.

we generate conclusions that are in sharp contrast to the previous literature on insider trading with exogenous information acquisition. However, the article does not make any normative welfare statements. In order to conduct a welfare analysis, one has to endogenize the trading activities of the liquidity traders. For example, one could consider risk-averse uninformed investors who are engaged in a private investment project. If the returns of these private investment projects are correlated with the value of the stock, they trade for hedging reasons even though they face trading costs. A thorough welfare analysis would allow us to evaluate insider trading laws more explicitly.

Finally, our analysis also offers support for the Short Swing Rule (Rule 16b of the SEA). This rule prohibits corporate insiders to profit from buying and selling the same security within a period of 6 months. Ideally, an early-informed corporate insider would like to unwind part of his position after the public announcement of the corporate news. This rule prevents them from applying their optimal trading strategy.

Appendix A

A.1 Proof of Proposition 1

Propose an arbitrary linear action rule profile for $t=1$, $\{\beta_1^S, \beta_1^L, \lambda_1\}$

A.1.1 Equilibrium in continuation game in $t=2$.

A.1.1.1 Information structure in $t=2$. After s is publicly announced, l is the only uncertain component of the stock's value.

Proof of Lemma 1. The *market maker* knows the aggregate order flow in $t=1$, $X_1 = \beta_1^S(s+\varepsilon) + \beta_1^L l + u_1$ in addition to s. His price signal T (aggregate order flow signal, X_1) can be written as

$$T = \frac{X_1 - \beta_1^S s}{\beta_1^L} = l + \frac{\beta_1^S}{\beta_1^L}\varepsilon + \frac{1}{\beta_1^L}u_1.$$

Since all market participants can invert the pricing function $p_1 = \lambda_1 X_1$ in $t=2$, they all know T. *Trader S* can also infer ε in $t=2$ and thus his price signal is $l + (1/\beta_1^L)u_1$. Each *trader L_i*'s information consists of T and his original signal $\frac{1}{I}l_i$. ■

The conjectured trading rules for $t=2$ are $x_2^S = \alpha^S T + \beta_2^S(l + 1/\beta_1^L u_1)$ for trader S and $x_2^{L_i} = \alpha^L T + \beta_2^L \frac{1}{I} l_i$ for all traders L_i. Each market participant tries to forecast each other's forecasts or more specifically the others' market order. Trader S's expectation of the aggregate order flow of all L traders is

$$E\left[\sum_j x_2^{L_j} \middle| l + \frac{1}{\beta_1^L}u_1, T\right] = I\alpha^L T + \beta_2^L E\left[l \middle| l + \frac{1}{\beta_1^L}u_1\right].$$

Trader L_i expects an order of size

$$E\left[x_2^S \middle| \frac{1}{I}l_i,\ T\right] = \beta_2^S E\left[l + k_u u_1 \middle| \frac{1}{I}l_i,\ T\right] + \alpha^S T$$

from trader S and of size

$$E\left[\sum_{j\neq i} x_2^{Lj}\Big|\frac{1}{I}l_i,\ T\right] = \beta_2^L E\left[\left(l-\frac{1}{I}l_i\right)\Big|\frac{1}{I}l_i,\ T\right] + (I-1)\ \alpha^L T$$

from all other L traders, where k_u is a constant. It proves useful to denote the regression coefficients by ϕ's. Let the market maker's expectations be

$$E[l|T] = \phi_{mm}^l T,$$

that is,

$$\phi_{mm}^l = \frac{1}{1+\left(\beta_1^S/\beta_1^L\right)^2\sigma_\varepsilon^2 + \left(1/\beta_1^L\right)^2\sigma_{u1}^2}.$$

Trader S's expectations are

$$E\left[l\Big|l+\frac{1}{\beta_1^L}u\right] = \phi_S^l\left(l+\frac{1}{\beta_1^L}u\right),\ \text{that is}\ \phi_S^l = \frac{1}{1+\left(1/\beta_1^L\right)^2\sigma_{u1}^2};$$

and for any trader L_i,

$$E\left[l-\frac{1}{I}l_i\Big|T-\frac{1}{I}l_i\right] = \phi_L^l\left(T-\frac{1}{I}l_i\right),\ \text{that is,}\ \phi_L^l = \frac{\frac{I-1}{I}}{\frac{I-1}{I}+\left(\beta_1^S/\beta_1^L\right)^2\sigma_\varepsilon^2+\left(1/\beta_1^L\right)^2\sigma_{u1}^2}.$$

For the conditional expectations of $\frac{1}{\beta_1^L}u_1$:

$$E\left[\frac{1}{\beta_1^L}u_1\Big|T\right] = \phi_{mm}^u T \quad \text{and} \quad E\left[\frac{1}{\beta_1^L}u_1\Big|T-\frac{1}{I}l_i\right] = \phi_L^u\left(T-\frac{1}{I}l_i\right).$$

In other words,

$$\phi_{mm}^u = \frac{\left(1/\beta_1^L\right)^2\sigma_{u1}^2}{1+\left(\beta_1^S/\beta_1^L\right)^2\sigma_\varepsilon^2+\left(1/\beta_1^L\right)^2\sigma_{u1}^2} \quad \text{and} \quad \phi_L^u = \frac{\left(1/\beta_1^L\right)^2\sigma_{u1}^2}{\frac{I-1}{I}+\left(\beta_1^S/\beta_1^L\right)^2\sigma_\varepsilon^2+\left(1/\beta_1^L\right)^2\sigma_{u1}^2}.$$

A.1.1.2 Action (trading) rules in $t=2$. Due to potential Bertrand competition the risk-neutral *market maker* sets the price

$$p_2 = E[v|X_1, X_2] = s + E[l|T] + \lambda_2[X_2 - E[X_2|T]].$$

Note that $\lambda_2 = \text{cov}[l,\ X_2|T]/\text{var}[X_2|T]$.

Trader S's optimization problem in $t=2$ is

$$\max_{x_2^S}\ x_2^S E\left[s+l-p_2|l+\left(1/\beta_1^L\right)u_1,\ T\right].$$

The first-order condition of

$$\max_{x_2^S}\ x_2^S E\left[l-E[l|T]-\lambda_2(X_2-E[X_2|T])|l+\frac{1}{\beta_1^L}u_1,\ T\right]$$

leads to

$$x_2^{S,*} = \alpha^S T + \beta_2^S\left(l+\left(1/\beta_1^L\right)u_1\right),$$

where $\alpha^S = -(1/\lambda_2)\phi_{mm}^l + (\beta_2^S+\beta_2^L)\phi_{mm}^l + \beta_2^S\phi_{mm}^u$ and $\beta_2^S = ((1/2\lambda_2)-(1/2)\beta_2^L)\phi_S^l$.

Trader L_i's optimization problem is $\max_{x_2^{L_i}} x_2^{L_i} E[s+l-p_2|\frac{1}{I}l_i, T]$. The first-order condition translates into

$$x_2^{L_i,*} = \alpha^L T + \beta_2^L \frac{1}{I} l_i,$$

where

$$\alpha^L = \left[\frac{1}{\lambda_2} - \left(\beta_2^S + \beta_2^L\right)\right]\left(\phi_L^l - \phi_{mm}^l\right) - \beta_2^S\left(\phi_L^u - \phi_{mm}^u\right)$$

and

$$\beta_2^L = \frac{1}{2\lambda_2}\left(1-\phi_L^l\right) + \frac{1}{2}\beta_2^L\phi_L^l - \frac{1}{2}\beta_2^S\left[\left(1-\phi_L^l\right) - \phi_L^u\right].$$

The second-order condition for all traders' maximization problem is $\lambda_2 > 0$.

The *equilibrium strategies* for $t=2$ for a given action (trading) rule profile in $t=1$ are given by

$$\alpha^S = \frac{1}{\lambda_2 4C}\left\{-\left[2-\phi_S^l\right]\phi_{mm}^l + \phi_S^l\phi_{mm}^u\right\},$$

$$I\alpha^L = \frac{1}{\lambda_2 4C}\left\{\left[2-\phi_S^l\right]I\left(\phi_L^l - \phi_{mm}^l\right) - \phi_S^l I\left(\phi_L^u - \phi_{mm}^u\right)\right\},$$

$$\beta_2^S = \frac{1}{2\lambda_2}\frac{1}{2C}\phi_S^l, \quad \beta_2^L = \frac{1}{2\lambda_2}\frac{2C-1}{C},$$

$$\lambda_2 = \sqrt{\frac{\left(1-\left(2-\phi_S^l\right)/4C\right)\frac{2-\phi_S^l}{4C}\mathrm{var}[l|T] - \left(\phi_S^l/4C\beta_1^L\right)^2\mathrm{var}[u|T]}{\sigma_{u2}^2}},$$

where $C = 1 - \frac{1}{2}\phi_L^l - \frac{1}{4}\phi_S^l + \frac{1}{4}\phi_S^l\phi_L^l + \frac{1}{4}\phi_S^l\phi_L^u$, $\mathrm{var}[l|T] = 1-\phi_{mm}^l$ and $\mathrm{var}[u_1|T] = \sigma_{u1}^2[1 + (\beta_1^S/\beta_1^L)^2\sigma_\varepsilon^2]/(1 + (\beta_1^S/\beta_1^L)^2\sigma_\varepsilon^2 + (1/\beta_1^L)^2\sigma_{u1}^2)$.

A.1.2 Equilibrium in $t=1$. The proposed arbitrary action rule profile is an equilibrium if no player wants to deviate given the strategies of the others.

The *market maker's pricing rule* in $t=1$ is always given by $p_1 = E[v|X_1] = \lambda_1 X_1$ with $\lambda_1 = \mathrm{cov}[v, X_1]/\mathrm{var}[X_1]$.

A.1.2.1 Trader S's best response. Deviation of trader S from $x_1^S(s+\varepsilon) = \beta_1^S(s+\varepsilon)$ to x_1^{dS} will not alter the subsequent trading intensities of the other market participants, $\lambda_1, \beta_2^L, \lambda_2$. They still believe that trader S plays his equilibrium strategy since they cannot detect his deviation. Nor does his deviation change his own price signals since he knows the distortion his deviation causes.

Other market participants' misperception in $t=2$. Trader S's deviation, however, distorts the other players' price signal, T to T^{dS}. This occurs because the other market participants attribute the difference in the aggregate order flow in $t=1$ not to trader S's deviation, but to a different signal realization or different noise trading. Deviation to $x_1^{dS}(\cdot)$ distorts the price signal by $T^{dS} = T + (1/\beta_1^L)(x_1^{dS} - x_1^S)$. Trader S expects that the aggregate order of all L traders is

$$\beta_2^L\phi_S^l\left(l + \frac{1}{\beta_1^L}u_1\right) + I\alpha^L\left[T + \frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right)\right].$$

Price p_2 is also distorted. The market maker's best estimate of v prior to trading in $t=2$ is $s + \phi_{mm}^l(T^{dS} - T)$ and after observing X_2^{dS},

$$E\left[p_2^{dS}|S_2^S, T, T^{dS}\right] = s + \phi_{mm}^l\left(T + \frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right)\right) + \lambda_2\left\{x_2^{dS} + \beta_2^L\phi_S^l\left(l + \frac{1}{\beta_1^L}u_1\right)\right.$$
$$\left. + I\alpha^L\left[T + \frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right)\right] - E_{mm}^{dS}[X_2|T]\right\},$$

where $E_{mm}^{dS}[X_2|T]$ denotes the market maker's expectations of X_2 thinking that trader S did not deviate. Using the above derived coefficients, trader S's expected execution price in $t=2$ is

$$\lambda_2 x_2^{dS} + \frac{2C-1}{2C}\phi_S^l\left(l + \frac{1}{\beta_1^L}u_1\right) - \left[\left(\frac{\phi_S^l - 2}{2C}\right)\phi_{mm}^l + \frac{1}{2C}\phi_S^l\phi_{mm}^u\right]\left(T + \frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right)\right).$$

Trader S's optimal trading rule in $t=2$ after deviation in $t=1$ results from the adjusted maximization problem

$$\max_{x_2^{dS}}\ E\left[x_2^{dS}\left(s + l - p_2^{dS}\right)|l + \frac{1}{\beta_1^L}u_1,\ T,\ T^{dS}\right].$$

It is given by

$$x_2^{dS,*} = x_2^S + \alpha^S\frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right),$$

if the second-order condition $\lambda_2 > 0$ is satisfied.

Trader S's value function is

$$V^S\left(x_1^{dS}\right) = x_2^{dS,*}E\left[s + l - p_2^{dS}|l + \frac{1}{\beta_1^L}u_1,\ T,\ T^{dS}\right],$$

which can be rewritten as

$$x_2^{dS,*}\left\{E[s + l|\cdot] - \lambda_2 E\left[\sum_i x_2^{L_i}|\cdot\right]\right\} - \lambda_2\{x_2^{dS,*}\}^2.$$

Note that the first-order condition in $t=2$ implies that $2\lambda_2 x_2^{dS,*} = \{E[s+l|\cdot] - \lambda_2 E[\sum_i x_2^{L_i}|\cdot]\}$, and hence

$$V^S\left(x_1^{dS}\right) = \lambda_2\left[x_2^{dS}\right]^2 = \lambda_2\left[x_2^S + \alpha^S\frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right)\right]^2.$$

Trader S's optimization problem in $t=1$ is thus $\max_{x_1^{dS}} E[x_1^{dS}(v - p_1^{dS}) + V^S(x_1^{dS})|s+\varepsilon]$, where $p_1^{dS} = \lambda_1 X_1^{dS} = \lambda_1(x_1^{dS} + \beta_1^L l + u_1)$. Since $s+\varepsilon$ is orthogonal to l, the first-order condition is

$$2\lambda_1 x_1^{dS} = \frac{\Sigma_s}{\Sigma_s + \sigma_\varepsilon^2}(s+\varepsilon) + \frac{\partial E[V|s+\varepsilon]}{\partial x_1^{dS}}.$$

Note that

$$\begin{aligned}\frac{\partial E[V|s+\varepsilon]}{\partial x_1^{dS}} &= \lambda_2 E\left[2\alpha^S\frac{1}{\beta_1^L}\left[x_2^S + \alpha^S\frac{1}{\beta_1^L}\left(x_1^{dS} - x_1^S\right)\right]|s+\varepsilon\right]\\ &= \lambda_2 2\alpha^S\frac{1}{\beta_1^L}E\left[x_2^S|s+\varepsilon\right] + 2\lambda_2\left(\alpha^S\frac{1}{\beta_1^L}\right)^2\left(x_1^{dS} - x_1^S\right).\end{aligned}$$

Since

$$E\left[x_2^S|s+\varepsilon\right] = \alpha^S E[T|s+\varepsilon] = \alpha^S\frac{(\beta_1^S/\beta_1^L)\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \Sigma_s}(s+\varepsilon),$$

the first-order condition is

$$2\lambda_1 x_1^{dS} = \frac{\Sigma_s}{\Sigma_s + \sigma_\varepsilon^2}(s+\varepsilon) + 2\lambda_2\left(\alpha^S\right)^2\frac{1}{\beta_1^L}\frac{(\beta_1^S/\beta_1^L)\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \Sigma_s}(s+\varepsilon) + 2\lambda_2\left(\frac{\alpha^S}{\beta_1^L}\right)^2\left(x_1^{dS} - x_1^S\right).$$

Note that in equilibrium $x_1^{dS} = x_1^S$, and hence

$$\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma_s}{\Sigma_s + \sigma_\varepsilon^2}\left[1 - \frac{\lambda_2}{\lambda_1}\left(\frac{\alpha^S}{\beta_1^L}\right)^2 \frac{\sigma_\varepsilon^2}{\Sigma_s + \sigma_\varepsilon^2}\right]^{-1}.$$

The second-order condition is $\lambda_1 > \lambda_2(\alpha^S/\beta_1^L)^2$. We consider only parameter values which satisfy the second-order condition.

A.1.2.2 Trader L_i's best response. *Other market participants' misperception in* $t=2$. Deviation from $x_1^{L_i}(1/I)l_i$ to $x_1^{dL_i}$ distorts the price signal by

$$T^{dL_i} = T + \frac{1}{\beta_1^L}\left(x_1^{L,dL} - x_1^L\right).$$

Hence, trader L_i's expectations of trader S's order size at $t=2$ is

$$\left[\beta_2^S\left(1-\phi_L^l\right) - \beta_2^S\phi_L^u\right]\frac{1}{I}l_i + \left[\beta_2^S\phi_L^l + \beta_2^S\phi_L^u + \alpha^S\right]\left(T + \frac{1}{\beta_1^L}\left(x_1^{dL_i} - x_1^{L_i}\right)\right)_i$$

and of all other L_j's order is

$$-\beta_2^L\phi_L^l\frac{1}{I}l_i + \left[\beta_2^L\phi_L^l + (I-1)\alpha^L\right]\left(T + \frac{1}{\beta_1^L}\left(x_1^{dL_i} - x_1^{L_i}\right)\right).$$

Price p_2 is also distorted. The market maker's best estimate of v prior to trading in $t=2$ is $s + \phi_{mm}^l(T^{dL_i})$, and after observing $X_2^{dL_i}$ it becomes

$$\lambda_2 x_2^{dL_i} + \left[\frac{1}{4C}\phi_S^l - \frac{\phi_S^l + 4C - 2}{4C}\phi_L^l - \frac{1}{4C}\phi_S^l\phi_L^u\right]\frac{1}{I}l_i + DT^{dL_i}$$

where

$$D = \left\{\phi_{mm}^l + \left(\frac{\phi_S^l + 2C - 2}{2C}\right)\left(\phi_L^l - \phi_{mm}^l\right) + 2\frac{1}{4C}\phi_S^l\left(\phi_L^u - \phi_{mm}^u\right)\right\}.$$

Trader L_i's optimal trading rule in $t=2$ after deviation in $t=1$ is the result of

$$\max_{x_2^{dL_i}} E\left[x_2^{dL_i}(s + l - p_2)\middle|\frac{1}{I}l_i,\ T^{dL_i},\ T\right].$$

Deriving the FOC and replacing the coefficients shows that the optimal order at $t=2$ after a deviation at $t=1$ is

$$x_2^{dL_i,*} = x_2^{L_i} - D\frac{1}{2\lambda_2}\frac{1}{\beta_1^L}\left(x_1^{dL_i} - x_1^{L_i}\right),$$

if the second-order condition $\lambda_2 > 0$ is satisfied.

Trader L_i's value function is

$$V^{L_i}\left(x_1^{dL_i}\right) = x_2^{dL_i,*}E\left[s + l - p_2\middle|\frac{1}{I}l_i,\ T^{dL_i},\ T\right].$$

Following the same steps as for trader S, it is easy to show that

$$V^{L_i}\left(x_1^{dL_i}\right) = \lambda_2\left[x_2^{dL_i}\right]^2 = \lambda_2\left[x_2^{L_i} - D\frac{1}{2\lambda_2}\frac{1}{\beta_1^L}\left(x_1^{dL_i} - x_1^{L_i}\right)\right]^2.$$

Trader L_i's optimization problem in $t=1$ is thus

$$\max_{x_1^{dL_i}} E\left[x_1^{dL_i}\left(v - p_1^{dL}\right) + V_2^L\left(x_1^{dL_i}\right)\middle|\frac{1}{I}l_i\right],$$

where

$$E\left[v\middle|\frac{1}{I}l_i\right] = \frac{1}{I}l_i \quad \text{and} \quad E\left[p_1^{dL}\middle|\frac{1}{I}l_i\right] = \lambda_1 x_1^{dL_i}.$$

The first-order condition is

$$2\lambda_1 x_1^{dL_i} = \frac{1}{I}l_i + \frac{\partial E\left[V^L|\frac{1}{I}l_i\right]}{\partial x_1^{L_i,dL_i}}.$$

Note that

$$\begin{aligned}\frac{\partial E\left[V^L|\frac{1}{I}l_i\right]}{\partial x_1^{L_i,dL_i}} &= -D\frac{1}{\beta_1^L}E\left[x_2^{L_i} - D\frac{1}{2\lambda_2}\frac{1}{\beta_1^L}\left(x_1^{dL_i} - x_1^{L_i}\right)\middle|\frac{1}{I}l_i\right] \\ &= -D\frac{1}{\beta_1^L}\left(\beta_2^L + \alpha^L\right)\left(\frac{1}{I}l_i\right) + (D)^2\frac{1}{2\lambda_2}\left(\frac{1}{\beta_1^L}\right)^2\left(x_1^{dL_i} - x_1^{L_i}\right),\end{aligned}$$

since

$$E\left[x_2^{L_i}\middle|\frac{1}{I}l_i\right] = \beta_2^L\left(\frac{1}{I}l_i\right) + \alpha^L E\left[T\middle|\frac{1}{I}l_i\right] = \left(\beta_2^L + \alpha^L\right)\left(\frac{1}{I}l_i\right).$$

In equilibrium $x_1^{dL_i} = x_1^{L_i}$, and hence

$$\beta_1^L = \frac{1}{2\lambda_1}\left[1 - \frac{D}{\beta_1^L}\left(\beta_2^L + \alpha^L\right)\right].$$

The second-order condition is given by $-2\lambda_1 + (D)^2\frac{1}{2\lambda_2}\left(\frac{1}{\beta_1^L}\right)^2 < 0$. Note that

$$\lambda_1 = \frac{\text{cov}[s,\ X_1] + \text{cov}[l,\ X_1]}{\text{var}[X_1]} = \frac{\text{cov}[s,\ X_1]}{\text{var}[X_1]} + \frac{\text{cov}[l,\ X_1]}{\text{var}[X_1]} = \frac{\beta_1^S\Sigma_s + \beta_1^L}{\left(\beta_1^S\right)^2\left(\Sigma + \sigma_\varepsilon^2\right) + \left(\beta_1^L\right)^2 + \sigma_{u1}^2}.$$

This fully describes the symmetric sequentially rational Bayesian Nash equilibrium for any number of L_i-traders. For tractability reasons, we primarily consider the limiting case $I \to \infty$.

A.1.3 Limiting case $I \to \infty$. Note that $\left(\phi_L^l - \phi_{mm}^l\right) \to 0$, $\left(\phi_L^u - \phi_{mm}^u\right) \to 0$, $D - \phi_{mm}^l \to 0$ as $I \to \infty$. Furthermore, the term

$$\lim_{I\to\infty} I\alpha^L = \frac{1}{\lambda_2 4D\phi_S^l}\left(\phi_{mm}^l\right)^2\left[\phi_S^l\left(\frac{\beta_1^S}{\beta_1^L}\right)^2\sigma_\varepsilon^2 - 2\left[\left(\frac{\beta_1^S}{\beta_1^L}\right)^2\sigma_\varepsilon^2 + \left(\frac{1}{\beta_1^L}\right)^2\sigma_{u1}^2\right]\right]$$

drops out of the system of equations. By slightly abusing the notation we consider from now on all parameters for the limiting case.

After replacing the ϕ-terms, the sequentially rational perfect Bayesian Nash equilibrium is given by the following system of equations.

$$\begin{aligned}\beta_1^S &= \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma + \sigma_\varepsilon^2}\left[1 - \frac{\lambda_2}{\lambda_1}\left(\frac{\alpha^S}{\beta_1^L}\right)^2\frac{\sigma_\varepsilon^2}{\Sigma + \sigma_\varepsilon^2}\right]^{-1}, \\ \beta_1^L &= \left[2\lambda_1 + \frac{1}{\left(\beta_1^L\right)^2 + \left(\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2}\beta_2^L\right]^{-1}, \\ \lambda_1 &= \frac{\beta_1^L + \beta_1^S\Sigma}{\left(\beta_1^S\right)^2\left(\Sigma + \sigma_\varepsilon^2\right) + \left(\beta_1^L\right)^2 + \sigma_{u1}^2}, \\ \alpha^S &= -\frac{1}{2\lambda_2}\frac{1}{2C}\frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2 + \left(\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2},\end{aligned}$$

$$\beta_2^S = \frac{1}{2\lambda_2}\frac{1}{2C}\frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2+\sigma_{u1}^2},$$

$$\beta_2^L = \frac{1}{2\lambda_2}\frac{2C-1}{C},$$

$$(\lambda_2)^2 = \frac{\left(1-\frac{\left(\beta_1^L\right)^2+2\sigma_{u1}^2}{4C\left[\left(\beta_1^L\right)^2+\sigma_{u1}^2\right]}\right)\frac{\left(\beta_1^L\right)^2+2\sigma_{u1}^2}{4C\left[\left(\beta_1^L\right)^2+\sigma_{u1}^2\right]}\left[\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2\right]}{\sigma_{u2}^2\left[\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2\right]},$$

$$-\frac{\left(\frac{\beta_1^L}{4C\left[\left(\beta_1^L\right)^2+\sigma_{u1}^2\right]}\right)^2\left[\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2\right]\sigma_{u1}^2}{\sigma_{u2}^2\left[\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2\right]},$$

$$C = \frac{\frac{3}{4}\left(\beta_1^L\right)^2+\sigma_{u1}^2}{\left(\beta_1^L\right)^2+\sigma_{u1}^2} - \frac{1}{4}\frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2}.$$

A.2 Proof of Proposition 2

A.2.1 Trade reversal. Trader S expects to trade

$$E\left[\alpha^S T + \beta_L^2\left(l + \frac{1}{\beta_1^L}u_1\right)\middle| s+\varepsilon\right]$$

in $t=2$. Note that

$$E[T|s+\varepsilon] = \frac{\beta_1^S}{\beta_1^L}\frac{\sigma_\varepsilon^2}{\Sigma+\sigma_\varepsilon^2}(s+\varepsilon).$$

Since $\alpha^S < 0$ and all other terms are positive, trader S expects to sell (buy) $\alpha^S(\beta_1^S/\beta_1^L)(\sigma_\varepsilon^2/(\Sigma+\sigma_\varepsilon^2))(s+\varepsilon)$ stocks in $t=2$ if he buys (sells) stocks in $t=1$.

A.2.2 Aggressive trading. Trader S trades excessively, that is, $\beta_1^S > \beta_1^{S,\text{myopic}}$ (given the strategies of the other market participants).

Let us write

$$\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\left[1-\frac{\lambda_2}{\lambda_1}\left(\frac{\alpha^S}{\beta_1^L}\right)^2\frac{\sigma_\varepsilon^2}{\Sigma+\sigma_\varepsilon^2}\right]^{-1} \quad \text{as } \beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}[1+M],$$

where

$$M = \left[\frac{\lambda_1}{\lambda_2}\left(\frac{\beta_1^L}{\alpha^S}\right)^2\frac{\Sigma+\sigma_\varepsilon^2}{\sigma_\varepsilon^2}-1\right]^{-1} \quad \text{and} \quad \beta_1^{S,\text{myopic}} = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}.$$

Note that $M>0$ since the second-order condition requires $\lambda_1 > \lambda_2(\alpha^S/\beta_1^L)^2$.

Furthermore, notice that for $\sigma_\varepsilon \to 0$, the M goes to zero. Hence, the trade reversal and excess trading vanish in the limiting case.

A.3 Proof of Proposition 3

This proposition compares two different equilibria: one with information leakage and one without. Let us denote all variables of the former equilibrium with upper bars and those of the equilibrium without information leakage with hats. Let us first prove the following lemma,

Lemma 2. $(\bar{\lambda}_1)^2 = \frac{1}{4\sigma_{u1}^2}\left\{\{(1-\bar{M}^2)\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}+(1-\bar{K}^2)\right\}$ *and* $(\hat{\lambda}_1)^2 = \frac{1}{4\sigma_{u1}^2}(1-\hat{K}^2)$.

Proof of Lemma 2. Recall

$$\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}[1+M],$$

where

$$M = \left[\frac{\lambda_1}{\lambda_2}\left(\frac{\beta_1^L}{\alpha^S}\right)^2\frac{\Sigma+\sigma_\varepsilon^2}{\sigma_\varepsilon^2}-1\right]^{-1} \quad \text{and} \quad \beta_1^L = \frac{1}{2\lambda_1}[1-K],$$

where

$$K = \frac{\frac{1}{2\lambda_1}\frac{1}{\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2}\beta_2^L}{1+\frac{1}{2\lambda_1}\frac{1}{\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2}\beta_2^L}$$

and

$$\lambda_1 = \frac{(1/2\lambda_1)\left(\Sigma^2/\left(\Sigma+\sigma_\varepsilon^2\right)\right)[1+M]+(1/2\lambda_1)[1-K]}{(1/4(\lambda_1)^2)[1+M]^2\left(\Sigma/\left(\Sigma+\sigma_\varepsilon^2\right)\right)^2\left(\Sigma+\sigma_\varepsilon^2\right)+(1/4(\lambda_1)^2)[1-K]^2+\sigma_{u1}^2}.$$

Collecting all λ_1-terms yields,

$$(\lambda_1)^2\sigma_{u1}^2 = \left\{\frac{1}{2}[1+M]-\frac{1}{4}[1+M]^2\right\}\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}+\left\{\frac{1}{2}[1-K]-\frac{1}{4}[1-K]^2\right\}$$
$$(\lambda_1)^2 = \frac{1}{\sigma_{u1}^2}\left\{\frac{1}{4}\left(1-M^2\right)\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}+\frac{1}{4}\left(1-K^2\right)\right\}.$$

Note that in the case without information leakage the first term in the brackets is zero. ■

Recall that

$$M = \frac{1}{\frac{\lambda_1}{\lambda_2}\left(\frac{\beta_1^L}{\alpha^S}\right)^2\frac{\Sigma+\sigma_\varepsilon^2}{\sigma_\varepsilon^2}-1} < \frac{\sigma_\varepsilon^2}{\Sigma}$$

follows simply from trader S's SOC, $\lambda_1 > \lambda_2(\alpha^S/\beta_1^L)^2$. Hence for $\sigma_\varepsilon^2 < \Sigma$, $M < 1$. Note also that $M < 1$ as long as the *short-term trader's* expected capital gain in $t=1$ is positive since a competitive myopic insider, who makes no profit in expectation, would submit an order of size $\frac{1}{\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}(s+\varepsilon)$. Appendix A.5 shows that the expected date $t=1$ profit is $\beta_1^S(\Sigma-\lambda_1\beta_1^S[\Sigma+\sigma_\varepsilon^2])$, which can be rewritten as $\frac{1}{4\lambda_1}\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}(1-M)$ and is non-positive for $M \geq 1$.

For $M < 1$, $\bar{\lambda}_1 > \hat{\lambda}_1$. In the case of myopic background traders, $K=0$ and $\beta_1^L = (1/2\lambda_1)$. Hence, $\bar{\beta}_1^L < \hat{\beta}_1^L$.

A.3.1 Prior to public announcement. $\bar{p}_1$ is more informative than $\hat{p}_1$, that is, $\text{var}[s+l|\bar{X}_1] < \text{var}[s+l|\hat{X}_1]$.

$$\text{var}[s+l|\bar{X}_1] = \Sigma+1-\bar{\lambda}_1\text{Cov}[s+l,\bar{X}_1] = \Sigma+1-\lambda_1\bar{\beta}_1^S\Sigma-\bar{\lambda}_1\bar{\beta}_1^L = \left(1-\lambda_1\bar{\beta}_1^S\right)\Sigma+\frac{1}{2}.$$

In contrast,

$$\text{var}\left[s+l|\hat{X}_1\right] = \Sigma+1-\bar{\lambda}_1\text{Cov}\left[l,\hat{X}_1\right] = \Sigma+1-\hat{\lambda}_1\hat{\beta}_1^L = \Sigma+\frac{1}{2}.$$

A.3.2 Prior to trading in $t=2$

$$\operatorname{var}\left[l|\bar{T}=l+\frac{\bar{\beta}_1^S}{\bar{\beta}_1^L}\varepsilon+\frac{1}{\bar{\beta}_1^L}u_1\right]>\operatorname{var}\left[l|\hat{T}=l+\frac{1}{\hat{\beta}_1^L}\right]\Leftrightarrow\operatorname{var}\left[\frac{\bar{\beta}_1^S}{\bar{\beta}_1^L}\varepsilon+\frac{1}{\bar{\beta}_1^L}u_1\right]>\operatorname{var}\left[\frac{1}{\hat{\beta}_1^L}u_1\right].$$

Recall that

$$\beta_1^L=\frac{1}{2\lambda_1}\quad\text{and}\quad\bar{\beta}_1^S=\frac{1}{2\bar{\lambda}_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}[1+M].$$

Hence, we have to show that

$$[1+M]^2\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\sigma_\varepsilon^2+(2\bar{\lambda}_1)^2\sigma_{u_1}^2>\left(2\hat{\lambda}_1\right)^2\sigma_{u_1}^2.$$

Substituting in for $\bar{\lambda}_1$ and $\hat{\lambda}_1$ from Lemma 2, we obtain

$$[1+M]^2\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\sigma_\varepsilon^2+\left[1-M^2\right]\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}+1>1,$$

which reduces to

$$M\left[\sigma_\varepsilon^2-\Sigma\right]+\sigma_\varepsilon^2+\Sigma>0 \tag{1}$$

Note that trader S's

$$\text{SOC: }\lambda_1\geq\lambda_2\left(\frac{\alpha^S}{\beta_1^L}\right)^2\Leftrightarrow\frac{\lambda_1}{\lambda_2}\left(\frac{\beta_1^L}{\alpha^S}\right)^2>1$$

implies that

$$M=1\Big/\left[\frac{\lambda_1}{\lambda_2}\left(\frac{\beta_1^L}{\alpha^S}\right)^2\frac{\Sigma+\sigma_\varepsilon^2}{\sigma_\varepsilon^2}-1\right]>0\quad\text{and } M<1\Big/\left[\frac{\Sigma+\sigma_\varepsilon^2}{\sigma_\varepsilon^2}-1\right]=\frac{\sigma_\varepsilon^2}{\Sigma}.$$

Hence,

1. for $\sigma_\varepsilon^2>\Sigma$, Equation (1) is always satisfied since $M>0$.
2. for $\sigma_\varepsilon^2<\Sigma$, Equation (1) is

$$M<\frac{\Sigma+\sigma_\varepsilon^2}{\Sigma-\sigma_\varepsilon^2}=1+\frac{2\sigma_\varepsilon^2}{\Sigma-\sigma_\varepsilon^2},$$

   which is also satisfied since $M<\sigma_\varepsilon^2/\Sigma<1$.

Notice also that $M<1$ implies that $\bar{p}_1$ is less informationally efficient than $\hat{p}_1$, that is,

$$\operatorname{var}[E[s|s+\varepsilon]+l|\bar{X}_1]+\operatorname{var}[l|\bar{X}_1]>\operatorname{var}\left[l|\hat{X}_1\right]$$

since

$$\bar{\beta}_1^L<\hat{\beta}_1^L\quad\text{and }\operatorname{var}\left[l|\bar{\beta}_1^L l+\bar{\beta}_1^S(s+\varepsilon)+u_1\right]>\operatorname{var}\left[l|\hat{\beta}_1^L l+u_1\right].$$

A.3.3 After trading in $t=2$. The continuation game in $t=2$ corresponds to a static Kyle (1985) model with multiple insiders. Note that $M<1$ implies that

$$\bar{\lambda}_1^2=\frac{1}{4\sigma_{u1}^2}\left\{\left(1-\bar{M}^2\right)\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}+1\right\}>\hat{\lambda}_1^2=\frac{1}{4\sigma_{u1}^2}$$

and $\bar{\beta}_1^L<\hat{\beta}_1^L$. Hence, the public price signal $\hat{T}$ in the case without information leakage is more informative than the private information of trader S in $t=2$, $l+(1/\bar{\beta}_1^L)u_1$, in the case of information leakage. From this follows immediately that the prices are more informationally efficient and more informative in the case without information leakage from $t=2$ onwards.

A.4 Proof of Proposition 4

Note that $\tilde{\alpha}_1^S = 1/2\tilde{\lambda}_1$ and the rest of the analysis is analogous to the one in Proposition 1. Therefore, we only add a tilde to all the coefficients. In any mixed strategy equilibrium, trader S has to be indifferent between any x_1^S, that is, $\tilde{\lambda}_1 = \tilde{\lambda}_2(\tilde{\alpha}^S/\tilde{\beta}_1^L)^2$. In addition, the second-order condition of long-run-information traders must hold

$$\tilde{\lambda}_1 \geq \frac{1}{4\tilde{\lambda}_2}\tilde{D}^2\left(\frac{1}{\tilde{\beta}_1^L}\right)^2,$$
$$\tilde{\lambda}_2\left(\tilde{\alpha}^S/\tilde{\beta}_1^L\right)^2 \geq \frac{1}{4\tilde{\lambda}_2}\tilde{D}^2\left(\frac{1}{\tilde{\beta}_1^L}\right)^2.$$

Note that

$$\alpha^S = \frac{1}{4C\tilde{\lambda}_2}\frac{\left(\tilde{\beta}_1^L\right)^2}{\left(\tilde{\beta}_1^L\right)^2+\left(\tilde{\beta}_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2}$$

and recall

$$\tilde{D} = \frac{\left(\tilde{\beta}_1^L\right)^2}{\left(\tilde{\beta}_1^L\right)^2+\left(\tilde{\beta}_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2} \quad \text{for } I \to \infty.$$

Hence, both necessary conditions are satisfied only if $\frac{1}{4C^2} > 1$. Since

$$C = \frac{\frac{3}{4}\left(\beta_1^L\right)^2+\sigma_{u1}^2}{\left(\beta_1^L\right)^2+\sigma_{u1}^2} + \frac{1}{4}\frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2+\left(\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2} > \frac{1}{2},$$

this is never satisfied.

A.5 Expected profit of short-run-information trader

Trader S's expected profit is

$$E\left[x_1^S\left(\frac{\Sigma_s}{\Sigma_s+\sigma_\varepsilon^2}(s+\varepsilon)-\lambda_1 x_1^S\right)\right]+\lambda_2 E\left[\left(x_2^S\right)^2\right].$$

That is,

$$E\left[\beta_1^S(s+\varepsilon)\left(\frac{\Sigma_s}{\Sigma_s+\sigma_\varepsilon^2}(s+\varepsilon)-\lambda_1\beta_1^S(s+\varepsilon)\right)\right]$$
$$+\lambda_2 E\left[\left(\beta_2^S\left(l+\frac{1}{\beta_1^L}u_1\right)+\alpha^S\left(l+\frac{\beta_1^S}{\beta_1^L}\varepsilon_1+\frac{1}{\beta_1^L}u_1\right)\right)^2\right].$$

Taking expectations yields

$$\beta_1^S\left(\Sigma-\lambda_1\beta_1^S\left[\Sigma+\sigma_\varepsilon^2\right]\right)+\lambda_2\left[\beta_2^S+\alpha^S\right]^2\left[1+\left(\frac{1}{\beta_1^L}\right)^2\sigma_1\right]+\lambda_2\left(\alpha^S\right)^2\left[\left(\frac{\beta_1^S}{\beta_1^L}\right)^2\sigma_\varepsilon^2\right].$$

A.6 Generalization to multiple short-term-information traders setting

Proposition 5. *A sequentially rational Bayesian Nash equilibrium in which all pure trading strategies are of the linear form*

$$x_1^{S_j} = \beta_1^S(s+\varepsilon), \quad x_1^{L_i} = \beta_1^L\left(\frac{1}{I}l_i\right)$$
$$x_2^{S_j} = \alpha^S T + \beta_2^S\left(l + \frac{1}{\beta_1^L}u_1\right), \quad x_2^{L_i} = \alpha^L T + \beta_2^L\left(\frac{1}{I}l_i\right)$$

and the market maker's pricing rule is of the linear form

$$p_1 = E[v|X_1] = \lambda_1 X_1,$$
$$p_2 = E[v|X_1,\, s,\, X_2] = s + \frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2 + \left(\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2}T + \lambda_2\{X_2 - E[X_2|X_1,\, s]\},$$

with $T = (X_1 - \beta_1^S s)/\beta_1^L$, is determined by the following system of equations:

$$\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\left[1 - \frac{J}{J+1}\frac{\lambda_2}{\lambda_1}\frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2+\Sigma_s}\frac{1}{\left(\beta_1^L\right)^2}\left(2\left(\alpha_2^S\right)^2 - \frac{1}{2\lambda_2}\frac{(J-1)}{(J+1)C_J}\phi_S^l\alpha_2^S\right)\right]^{-1},$$
$$\alpha^S = \frac{-1}{2\lambda_2(J+1)C_J}\frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2 + \left(J\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2};$$
$$\beta_2^S = \frac{1}{2\lambda_2}\frac{1}{(J+1)C_J}\frac{\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2 + \sigma_{u1}^2},$$
$$\beta_1^L = \left[2\lambda_1 + \frac{1}{\left(\beta_1^L\right)^2 + \left(\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2}\beta_2^L\right]^{-1},$$
$$\alpha^L \to 0,$$
$$\beta_2^L = \frac{1}{2\lambda_2}\frac{2C_J - 1}{C_J},$$
$$\lambda_1 = \frac{\beta_1^L + J\beta_1^S\Sigma}{\left(J\beta_1^S\right)^2\left(\Sigma+\sigma_\varepsilon^2\right) + \left(\beta_1^L\right)^2 + \sigma_{u1}^2},$$
$$\lambda_2 = \frac{\left(\beta_2^L + J\beta_2^S\right)\mathrm{var}[l|T]}{\left(\beta_2^L + J\beta_2^S\right)^2\mathrm{var}[l|T] + \left(\frac{\beta_2^S}{\beta_1^L}\right)^2\mathrm{var}[u_1|T] + \sigma_{u2}^2},$$
$$C_J = \frac{\sigma_{u1}^2 + \frac{J+2}{2(J+1)}\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2 + \sigma_{u1}^2} - \frac{1}{2(J+1)}\frac{\left(\beta_1^L\right)^2}{\left(\left(\beta_1^L\right)^2 + \left(J\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2\right)};$$

if the second-order conditions

$$\lambda_1 > \lambda_2\left[\frac{-\beta_1^L}{4\lambda_2(J+1)C_J}\left(\frac{2}{\left(\beta_1^L\right)^2 + \left(J\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2} - \frac{J-1}{\left(\beta_1^L\right)^2 + \sigma_{u1}^2}\right)\right]^2,$$
$$\lambda_1 > \frac{1}{4\lambda_2}\frac{\left(\beta_1^L\right)^2}{\left[\left(\beta_1^L\right)^2 + \left(J\beta_1^S\right)^2\sigma_\varepsilon^2 + \sigma_{u1}^2\right]^2}$$

and $\lambda_2 > 0$ are satisfied.

It follows that $\lim_{J\to\infty} J\alpha^S = \frac{-1}{2\lambda_2}\frac{(\beta_1^L)^2+\sigma_{u1}^2}{\sigma_{u1}^2+\frac{1}{2}(\beta_1^L)^2}\frac{(\beta_1^L)^2}{(\beta_1^L)^2+(J\beta_1^S)^2\sigma_\varepsilon^2+\sigma_{u1}^2}$,

$$\lim_{J\to\infty} J\beta_1^S = \frac{1}{2\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}.$$

Furthermore, C_J simplifies to

$$\lim_{J\to\infty} C_J = \frac{\sigma_{u1}^2+\frac{1}{2}\left(\beta_1^L\right)^2}{\left(\beta_1^L\right)^2+\sigma_{u1}^2}.$$

Proposition 6. *Proposition 3 extends to the case with multiple short-term-information traders.*

Proof of Proposition 6. We can write

$$J\beta_1^S = \frac{J}{(J+1)\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}[1+M_J]$$

and

$$\beta_1^L = (1/2\lambda_1)[1-K],$$

where

$$K = \frac{\frac{1}{2\lambda_1}\frac{1}{\left(\beta_1^L\right)^2+\left(J\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2}\beta_2^L}{1+\frac{1}{2\lambda_1}\frac{1}{\left(\beta_1^L\right)^2+\left(J\beta_1^S\right)^2\sigma_\varepsilon^2+\sigma_{u1}^2}\beta_2^L}.$$

Step 1: As long as expected profit in first trading round of traders S is positive, $M_J \leq 1/J$.
The expected profit in the first period is

$$E\left[x_1^S\left(\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}(s+\varepsilon)-\lambda_1 J x_1^S\right)\right] = \beta_1^S\left(\Sigma-\lambda_1 J\beta_1^S\left(\Sigma+\sigma_\varepsilon^2\right)\right)\geq 0 \text{ iff } \lambda_1 J\beta_1^S\left(\Sigma+\sigma_\varepsilon^2\right)<\Sigma$$

Substituting in

$$J\beta_1^S = \frac{J}{(J+1)\lambda_1}\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}[1+M_J]$$

yields the result.

Step 2: λ_1 in case of information leakage is higher, that is, $\bar{\lambda}_1 \geq \hat{\lambda}_1$. Collecting all λ_1-terms

$$\lambda_1 = \frac{\frac{J}{(J+1)\lambda_1}\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}[1+M_J]+\frac{1}{2\lambda_1}[1-K]}{\left(\frac{J}{J+1}\right)^2\frac{1}{(\lambda_1)^2}[1+M_J]^2\left(\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\right)^2\left(\Sigma+\sigma_\varepsilon^2\right)+\frac{1}{4(\lambda_1)^2}[1-K]^2+\sigma_{u1}^2}$$

results in

$$(\lambda_1)^2 = \frac{1}{\sigma_{u1}^2}\left\{\left(\frac{J}{J+1}\right)^2\left[\frac{1}{J}-\frac{J-1}{J}M_J-M_J^2\right]\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2}+\frac{1}{4}\left(1-K^2\right)\right\}.$$

Recall that we consider the case where $K=0$. Since $M_J \leq \frac{1}{J}$, $[\frac{1}{J}-\frac{J-1}{J}M_J-M_J^2]\geq 0$, $\bar{\lambda}_1 \geq \hat{\lambda}_1$.

Step 3: Proposition 3 holds for the general case.

1. Prior to the public announcement, $\bar{p}_1$ is more informative than $\hat{p}_1$. Following the same steps as in Proposition 3,

$$\mathrm{var}[s+l|\bar{X}_1] = \left(1-\lambda_1 J\bar{\beta}_1^S\right)\Sigma + \frac{1}{2} < \mathrm{var}\left[s+l|\hat{X}_1\right] = \Sigma + \frac{1}{2}.$$

2. Prior to trading in $t=2$, $\hat{p}_1$ is more informative and more informationally efficient than $\bar{p}_1$, if

$$\mathrm{var}\left[\frac{1}{\hat{\beta}_1^L}u_1\right] < \mathrm{var}\left[\frac{I\beta_1^S}{\bar{\beta}_1^L}\varepsilon\right] + \mathrm{var}\left[\frac{1}{\bar{\beta}_1^L}u_1\right].$$

Substituting out β-terms, yields

$$\left[\left(2\hat{\lambda}_1\right)^2 - \left(2\bar{\lambda}_1\right)^2\right]\sigma_{u_1}^2 < \left(\frac{2I}{I+1}\right)^2 (1+M_J)^2 \left(\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\right)^2 \sigma_\varepsilon^2.$$

Using the result of Step 2, we get

$$\left[\frac{1}{4\sigma_{u_1}^2} - \left(\frac{J}{(J+1)^2\sigma_{u_1}^2}(1+M_J)(1-JM_J)\frac{\Sigma^2}{\Sigma+\sigma_\varepsilon^2} + \frac{1}{4\sigma_{u_1}^2}\right)\right]4\sigma_{u_1}^2 < \left(\frac{2J}{J+1}\right)^2 (1+M_J)^2 \left(\frac{\Sigma}{\Sigma+\sigma_\varepsilon^2}\right)^2 \sigma_\varepsilon^2.$$

This simplifies to

$$M_J < \frac{1}{J} + \frac{J+1}{J}\frac{\sigma_\varepsilon^2}{\Sigma},$$

which is satisfied by Step 1.

3. The proof of Proposition 3 applies directly for the case after trading in $t=2$. ■

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