Rational Information Leakage

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Abstract

Empirical evidence suggests that information leakage in capital markets is common. We present a trading model to study the incentives of an informed trader (e.g., a well-informed insider) to voluntarily leak information about an asset’s value to another independent trader. Our model shows that, while leaking information dissipates the insider’s information advantage about the asset’s value, it enhances his information advantage about the asset’s execution price relative to other informed traders. These two effects are countervailing. When the profit impact from enhanced information about the execution price dominates, the insider has incentives to leak some of his private information. We label this rational information leakage and discuss its implications for empirical research and the regulation of insider trading.

Keywords: Information leakage, insider trading, securities regulations.

JEL Classifications: G14, G18, D82.
1 Introduction

The role of information and information-based trading in capital markets has long been a topic of interest to investors, financial regulators, as well as academics. Information-based trades are often credited with contributing to the efficiency of capital markets but they are alleged also to lead to wealth transfers among investors, particularly when such trades are based on private (perhaps inside) information (e.g., Bhattacharya and Nicodano, 2001; Jeng, Metrick and Zeckhauser, 2003; De Franco, Lu and Vasvari, 2007). An important channel through which private information affects trades is through information leakage. Evidence suggests that information leakage is common. For example, evidence of abnormal changes in stock prices and trading volumes shortly before analyst recommendations or major corporate events is often attributed to leaked information (Irvine, Lipson and Puckett, 2007; Christophe, Ferri and Hsieh, 2010). Similarly, Khan and Lu (2011) suggest that leaked information can explain the increased short-sale activities of both market makers and non-market makers shortly before the sale of shares by corporate executives.

If information leakage is an important channel through which private information affects stock prices and trading behavior, then it is important to understand why insiders are motivated to leak their private information. The standard intuition holds that some informed traders, e.g., insiders or executives hindered from actively trading in their firms’ shares, sell or reveal their private information to related parties and associates who then trade on the private information for their joint benefit. For instance, the U.S. Securities and Exchange Commission (SEC), in its ongoing campaign against insider trading, has noted the rise of so-called “expert networks” where insiders with access to private information are hired as hedge fund consultants (Zuckerman and Pulliam, 2010). In this paper, we argue that informed traders’ incentives for leaking information extend beyond the above standard logic. In particular, we show that an insider who is allowed to trade actively may voluntarily reveal some of his private information to an independent (i.e., unrelated) third party and yet ben-

1 Of course, private information can also be stolen by (or involuntarily leaked to) individuals intent on exploiting informed investors’ private information. For example, in 2009, the U.S. Securities Exchange Commission (SEC) charged a major brokerage firm for illegally allowing traders from other firms to listen to confidential trading information of its institutional customers without their knowledge using “Squawk Boxes” (SEC press release #2009-54).
enefit from this leakage even in the absence of explicit payments or claims to the other party’s trading profits.

To illustrate an informed trader’s incentives to leak private information to another trader, we consider a standard Kyle model (Kyle, 1985) where a single well informed insider trades a single security in a market populated with other less well informed traders as well as liquidity traders. We characterize information leakage as the insider’s decision to provide a garbled version of his information to an unrelated informed trader whom we label as a designated trader. We find that leaking information to the designated trader (without receiving compensation in return) affects the insider’s expected trading profits in two ways. The first effect is straightforward; leaking information to another trader dissipates the insider’s information advantage concerning the fundamental value of the asset. This reduces the insider’s trading profit. The second effect reflects the fact that leaking information increases the insider’s information advantage concerning the execution price of the asset relative to other informed traders. This is because the designated trader’s reliance on the leaked information implies that the asset’s price is also sensitive to the noise or non-fundamental component of the leaked information which is observable by the insider. This effect increases the insider’s trading profit.

The two effects of leaking information on the insider’s trading profit described above are countervailing. Clearly, when the profit impact of the first effect dominates the profit impact of the second effect, the insider has no incentive to leak information to a designated trader. Conversely, when the second effect dominates the first effect, information leakage is rational. We also show that information leakage helps the designated trader but is detrimental to other informed traders in the marketplace. This latter finding is consistent with recent empirical evidence that institutional investor trades (which are analogous to other informed traders in our model) are inversely associated with insider trades (Sias and Whidbee, 2010). Our finding also implies that other informed traders will reduce their information collection efforts as the marginal benefit of doing so declines due to information leakage. Finally, our model demonstrates that information leakage makes price of the security informationally more efficient and may enhance market depth and renders the uninformed liquidity traders better-off by dampening liquidity traders’ losses. This latter result complements Leland’s
finding that more insider trading can benefit liquidity traders by lowering the cost of capital.

Our contribution can be summarized as follows: First, we characterize a novel channel of information leakage and show that such leakage might indeed be rational. This is in sharp contrast to the standard intuition in the information selling literature (e.g., Admati and Pfleiderer, 1986, 1988, 1990; Allen, 1990; Garcia and Sangiorgi, 2011) that an informed insider cannot benefit from such leakage without a commensurate fee or direct compensation. Second, our study provides a possible explanation for empirical findings that find abnormal trading behavior immediately prior to insider trades, analyst stock recommendations, or major corporate events. In this spirit, we identify settings where information leakage can occur and highlight potential empirical implications. For example, the insider is more likely to leak information when there are more informed traders, when other traders are relatively well informed, and/or when the underlying asset has more volatile cash flows.

Finally, our paper contributes to the debate on how to regulate insider trading. Information leakage has been a critical concern of capital market regulators and has attracted significant attention from academics over several decades. The wealth transfer effect from other informed traders to the designated trader and insider in our model illustrates that those who diligently collect and process information (i.e., other informed traders in our model) are not appropriately rewarded for their efforts. Thus, understanding this rational mechanism would help regulators by focusing on underlying incentives rather than simply building a Chinese Wall.

While prior theoretical studies have not considered the type of information leakage we highlight in this paper, in a broad sense our model is related to existing theoretical research investigating the role of information in financial markets. The closest studies are van Bommel (2003) and Brunnermeier (2005), both of which use a dynamic Kyle model to show that an informed trader can exploit his information twice; first when he receives information, and second when he expects the price to overshoot. In van Bommel (2003), an informed investor with limited investment capacity spreads imprecise rumours to a group of followers whose collective trading can cause the price to overshoot. In Brunnermeier (2005), an insider receives a noisy signal about a forthcoming public announcement and the noise contained
in his signal provides the insider an information advantage about how much the price will likely overshoot after the public announcement, as he knows best the extent to which his information is already reflected in the pre-announcement price. Our paper is consistent with both studies which emphasize the importance of the noise or non-fundamental component of the leakage information as a source of information advantage for the insider.²

Our study is also related to a number of studies examining the effect of selling information in financial markets; for example, Admati and Pfleiderer (1986, 1988, 1990), Benabou and Laroque (1992), Fishman and Hagerty (1995), Veldkamp (2006), Cespa (2008) and Garcia and Vanden (2009). These studies are typically cast in the context of investment and brokerage analysts who collect and process fundamental information and then sell the information to other traders either directly or through a mutual fund. In contrast, our paper studies an insider’s information leakage decision and emphasizes the insider’s tradeoff between losing information advantage about the fundamental value of the asset and gaining information advantage about the asset’s future execution price. Our analysis extends this information selling literature by showing that, even in the absence of sales revenue, an informed trader may be motivated to leak information to an unrelated party.

The third strand of related literature are the studies examining the implication of disclosures using strategic Kyle-type models (e.g., Bushman and Indjejikian, 1995; Huddart, Hughes and Levine, 2001). For instance, Bushman and indjejikian (1995) demonstrate that publicly disclosing (or leaking) information to all market participants, including the market maker, can benefit an insider by driving out some informed traders who would otherwise stay in the market. In contrast, the insider in our model leaks the information to a single designated trader or a select few traders who benefit from the information at the expense of all other traders in the marketplace. Moreover, in contrast to public disclosure, private leakage of information raises the possibility that the insider is more strategic in the sense that he prefers to leak the information to certain types of traders more than others. Although a full characterization of this issue is beyond the scope of this paper, our numerical analysis suggests that, among all informed traders, the insider prefers to leak the information to the

²The general idea that noise or non-fundamental information is a source of information advantage is also illustrated in Cheynel and Levine (2010) who suggest that sell-side analysts can profit from the disclosure of non-fundamental information about order flow.
less informed.

The remainder of the paper is organized as follows. Section 2 describes the model setup and equilibrium. Section 3 shows the possibility of rational information leakage, outlining the conditions that must be met for the insider to leak proprietary information. Section 4 discusses the robustness of our results to some alternative settings. Section 5 concludes.

2 The Model

2.1 Setup

Consider a Kyle-type model with a single risky-asset whose uncertain liquidating value is represented by

\[ \tilde{\varepsilon} \sim N(\bar{\varepsilon}, 1/e), \text{ with } \bar{\varepsilon} \in \mathbb{R} \text{ and } e > 0. \]  

There are two types of risk-neutral informed traders: (1) an insider who privately observes \( \tilde{\varepsilon} \); and, (2) \( N+1 \) informed traders who observe distinct (but equally precise) signals,

\[ \tilde{y}_j = \tilde{\varepsilon} + \tilde{n}_j, \text{ with } \tilde{n}_j \sim N(0, 1/h) \text{ and } h > 0, \]

where \( j = D, 1, 2, \ldots, N \). Descriptively, the insider in our model can be thought of as a hedge fund manager or corporate executive with superior information about a firm’s prospects, while the other informed traders in our model can be thought of as institutional investors that actively engage in information acquisition but nonetheless are less well informed than corporate insiders.

Before trade occurs, we assume that the insider leaks a garbled version of his information

\[ \tilde{y}_L = \tilde{\varepsilon} + \tilde{\zeta}, \text{ with } \tilde{\zeta} \sim N(0, 1/z) \text{ and } z \geq 0, \]

to one of the other informed traders which we denote as trader D, which means a “designated trader”. In Section 3, we address the insider’s incentive to reveal \( \tilde{y}_L \) to trader D; for now, we assume \( \tilde{y}_L \) is exogenously specified so that trader D has two pieces of information \( \tilde{y}_{LD} \) and \( \tilde{y}_L \). We note that the precision of \( \tilde{\zeta} \) dictates the extent to which the insider’s information
is leaked to trader D. When $z = 0$, there is no information leakage because the signal $\tilde{y}_L$ is uninformative about $\tilde{\xi}$. In contrast, when $z \to \infty$, there is full leakage in the sense that trader D is as equally well informed as the insider.\(^3\)

There are risk-neutral liquidity traders whose net order is represented by

$$\tilde{u} \sim N\left(0, \sigma_u^2\right), \text{with } \sigma_u > 0.$$ \hspace{1cm} (4)

The market-maker is risk-neutral and sets the price according to the weak efficiency rule:

$$\tilde{p} = E(\tilde{\xi}|\tilde{\omega}) = \tilde{\xi} + \lambda \tilde{\omega},$$ \hspace{1cm} (5)

where $\tilde{\omega}$ is the aggregate market order flow

$$\tilde{\omega} = \tilde{x}_I + \tilde{x}_D + \sum_{j=1}^{N} \tilde{x}_j + \tilde{u},$$ \hspace{1cm} (6)

with $\tilde{x}_I$, $\tilde{x}_D$ and $\tilde{x}_j$ representing the orders submitted by the insider, the designated trader and the $j$-th other informed traders. Parameter $\lambda$ will be endogenously determined.

### 2.2 Equilibrium

Any trader $i$ (insider, designated trader or other informed) taking the strategies of others and the price function as given solves

$$\max_{\tilde{x}_i} E\left[ (\tilde{\xi} - \tilde{p}) \tilde{x}_i | I_i \right],$$

where $I_i$ is his information set.

The first-order condition is

$$E\left[ \frac{\partial (\tilde{\xi} - \tilde{p})}{\partial \tilde{x}_i} \tilde{x}_i + (\tilde{\xi} - \tilde{p}) \bigg| I_i \right] = 0,$$ \hspace{1cm} (7)

\(^3\)The model can also accommodate a setting where the insider leaks (potentially distinct) signals to several other designated traders. However, in what follows we illustrate our intuition with a simpler model that features only one designated trader that observes the leaked information.
which, by $\tilde{p} = \bar{\varepsilon} + \lambda \tilde{\omega} = \bar{\varepsilon} + \lambda \left( x_I + \tilde{x}_D + \sum_{j=1}^{N} \tilde{x}_j + \tilde{u} \right)$, implies that the optimal order flow is

$$\tilde{x}_i^* = \frac{1}{2\lambda} \left[ E (\bar{\varepsilon} - \tilde{\varepsilon} | \mathcal{I}_i) - \lambda \sum_{k \neq i} E (\tilde{x}_k | \mathcal{I}_i) \right].$$  

(8)

In addition, the first-order condition implies that $E (\bar{\varepsilon} - \tilde{p} | \mathcal{I}_i) = \lambda \tilde{x}_i^*$ and thus the optimal expected profit is

$$\pi_i = E \{ E [(\bar{\varepsilon} - \tilde{p}) \tilde{x}_i^* | \mathcal{I}_i] \} = \lambda \text{Var} (\tilde{x}_i^*),$$  

(9)

where the last equality follows because, as we show shortly, the equilibrium trading strategies have a mean of zero.

Given the information structure, the optimal trading strategies of the insider, the designated trader or the $j$-th other informed trader take the following linear structure:

$$\begin{bmatrix}
\tilde{x}_I = \alpha_I (\bar{\varepsilon} - \tilde{\varepsilon}) + \alpha_L (\tilde{y}_L - \bar{\varepsilon}) \\
\tilde{x}_D = \beta_D \left[ E (\bar{\varepsilon} | \tilde{y}_D, \tilde{y}_L) - \bar{\varepsilon} \right] + \beta_L (\tilde{y}_L - \bar{\varepsilon}) \\
\tilde{x}_j = \gamma \left[ E (\bar{\varepsilon} | \tilde{y}_j) - \bar{\varepsilon} \right]
\end{bmatrix},$$  

(10)

where coefficients $\alpha_I, \alpha_L, \beta_D, \beta_L$ and $\gamma$ are endogenously determined. The coefficients $\alpha_I$ and $\beta_D$ respectively represent the trading aggressiveness of the insider and the designated trader when they make decisions based on their predictions regarding $\tilde{\varepsilon}$ with their own information. The coefficients $\alpha_L$ and $\beta_L$ capture the strategic interaction between the insider and the designated trader.

As standard in the literature, using the first-order condition (equation (8)) and the conjectured linear trading strategy structure (equation (10)), we can form a system of five unknowns $\alpha_I, \alpha_L, \beta_D, \beta_L$ and $\gamma$ as follows:

$$\begin{bmatrix}
2\alpha_I + \frac{h}{e+h+z} \beta_D + \frac{N_h}{e+h} \gamma = \frac{1}{\lambda} \\
2\alpha_L + \frac{z}{e+h+z} \beta_D + \beta_L = 0 \\
2 \beta_D + \alpha_I + \frac{N_h}{e+h} \gamma = \frac{1}{\lambda} \\
\alpha_L + 2 \beta_L = 0 \\
\alpha_I + \alpha_L + \frac{h+z}{e+h+z} \beta_D + \beta_L + \left[ 2 + \frac{(N-1)h}{e+h} \right] \gamma = \frac{1}{\lambda}
\end{bmatrix}. $$  

(11)
Combining the above five equations with $\lambda = \frac{C_{\text{tr}}(\tilde{\omega})}{\text{tr}(\tilde{\omega})}$ gives a system of six equations and six unknowns ($\lambda, \alpha_I, \alpha_L, \beta_D, \beta_L$ and $\gamma$). In Appendix A1, we solve this system and summarize the results in the following proposition.

**Proposition 1**  The equilibrium price function is

$$\tilde{p} = \tilde{e} + \lambda \tilde{\omega},$$

and the trading strategies of the insider, designated trader, and the other informed are,

\[
\begin{align*}
\tilde{x}_I &= \alpha_I (\tilde{e} - \tilde{e}) + \alpha_L (\tilde{y}_L - \tilde{e}), \\
\tilde{x}_D &= \frac{h}{e + h + z} \beta_D (\tilde{y}_D - \tilde{e}) + \left( \frac{z}{e + h + z} \beta_D + \beta_L \right) (\tilde{y}_L - \tilde{e}), \\
\tilde{x}_j &= \frac{h}{e + h} \gamma (\tilde{y}_j - \tilde{e}),
\end{align*}
\]

where $j = 1, 2, \ldots, N$, and where

\[
\begin{align*}
\lambda &= \frac{\Delta_1}{\sigma_u e^{1/2} \Delta_2}, \beta_D = \frac{1}{\lambda \Delta_2}, \beta_L = \frac{1}{3} \frac{z}{e + h + z} \beta_D, \\
\alpha_I &= \left( 1 + \frac{e + z}{e + h + z} \right) \beta_D, \alpha_L = -\frac{2}{3} \frac{z}{e + h + z} \beta_D, \\
\gamma &= \frac{1 + \frac{e}{e + h + z} + \frac{1}{3} \frac{z}{e + h + z}}{1 + \frac{e}{e + h}} \beta_D,
\end{align*}
\]

with

\[
\begin{align*}
\Delta_1 &= \left[ \frac{2}{e + h + z} \left( 1 + \frac{e + z}{e + h + z} \right) + \frac{2}{3} \frac{z}{e + h + z} \left( 2 + \frac{1}{3} \frac{e + z}{e + h + z} \right) \right]^{1/2}, \\
\Delta_2 &= 2 \left( 1 + \frac{e + z}{e + h + z} \right) + \frac{h}{e + h + z} + \left( \frac{Nh}{e + h} \right) \left( 1 + \frac{e + h + z}{1 + \frac{e}{e + h}} \right).
\end{align*}
\]

**Proof.** See Appendix A1. ■

Three notable observations emerge from Proposition 1. First, we note that the insider's trading strategy depends explicitly on the leaked information $\tilde{y}_L = \tilde{e} + \tilde{\zeta}$ (i.e., $\alpha_L \neq 0$) despite the fact that the insider observes $\tilde{e}$, and $\tilde{y}_L$ is simply a garbled version of $\tilde{e}$. This means
that price is sensitive to the $\tilde{y}_L$-based trades of both the insider and trader D whose joint $\tilde{y}_L$-based order flow equals $\alpha_L + \left(\frac{\tilde{\tau}}{e+\tilde{h}+z}\beta_D + \beta_L\right) = \frac{2}{3}\frac{\tilde{\tau}}{e+\tilde{h}+z}\beta_D$.

Second, we note that the insider’s $\tilde{y}_L$-based trading strategy (i.e., $\alpha_L$) is negative while trader D’s $\tilde{y}_L$-based trading strategy, $\left(\frac{\tilde{\tau}}{e+\tilde{h}+z}\beta_D + \beta_L\right)$, is positive which means that the insider trades in the opposite direction to trader D with respect to the leaked information. This reflects the insider’s desire to dampen the market order flow by (partially) offsetting orders submitted by trader D that are sensitive to $\tilde{y}_L$ in order to secure favorable price terms from the market maker.

Third, we note that when $z = 0$, $\bar{x}_D = \bar{x}_j$; otherwise, when $z > 0$, trader D trades more than the other $N$ informed traders in the sense that $Var(\bar{x}_D) > Var(\bar{x}_j)$, which can be shown by direct computation (see also Proposition 2 below).

### 3 Rational Information Leakage

In this section, we address the insider’s rationale for leaking information based on the equilibrium results in Proposition 1. We begin by first characterizing the ex ante profits of the designated trader and other $N$ informed traders. Substituting the trading strategies $\bar{x}_D$ and $\bar{x}_j$ described in Proposition 1 into the traders’ respective profit expressions, we have:

$$
\pi_D (z, e, h, N) = \frac{\sigma_u \left[ \left( \frac{h}{e+\tilde{h}+z} + \frac{4}{3} \frac{z}{e+\tilde{h}+z} \right)^2 + \left( \frac{h}{e+\tilde{h}+z} \right)^2 \frac{e}{h} + \left( \frac{4}{3} \frac{z}{e+\tilde{h}+z} \right)^2 \frac{e}{z} \right]}{e^{1/2}\Delta_1\Delta_2}
$$

$$
= \pi_j (z, e, h, N) + \frac{8}{9} \left( \frac{z\sigma_u e^{1/2}}{\Delta_1\Delta_2} \right) \left[ \frac{8e^2 + 14he + 8ze + 6hz + 5h^2}{(h + 2e)^2(h + z + e)^2} \right], \quad (12)
$$

$$
\pi_j (z, e, h, N) = \left( \frac{\sigma_u}{e^{1/2}\Delta_1\Delta_2} \right) \left( \frac{h}{e + h} \right) \left( \frac{1 + \frac{e}{e + h + z} + \frac{1}{3} \frac{z}{e + h + z}}{1 + \frac{e}{e + h}} \right)^2, \quad (13)
$$

where $j = 1, 2, \ldots, N$. We note that the profit expressions in (12) and (13) are characterized as functions of the four exogenous parameters of interest: $z$, the precision of leaked information $\tilde{y}_L$; $e$, the precision of the cash flow of the underlying asset $\tilde{\varepsilon}$; $h$, the precision of the other informed traders’ private signal $\tilde{y}_j$; and $N$, the number of the other informed traders.

As expected, expressions (12) and (13) suggest that $\pi_D \geq \pi_j$ so that the leaked informa-
tion makes the designated trader (weakly) better off. This is because the leaked information provides the designated trader with additional information about the asset payoff unavailable to the other traders. Moreover, we can show that as the leaked information becomes increasingly more precise (i.e., as \( z \) increases), the other \( N \) traders become less active and trade less aggressively. As a consequence, the profits of the other \( N \) traders decrease while the profit of the designated trader increases. We summarize these observations in the following proposition.

**Proposition 2** The expected profit of the designated trader is increasing in the precision of the leaked information. The expected profits of the other \( N \) informed traders are decreasing in the precision of leaked information. That is, \( \pi_D \geq \pi_j \) with \( \frac{\partial \pi_D(z, e, h, N)}{\partial z} \geq 0 \) and \( \frac{\partial \pi_j(z, e, h, N)}{\partial z} \leq 0 \).

**Proof.** See Appendix A2. ■

Whereas the profit impact of leaking information on the designated trader and other \( N \) traders is clear, the impact on the insider is more subtle. In particular, we find that an increase in \( z \), the precision of leaked information, can increase or decrease the insider’s expected profit. Intuitively, leaked information can decrease the insider’s profit because it renders a competing trader (i.e., the designated trader) better informed. At the same time, leaked information can increase the insider’s profit because it makes other competing traders (i.e., the other \( N \) traders) less active or aggressive. This means that, if we interpret \( z \) as the insider’s choice variable, then there are settings where the insider will choose to leak information as well as settings where he will refrain from doing so. Hence, we write,

\[
z^* = \max \left\{ 0, \arg \max_z \pi_I(z, e, h, N) \right\}
\]

where \( z^* \) represents the insider’s optimal choice of \( z \) and \( \pi_I(z, e, h, N) \) represents the expected profit of the insider. Clearly, if \( \arg \max_z \pi_I(z, e, h, N) > 0 \), i.e. \( z^* > 0 \), information leakage is “rational”.

To characterize conditions under which information leakage is “rational,” we rewrite the
insider’s trading strategy (from Proposition 1) as follows:

\[
\tilde{x}_I^* = \alpha_I (\tilde{\varepsilon} - \bar{\varepsilon}) + \alpha_L (\tilde{y}_L - \bar{\varepsilon}) \\
= (\alpha_I + \alpha_L) (\tilde{\varepsilon} - \bar{\varepsilon}) + \alpha_L \tilde{\zeta},
\]

where the second equality follows from \( \tilde{y}_L = \tilde{\varepsilon} + \tilde{\zeta} \). Substituting the above trading strategy into the profit expression (equation (9)), we can decompose the insider’s ex ante profit as follows:

\[
\pi_I (z, e, h, N) = \lambda Var (\tilde{x}_I^*) = \lambda (\alpha_I + \alpha_L)^2 e^{-1} + \lambda \alpha_L^2 z^{-1} .
\]

The first term in (16), labeled “fundamental-based profit,” is based on the first component of the insider’s order in equation (15) which depends on his information \( \tilde{\varepsilon} \). Information leakage lowers the insider’s fundamental-based profit, i.e., \( \delta [\lambda (\alpha_I + \alpha_L)^2 e^{-1}] / \delta z < 0 \), because as \( z \) increases the designated trader becomes more informed about the asset’s fundamental value and captures some of the insider’s information advantage. In the extreme, when \( z \to \infty \), the insider’s fundamental-based profit is minimized because leaking perfect information is equivalent to making trader D just another insider.

The second term in (16), labeled “noise-based profit,” is based on the second component of the insider’s order in equation (15) which depends on the insider’s observation of \( \tilde{\zeta} \). Recall that because price is sensitive to \( \tilde{y}_L \)-based trades, the insider enjoys an information advantage over the execution price, \( \tilde{\rho} \). Of course, when there is no information leakage (i.e., \( z = 0 \)), the insider’s noise-based profit is zero. In the other extreme, when \( z \to \infty \), the insider’s noise-based profit is also zero because with perfect leakage trader D perfectly observes \( \tilde{\varepsilon} \) and hence price is no longer sensitive to \( \tilde{\zeta} \). This means that the insider’s noise-based profit, i.e., \( \lambda \alpha_L^2 z^{-1} \), increases for lower values of \( z \) and decreases for higher values of \( z \). Moreover, we can show that \( \lambda \alpha_L^2 z^{-1} \) is a single-peaked function of \( z \) and hence, some information leakage always increases the insider’s noise-based profit.

In sum, the decomposition in (16) suggests that information leakage weakens the insider’s information advantage about the fundamental value \( \tilde{\varepsilon} \) but at the same time strengthens the insider’s information advantage about the execution price. Therefore, the rationality of
information leakage by the insider (i.e., the choice of a nonzero \( z \)) depends on the relative importance of these two effects. Because the complexity of the expression for \( \pi_I (z, e, h, N) \) precludes a full characterization, we describe a sufficient condition for rational information leakage, namely, a characterization for when the function \( \pi_I (z, e, h, N) \) is strictly increasing at \( z = 0 \). We have:

**Proposition 3** [Rational Information Leakage] Information Leakage is rational when 
\[ \frac{\partial \pi_I (z, e, h, N)}{\partial z} \bigg|_{z=0} > 0, \] a condition that is satisfied if and only if \( N \), the number of other informed traders, is sufficiently large.

**Proof.** See Appendix A3.

In Appendix A3, we characterize \( N \) being sufficiently large as \( N \) exceeding a threshold \( \tilde{N} \) (see equation (50) in Appendix A3) defined as a decreasing function of other traders’ signal-to-noise ratio \( (h/e) \). Figure 1 plots the function \( \tilde{N} (\frac{h}{e}) \) with a solid curve in the plane of \( (\frac{h}{e}, N) \). We label the solid curve separating the leakage versus non-leakage regions as the “information leakage frontier.” Information leakage occurs in this region above the frontier (with “+” marks), i.e., when \( N \) is greater than \( \tilde{N} (\frac{h}{e}) \).

**INSERT FIGURE 1 HERE**

Proposition 3 (and Figure 1) suggest that information leakage is more likely when (i) there are more informed traders in the market (\( N \) is large) and/or (ii) other informed traders’ are relatively well informed about the underlying asset (\( h/e \) is large). The intuition is as follows: the insider’s benefit of leaking information comes from the reduced trading of the other informed traders; if there are many such traders (\( N \) is large) and/or if these traders trade aggressively due to their precise signals (\( \frac{h}{e} \) is large), the benefit of leaking information to the insider is large and it is potentially rational for him to leak the information to a designated trader. Figure 2 illustrates two settings, one where information leakage is optimal and one where it is not. Specifically, in Panel (a), \( N = 10 \), while in Panel (b), \( N = 50 \). The common parameter values for the two economies are \( e = h = \sigma_u = 1 \). In Panel (a), the optimal \( z^* \) is 0, suggesting no information leakage, while in Panel (b), the optimal \( z^* \) is 0.55, suggesting
the existence of rational information leakage. This is consistent with Proposition 3: For the two economies, we have \( \hat{N} \left( \frac{2}{\beta} \right) = \hat{N}(1) = 27.4 \); in Panel (a), \( N = 10 < \hat{N}(1) \), so that \( z^* = 0 \), while in Panel (b), \( N = 50 > \hat{N}(1) \), so that \( z^* > 0 \).

**INSERT FIGURE 2 HERE**

Taken together, Propositions 2 and 3 suggest that rational information leakage benefits the designated trader and the insider at the expense of other informed traders. An important implication is that other informed traders have less of an incentive to collect and process information. Information leakage also has important market-wide consequences including price efficiency and liquidity effects. For instance, we expect the price of the risky asset to be informationally more efficient because rational information leakage promotes more aggressive trading by the designated trader and hence more information is impounded in price. In the context of our model, if we define price informativeness as \( \frac{1}{\text{Var}(\hat{z}|\hat{p})} \), the precision of the risky asset payoff conditional on its price, then we expect \( \frac{1}{\text{Var}(\hat{z}|\hat{p})} \) evaluated at all values of \( z^* > 0 \) to be greater than \( \frac{1}{\text{Var}(\hat{z}|\hat{p})} \) evaluated at \( z = 0 \). In Appendix A4, we provide a more general proof of this result where we show that \( \hat{\sigma}_\lambda \left[ \frac{1}{\text{Var}(\hat{z}|\hat{p})} \right] \hat{\zeta} > 0 \).

To assess the liquidity effects of information leakage, we begin with the observation that the aggregate expected profit of all informed traders, \( \pi_I + \pi_D + N\pi_j \), equals the expected cost borne by liquidity traders, namely \( \lambda\sigma^2 \). Thus, we conjecture that markets are more liquid (i.e., \( \lambda \) is lower) with information leakage than without because the benefit of information leakage that accrue to the insider and the designated trader (i.e., the increase in \( \pi_I \) and \( \pi_D \) established in Propositions 2 and 3) are likely much less than the cost of information leakage borne by \( N \) other informed traders (the decrease in \( \pi_j \) established in Proposition 2). Because the complexity of the expression for \( \lambda \) precludes a general proof of this result, we establish a more local result around the information leakage frontier (see Figure 1) and then resort to extensive numerical analysis to reinforce our conjecture. Recall that, when \( N = \hat{N} \), \( z^* \) is zero because the insider is indifferent between leaking information and refraining from doing so. At \( N = \hat{N} \), we can show that \( \frac{\partial\lambda}{\partial z} < 0 \) (see Appendix A4). Of course, this implies that, for all optimal values of \( z^* \) not too large, markets are more liquid with information leakage.
than without. While we cannot establish this result formally for all possible values of \( z^* \), our numerical analysis confirms our conjecture that markets are more liquid with information leakage than without.

4 Model Extensions

In this section, we discuss the robustness of our results to some alternative modeling assumptions and potential extensions of the model.

4.1 Insider’s Choice of Trader D

Our model establishes that an insider leaks information to an independent “designated” trader who is, a priori, as equally well informed as the other N traders. In this subsection, we consider the possibility that an insider prefers to leak information to better informed versus less well informed traders in the event that traders are differentially informed.

Consider an extension of our model with two groups of informed traders: Group 1 has \( N_1 \) traders whose private signals have precision \( h_1 \) while group 2 has \( N_2 \) traders whose private signals have precision \( h_2 \). We assume \( h_1 \) is greater than \( h_2 \) and compare a regime where the designated trade is from the better informed group (group 1) to a regime where the designated trader is from the less well informed group (group 2). Because the complicated expression for the insider’s profit precludes an analytical comparison of the two regimes, we resort to numerical analysis to draw our inferences. Figure 3 illustrates a typical example with the following parameters: \( e = \sigma_u = 1, h_1 = 2, h_2 = 0.5, N_1 = 25 \) and \( N_2 = 26 \). For this example, we find that when the insider leaks information to a designated trader from the better informed group, his maximum profit (at \( z^* \)) is 0.013864 while if he leaks information to a designated trader from the less well informed group, his maximum profit (at \( z^* \)) is 0.013914.

4 Analytically, we can show that at \( z = 0 \) the insider’s marginal benefit of leaking information to a less well informed designated trader is higher than the marginal benefit of leaking information to a less well informed designated trader.
The insider’s preference to leak information to a designated trader from the less well informed group can be explained as follows. Recall that information leakage confers to the insider an information advantage about execution price because trades by the designated trader renders price sensitive to the noise component of leaked information. A less well-informed designated trader relies more on leaked information than his own private signal in formulating his trading strategy, certainly relative to an initially better informed designated trader. This implies that price is more sensitive to noise in leaked information and therefore the insider gains more of an information advantage about execution price if the designated trader is less well informed.

4.2 Sale of Information to the Designated Trader

Our model assumes that the insider voluntarily leaks private information to a designated trader without any fee or direct compensation in return. In light of prior literature that examines the direct sale of information in financial markets, we also consider the possibility that an insider has the option to sell his private information for a fee, perhaps as an alternative to (or in addition to) leaking information for free. While such an extension does not eliminate an insider’s incentive to leak information, we argue that, as a practical matter, a direct sale of information may be a less profitable way of benefiting from private information than leakage, and particularly more so if we interpret our insider as a corporate executive or a hedge fund manager. Indeed, we conjecture that the probability of prosecution and its attendant consequence is likely to be higher if an insider were to directly sell his information for a fee as opposed to leaking it freely to an independent designated trader. As preliminary evidence of our conjecture, we note that the recent insider trading cases cited by the SEC on their website almost always involve the receipt or payment of direct fees and benefits by various parties.

4.3 Endogenous Number of Other Informed Traders

Our model assumes that there are $N$ other informed traders in the market, where $N$ is exogenously fixed. To assess how information leakage might affect $N$ if $N$ were endogenous,
we assume that the other informed traders enter the market by acquiring the signal $\tilde{y}_j$ at a fixed cost $C > 0$. Hence, the endogenous number $N^*$ of other informed traders is determined by $\pi_j (z, e, h, N^*) = C$. Briefly, we find that information leakage reduces $\pi_j$ (Proposition 2), and by virtue of $\pi_j (z, e, h, N^*) = C$, drives out some informed traders from the market (i.e., $N^*$ decreases). Hence, we show that the insider is more likely to leak information when $N$ is endogenous than otherwise.

4.4 Mixed Trading Strategy of the Insider

In our model, the insider’s information advantage about execution price arises because the designated trader submits orders based on the leaked information. Given that the insider is responsible for leaking the information in the first place, an important question that arises is whether the insider can produce a similar information advantage about execution price on his own; for example, by simply adding or subtracting some noise to/from his optimal trading strategy. We argue that this is not feasible because this is akin to the insider employing a mixed strategy to introduce a privately known noise into the price function. As Brunnermeier (2005) shows, such a mixed strategy is not supported in equilibrium because the insider’s problem is concave and admits a unique optimal solution.

To be more precise, the insider in our model gains an information advantage about execution price because the noise contained in the leaked information affects order flow and hence price. This requires that the designated trader have a credibly different objective function than the insider. Otherwise, market participants will treat both traders as one. For example, if the insider leaks information to a relative or an affiliated trader, then the leaked information is not credible in the sense that both the market maker and the other informed traders will consider the insider and the designated trader to have a common objective function. In such a setting, leaking information is not valuable because the noise in the leaked information does not affect price. In this sense, leaking information to an unrelated designated trader and the profit that the insider forgoes in doing so can be viewed as the

---

5 The notion that information leakage can drive out other informed traders is consistent with recent evidence that finds a strong inverse relation between insider trading and institutional trades (Sias and Whidbee, 2010).
insider’s commitment cost.

4.5 Information Stealing

In this subection, we consider “information stealing” as opposed to “information leakage” as a means of informing a designated trader. In contrast to information leakage, we assume that the information that is stolen is not observed by the insider (but the fact that it is stolen is common knowledge). This distinction is important because stolen information has been long considered another important channel of how prices reflect private information. For example, in 2009, the SEC charged a major brokerage firm for illegally allowing traders from other firms to listen to confidential trading information of its institutional customers without their knowledge using “Squawk Boxes” (SEC press release #2009-54). Thus, this channel per se deserves serious examination.

The distinction between information leakage and information stealing is also important because, unlike information leakage, stolen information does not convey an information advantage to the insider over execution price. In the context of our model, this means that stolen information makes the designated trader better off but renders the insider unambiguously worse off.

5 Summary and Discussion

In this paper we examine an insider’s incentives to voluntarily leak information about an asset’s value to an unrelated third party to whom we refer to as a designated trader. Using a stylized Kyle model, we show that, while leaking information dissipates the insider’s information advantage about the asset’s value, it enhances his information advantage about the asset’s execution price relative to other informed traders. These two effects are countervailing. When the profit impact from enhanced information about the execution price dominates, the insider has incentives to leak some of his private information.

Although admittedly stylized, our model highlights a number of issues and implications for capital markets, particularly those that pertain to insider trading regulations designed to enhance public confidence in capital markets. The Securities and Exchange Act of 1934 and
the subsequent amendments state that it is illegal to use or pass on to others material, non-
public information or enter into transactions while in possession of such information. The
regulations give the enforcement power to the SEC which can bring civil charges against any
violators and refer cases to the Justice Department for criminal prosecution.

In the context of our model, if we interpret the insider as a corporate executive, officer, or
director, then rational information leakage in our model can be characterized potentially as
illegal insider trading behavior by the SEC. On the other hand, if we interpret the insider in
our model as a brokerage firm whose analysts inform (or tip-off) their clients about some of
the information they collect and process, then the impropriety of information leakage is less
obvious. In these latter types of settings, the SEC usually evaluates potential insider trading
violations on a case by case basis because the SEC regulations do not explicitly address such
tipping-off practices by security analysts. In a similar vein, although the financial industry’s
professional code of conduct explicitly prohibits trading by a brokerage firm before the public
release of its own analysts’ reports, it does not preclude the brokerage firm’s clients from
trading before the reports become public.6

Notwithstanding the legalities of insider trading and the SEC’s enforcement efforts, there
is a plethora of evidence to suggest that information leakage and insider trading is prevalent.
For example, Seyhun (1992) shows that both the profitability and the volume of insider
trading increased significantly (by a factor of 4 to 6) during the 1980s despite increased SEC
enforcement efforts. Similarly, Irvine et al. (2007) provide evidence that institutional traders
are unusually active ahead of analyst buy recommendations, and Christope et al. (2010) find
that short sellers tend to short more shares ahead of analyst sell recommendations. Taken
together, these findings are consistent with the perception that difficulties in investigating
and proving insider trading cases renders the likelihood of being caught and prosecuted
for leaking information very low (see also SEC’s insider trading website). The chance of
detection and prosecution is likely to be even lower if the insider leaks information to an
unrelated third party (interpreted as the designated trader in our model) who can disavow a
duty of trust. Finally, in the event of prosecution, the designated trader (at least as captured

6For instance, see National Association of Securities Dealers (formerly NASD now FINRA) professional
code of conduct Rule 2110 “Standards of Commercial Honor and Principles of Trades”.

in our model) can mount an affirmative defense that the leaked information was not a factor in his decision to trade and that his trades are based on other private sources of information.

Our model also identifies settings where information leakage is likely to be observed as well as settings where current SEC regulations are most likely to be effective. For example, our model shows that the insider is more likely to leak information when more informed traders actively trade in the security, when other traders are better informed about the underlying asset value, and when the underlying asset has more volatile cash flows, suggesting the leakage problem might be more severe in the trading of growth firms. Similarly, our analysis suggests that Reg FD (issued by the SEC in 2000 mandating that all publicly traded companies disclose material information to all investors at the same time) is most effective in reducing insider trading for those firms above the information leakage frontier described by our model.
References


Appendix: Proofs

A1 Proof of Proposition 1

A1.1 Form the System of Coefficients

We first use equations (8), (10) and the equation \( \lambda = \frac{\text{Cov}(\tilde{\varepsilon}, \omega)}{\text{Var}(\omega)} \) to form the system of the unknown coefficients \( \alpha_I, \alpha_L, \beta_D, \beta_L, \gamma \) and \( \lambda \).

**Insider.** The insider has an information set of \( \mathcal{I}_I = \{\tilde{\varepsilon}, \tilde{y}_L\} \). Thus, his forecast for the fundamental value is

\[ E(\tilde{\varepsilon} - \tilde{\varepsilon}|\mathcal{I}_I) = \tilde{\varepsilon} - \tilde{\varepsilon}, \]

and his forecasts of the order-flows of the designated trader and other \( N \) informed traders are:

\[ \tilde{x}_D = \beta_D \left[ E(\tilde{\varepsilon}|\tilde{y}_D, \tilde{y}_L) - \tilde{\varepsilon} \right] + \beta_L (\tilde{y}_L - \tilde{\varepsilon}) \]

\[ = \beta_D \frac{h}{e + h + z} (\tilde{y}_D - \tilde{\varepsilon}) + \left( \beta_D \frac{z}{e + h + z} + \beta_L \right) (\tilde{y}_L - \tilde{\varepsilon}) \]

\[ E(\tilde{x}_D|\mathcal{I}_I) = \beta_D \frac{h}{e + h + z} (\tilde{\varepsilon} - \tilde{\varepsilon}) + \left( \beta_D \frac{z}{e + h + z} + \beta_L \right) (\tilde{y}_L - \tilde{\varepsilon}), \]

\[ \tilde{x}_j = \gamma [E(\tilde{\varepsilon}|\tilde{y}_j) - \tilde{\varepsilon}] = \gamma \frac{h}{e + h} (\tilde{y}_j - \tilde{\varepsilon}) \]

\[ E(\tilde{x}_j|\mathcal{I}_I) = E(\tilde{x}_j, \tilde{y}_L) = \gamma \frac{h}{e + h} (\tilde{\varepsilon} - \tilde{\varepsilon}). \]

Plugging the expressions of \( E(\tilde{\varepsilon} - \tilde{\varepsilon}|\mathcal{I}_I), E(\tilde{x}_D|\mathcal{I}_I) \) and \( E(\tilde{x}_j|\mathcal{I}_I) \) into the optimal trading strategy of the insider (equation (8)):

\[ \tilde{x}_I = \frac{E(\tilde{\varepsilon} - \tilde{\varepsilon}|\mathcal{I}_I) - \lambda \sum_{k \neq I} E(\tilde{x}_k|\mathcal{I}_I)}{2\lambda} \]

\[ = \frac{\left[ 1 - \lambda \frac{h}{e + h + \tilde{\varepsilon}} \right] (\tilde{\varepsilon} - \tilde{\varepsilon}) - \lambda \left( \frac{h}{e + h + \tilde{\varepsilon}} \beta_D + \beta_L \right) (\tilde{y}_L - \tilde{\varepsilon})}{2\lambda}. \]

Comparing the above expression with the conjectured trading strategy of the insider (i.e., \( \tilde{x}_I = \alpha_I (\tilde{\varepsilon} - \tilde{\varepsilon}) + \alpha_L (\tilde{y}_L - \tilde{\varepsilon}) \)), we have the following two equations of \( \alpha_I \) and \( \alpha_L \):

\[ \alpha_I = \frac{1 - \lambda \frac{h}{e + h + \tilde{\varepsilon}} \beta_D - \lambda \frac{Nh}{e + h + \gamma}}{2\lambda}, \]

\[ \alpha_L = \frac{- \frac{\tilde{\varepsilon}}{e + h + \beta_D + \beta_L}}{2}, \]

which implies

\[ 2\alpha_I + \frac{h}{e + h + \tilde{\varepsilon}} \beta_D + \frac{h}{e + h + \gamma} = \frac{1}{\lambda}, \quad (17) \]

\[ 2\alpha_L + \frac{z}{e + h + \tilde{\varepsilon}} \beta_D + \beta_L = 0. \quad (18) \]

**Trader D.** The information set of the designated trader is \( \mathcal{I}_D = \{\tilde{y}_D, \tilde{y}_L\} \). Thus, his forecast for the fundamental value of the underlying asset is \( E(\tilde{\varepsilon} - \tilde{\varepsilon}|\mathcal{I}_D) = E(\tilde{\varepsilon} - \tilde{\varepsilon}|\tilde{y}_D, \tilde{y}_L) \). His forecasts of the order-flows of the insider and other informed traders are

\[ \tilde{x}_I = \alpha_I (\tilde{\varepsilon} - \tilde{\varepsilon}) + \alpha_L (\tilde{y}_L - \tilde{\varepsilon}) \]

\[ E(\tilde{x}_I|\tilde{y}_D, \tilde{y}_L) = \alpha_I E(\tilde{\varepsilon} - \tilde{\varepsilon}|\tilde{y}_D, \tilde{y}_L) + \alpha_L (\tilde{y}_L - \tilde{\varepsilon}), \]
Comparing with the conjectured trading strategy of the designated trader, we have:

Further simplifying, we have two additional equations:

Informed Trader j.

The information set of trader $j$ is $\mathcal{I}_j = \{\tilde{y}_j\}$. His forecast of the fundamental value of the underlying asset is $E(\tilde{\varepsilon} - \tilde{z}|\mathcal{I}_j)$. His forecasts of the submitted order flows of the insider, the designated trader and other informed traders are

and

Thus, plugging those expressions in equation (8) delivers

Comparing with the conjectured trading strategy of the designated trader, we have

Further simplifying, we have two additional equations:

Informed Trader j.

The information set of trader $j$ is $\mathcal{I}_j = \{\tilde{y}_j\}$. His forecast of the fundamental value of the underlying asset is $E(\tilde{\varepsilon} - \tilde{z}|\mathcal{I}_j)$. His forecasts of the submitted order flows of the insider, the designated trader and other informed traders are

and

Plugging those expressions into equation (8), we have

Comparing with the conjectured trading strategy of the informed traders, we have:

$$\gamma = \frac{1 - \lambda (\alpha_I + \alpha_L) - \lambda \left( \frac{h + z}{e + h + z} \beta_D + \beta_L \right) - \lambda (N - 1) \frac{h}{e + h} \gamma}{2\lambda},$$

23
which implies:

$$(\alpha_I + \alpha_L) + \left( \frac{h+z}{e+h+z} \beta_D + \beta_L \right) + \left[ 2 + (N-1) \frac{h}{e+h} \right] \gamma = \frac{1}{\lambda}, \quad (21)$$

Equations (17)-(21) form the system specified by equation (11) in the main text. Then combining this system with equation $\lambda = \frac{\text{Cov}(\tilde{z}, \tilde{\omega})}{\text{Var}(\tilde{\omega})}$, we have a system of the underlying six unknowns $\alpha_I, \alpha_L, \beta_D, \beta_L, \gamma$ and $\lambda$.

A1.2 Solve the System

We solve the system in two steps. First, we use equations (17)-(21) to express $\alpha_I, \alpha_L, \beta_D, \beta_L$ and $\gamma$ in terms of $\lambda$. Second, we use $\lambda = \frac{\text{Cov}(\tilde{z}, \tilde{\omega})}{\text{Var}(\tilde{\omega})}$ to solve $\lambda$.

Step 1. Express $\alpha_I, \alpha_L, \beta_D, \beta_L$ and $\gamma$ in terms of $\lambda$.

We first express $\alpha_I, \alpha_L, \beta_D$ and $\gamma$ in terms of $\beta_D$ and then solve $\beta_D$ in terms of $\lambda$. By equations (18) and (20), we can express the two coefficients related to the leaked information, $\alpha_L$ and $\beta_L$, as follows:

$$\beta_L = \frac{1}{3} \frac{z}{e+h+z} \beta_D, \quad (22)$$

$$\alpha_L = -\frac{2}{3} \frac{z}{e+h+z} \beta_D. \quad (23)$$

By equations (17) and (19), we have

$$\alpha_I = \left( 1 + \frac{e+z}{e+h+z} \right) \beta_D. \quad (24)$$

Equations (19) and (21) combine to produce

$$\gamma = \frac{1 + \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z} \beta_D}{1 + \frac{e}{e+h+z}}. \quad (25)$$

Then, plugging the expressions of $\alpha_I$ and $\gamma$ in equations (24) and (25) into (19), we have

$$\beta_D = \frac{1}{\lambda} \left( 3 + \frac{e+z}{e+h+z} + N \frac{h}{e+h} \frac{1 + \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z}}{1 + \frac{e}{e+h+z}} \right)^{-1} \quad (26)$$

Define the following coefficients:

$$C_0 = \left( 3 + \frac{e+z}{e+h+z} + N \frac{h}{e+h} \frac{1 + \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z}}{1 + \frac{e}{e+h+z}} \right)^{-1} \quad (27)$$

So, equations (22)-(26) imply

$$\beta_L = c_{\beta_L} \beta_D, \alpha_L = c_{\alpha_L} \beta_D, \alpha_I = c_{\alpha_I} \beta_D, \gamma = c_{\gamma} \beta_D, \beta_D = C_0 / \lambda. \quad (28)$$
Step 2. Solve \( \lambda \).

By the definition of the total order flow:

\[
\tilde{\omega} = \tilde{x}_I + \tilde{x}_D + \sum_{j=1}^{N} \tilde{x}_j + \tilde{u} = \alpha_I (\tilde{z} - \tilde{\epsilon}) + \alpha_L (\tilde{y}_L - \tilde{\epsilon}) + \beta_D \left[ E (\tilde{z} | \tilde{y}_D, \tilde{y}_L) - \tilde{\epsilon} \right] + \beta_L (\tilde{y}_L - \tilde{\epsilon}) + \sum_{j=1}^{N} \gamma \left[ E (\tilde{z} | \tilde{y}_j) - \tilde{\epsilon} \right] + \tilde{u}
\]

By equation (28),

\[
\tilde{\omega} = \left( c_{\alpha_I} + c_{\alpha_L} + \frac{z}{e + h + z} + c_{\beta_L} + \frac{h}{e + h + z} + \frac{Nc_{\gamma}}{e + h} \right) \beta_D (\tilde{z} - \tilde{\epsilon}) + \left( c_{\alpha_L} + \frac{z}{e + h + z} + c_{\beta_L} \right) \beta_D \tilde{\zeta} + \frac{h}{e + h + z} \beta_D \tilde{\eta}_D + c_{\gamma} \frac{h}{e + h} \beta_D \sum_{j=1}^{N} \tilde{\eta}_j + \tilde{u}.
\]

Define

\[
\begin{bmatrix}
A_{\epsilon} &=& c_{\alpha_I} + c_{\alpha_L} + \frac{z}{e + h + z} + c_{\beta_L} + \frac{h}{e + h + z} + \frac{Nc_{\gamma}}{e + h}, \\
A_{\zeta} &=& c_{\alpha_L} + \frac{z}{e + h + z} + c_{\beta_L}, \\
A_D &=& \frac{h}{e + h + z}, \quad A_{\gamma} = -c_{\gamma} \frac{h}{e + h},
\end{bmatrix}
\]

Thus,

\[
\tilde{\omega} = A_{\epsilon} \beta_D (\tilde{z} - \tilde{\epsilon}) + A_{\zeta} \beta_D \tilde{\zeta} + A_D \beta_D \tilde{\eta}_D + A_{\gamma} \beta_D \sum_{j=1}^{N} \tilde{\eta}_j + \tilde{u}.
\]

As a result,

\[
\lambda = \frac{\text{Cov}(\tilde{z}, \tilde{\omega})}{\text{Var}(\tilde{\omega})} = \frac{A_{\epsilon} \beta_D / e}{A_{\epsilon}^2 \beta_D / e + A_{\zeta}^2 \beta_D / z + A_D^2 \beta_D / h + A_{\gamma}^2 \beta_D N / h + \sigma_u^2} \Rightarrow \sigma_u^2 \lambda^2 = A_{\epsilon} \epsilon / \beta_D \lambda - (A_{\epsilon}^2 / e + A_{\zeta}^2 / z + A_D^2 / h + A_{\gamma}^2 N / h) \beta_D^2 \lambda^2.
\]

Recall that

\[
\beta_D = C_0 / \lambda \Rightarrow \beta_D \lambda = C_0 \text{ and } \beta_D^2 \lambda^2 = C_0^2.
\]

Thus,

\[
\sigma_u^2 \lambda^2 = A_{\epsilon} \epsilon / C_0 - \left( A_{\epsilon}^2 / e + A_{\zeta}^2 / z + A_D^2 / h + A_{\gamma}^2 N / h \right) C_0^2 \Rightarrow \lambda = \sigma_u^{-1} e^{-1/2} C_0 \sqrt{A_{\epsilon} / C_0 - \left( A_{\epsilon}^2 / e + A_{\zeta}^2 / z + A_D^2 / h + A_{\gamma}^2 N / h \right)} \Rightarrow \lambda = \sigma_u^{-1} e^{-1/2} \Delta_1 \Delta_2^{-1},
\]

where

\[
\Delta_1 = \sqrt{A_{\epsilon} A_2 - \left( A_{\epsilon}^2 + A_D^2 e / h + A_A^2 N e / h \right)}, \quad \Delta_2 = 2 \left(1 + \frac{e + z}{e + h + z} + \frac{h}{e + h + z} + \frac{Nh}{e + h} + \frac{1}{1 + \frac{e}{e + h} + \frac{z}{e + h + z}}\right),
\]

where \( \Delta_2 \) is essentially \( C_0^{-1} \).

By the definitions of \( \sigma \)'s in equation (27) and the definitions of \( A \)'s in equation (29), we can
further show that
\[
\Delta_1 = \left[ 2 + \frac{e}{e+h+z} \left( 1 + \frac{e+z}{e+h+z} \right) + \frac{2}{3} \frac{z}{e+h+z} \left( 2 + \frac{1}{3} \frac{e+z}{e+h+z} \right) \right]^{1/2} 
+ \frac{Nh}{e+h} \left( 1 + \frac{e}{e+h+z} \right) \left( 1 + \frac{z}{e+h+z} \right).
\]  

(34)

By equations (27), (28), (31) and (33), we have
\[
\beta_D = C_0/\lambda = \sigma_u e^{1/2} \Delta_1^{-1}.
\]  

(35)

Then equations (27) and (28) give the expressions of \( \beta_L, \alpha_L, \alpha_I \) and \( \gamma \) and equations (34) and (33) give the expressions of \( \Delta_1 \) and \( \Delta_2 \) in Proposition 1.

A2 Proof of Proposition 2

A2.1 Expressions of the Profit Functions of Trader D and Other Informed Traders

Trader D’s Profit. By the expression of \( \tilde{x}_D^* \) in Proposition 1:
\[
Var(\tilde{x}_D^*) = \left( \frac{\beta_D}{e+h+z} + \frac{\beta_L}{e+h+z} \right)^2 / e + \left( \frac{\beta_D h}{e+h+z} \right)^2 / h + \left( \frac{\beta_D z}{e+h+z} + \frac{\beta_L}{e+h+z} \right)^2 / z.
\]

Then by the expressions of \( \beta_L \) and \( \beta_D \) in equations (22) and (35), we have
\[
Var(\tilde{x}_D^*) = \frac{\sigma_u^2}{\Delta_1^2} \left[ \left( \frac{h}{e+h+z} + \frac{4}{3} \frac{z}{e+h+z} \right)^2 + \left( \frac{h}{e+h+z} \right)^2 e/h + \left( \frac{4}{3} \frac{z}{e+h+z} \right)^2 e/z \right].
\]

Thus, by equation (9), the expected profit of trader D is:
\[
\pi_D(z,e,h,N) = \lambda Var(\tilde{x}_D^*) = \frac{\sigma_u S_D}{e^{1/2} \Delta_1 \Delta_2}.
\]  

(36)

where
\[
S_D = \left( \frac{h}{e+h+z} + \frac{4}{3} \frac{z}{e+h+z} \right)^2 + \left( \frac{h}{e+h+z} \right)^2 e/h + \left( \frac{4}{3} \frac{z}{e+h+z} \right)^2 e/z.
\]  

(37)

Other Informed’s Profit. By the expression of \( \tilde{x}_j^* \) in Proposition 1, we have
\[
Var(\tilde{x}_j^*) = \left( \frac{\gamma}{e+h} \right)^2 (1/e + 1/h).
\]

By the expressions of \( \gamma \) and \( \beta_D \) in equations (25) and (35), we have
\[
Var(\tilde{x}_j^*) = \frac{\sigma_u^2}{\Delta_1^2} \frac{h}{e+h} \left( 1 + \frac{1}{e+h} \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z} \right)^2.
\]

Thus,
\[
\pi_j(z,e,h,N) = \lambda Var(\tilde{x}_j^*) = \frac{\sigma_u S_O}{e^{1/2} \Delta_1 \Delta_2}.
\]  

(38)

where
\[
S_O = \frac{h}{e+h} \left( 1 + \frac{1}{e+h} \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z} \right)^2.
\]  

(39)
A2.2 Impact of Information Leakage

Impact on Trader D. By equation (36), taking derivative of \( \log(\pi_D) \) with respect to \( z \) (note that \( S_D, \Delta_1 \) and \( \Delta_2 \) are functions of \( z \) by equations (37), (34) and (33)) yields:

\[
\frac{\partial \log(\pi_D)}{\partial z} = \frac{\partial}{\partial z} \left[ \log \left( \sigma_u e^{-1/2} \right) + \log(S_D) - \log(\Delta_1) - \log(\Delta_2) \right] \\
= \frac{1}{S_D} \frac{\partial S_D}{\partial z} - \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z}. 
\]  

(40)

Direct computations show

\[
\frac{\partial S_D}{\partial z} = \left[ 2 \left( \frac{h}{e+h+z} + \frac{3}{3} \frac{z}{e+h+z} \right) \left( - \frac{h}{(e+h+z)^2} + \frac{3}{3} \frac{e+h}{(e+h+z)^2} \right) + 2 \left( \frac{h}{e+h+z} \right) \frac{e}{h} \left( - \frac{h}{(e+h+z)^2} \right) \right] \\
+ 2 \left( \frac{3}{3} \frac{z}{e+h+z} \right) \left( \frac{3}{3} \frac{e+h}{(e+h+z)^2} \right) + \left( \frac{3}{3} \frac{z}{e+h+z} \right) \left( \frac{3}{3} \frac{e+h}{(e+h+z)^2} \right)^2, 
\]  

(41)

and

\[
\frac{\partial \Delta_1}{\partial z} = \left[ \frac{h}{e+h+z} \frac{1}{1+ \frac{e}{e+h+z}} \left( \frac{2}{2} \frac{e}{e+h+z} \left( \frac{1+ 2 \frac{e}{e+h+z}}{(1+ \frac{e}{e+h+z})^2} \right) \right) \right] \\
+ \frac{h}{e+h+z} \frac{1}{1+ \frac{e}{e+h+z}} \left( \frac{2}{2} \frac{e}{e+h+z} \left( \frac{1+ 2 \frac{e}{e+h+z}}{(1+ \frac{e}{e+h+z})^2} \right) \right)^2. 
\]  

(42)

and

\[
\frac{\partial \Delta_2}{\partial z} = \left[ \frac{h}{e+h+z} \frac{1}{1+ \frac{e}{e+h+z}} \left( \frac{2}{2} \frac{e}{e+h+z} \left( \frac{1+ 2 \frac{e}{e+h+z}}{(1+ \frac{e}{e+h+z})^2} \right) \right) \right] \\
+ \frac{h}{e+h+z} \frac{1}{1+ \frac{e}{e+h+z}} \left( \frac{2}{2} \frac{e}{e+h+z} \left( \frac{1+ 2 \frac{e}{e+h+z}}{(1+ \frac{e}{e+h+z})^2} \right) \right)^2. 
\]  

(43)

Substituting the derivative expressions above along with the expressions for \( S_D, \Delta_1 \) and \( \Delta_2 \) (equations (37), (34) and (33)) into equation (40), we can show that \( \frac{\partial \pi_D(z,e,h,N)}{\partial z} \) is positive.

Impact on the Other Informed Trader \( j \). By equation (38),

\[
\frac{\partial \log(\pi_j)}{\partial z} = \frac{\partial}{\partial z} \left[ \log \left( \sigma_u e^{-1/2} \right) + \log(S_O) - \log(\Delta_1) - \log(\Delta_2) \right] \\
= \frac{1}{S_O} \frac{\partial S_O}{\partial z} - \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z}. 
\]  

Take derivative of \( S_O \) with respect to \( z \), we have

\[
\frac{\partial S_O}{\partial z} = 2 \left( 1 + \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z} \right) \left( - \frac{e}{(e+h+z)^2} + \frac{1}{3} \frac{e+h}{(e+h+z)^2} \right) \frac{h}{e+h} \left( 1 + \frac{e}{e+h} \right)^{-2}. 
\]  

(44)

Plugging equations (42), (43), (44), (34) and (33) into \( \frac{1}{S_O} \frac{\partial S_O}{\partial z} - \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z} \), we can show that it is negative. Thus, \( \frac{\partial \pi_j(z,e,h,N)}{\partial z} < 0 \), for \( j = 1, ..., N \).

A3 Proof of Proposition 3

Plugging in the expressions of \( \alpha_L \) and \( \alpha_I \) in equations (23) and (24) and the expression of \( \beta_D \) in equation (35), we have

\[
Var(\tilde{x}_I) = (\alpha_I + \alpha_L)^2 / e + \alpha_L^2 / z \\
= \frac{\sigma_u^2}{\Delta_1} \left[ \left( 1 + \frac{e}{e+h+z} + \frac{1}{3} \frac{z}{e+h+z} \right)^2 + \left( \frac{2}{3} \frac{z}{e+h+z} \right)^2 \frac{e}{z} \right]. 
\]

Thus, by equation (31),

\[
\pi_I(z,e,h,N) = \lambda Var(\tilde{x}_I) = \frac{\sigma_u S_I}{e^{1/2} \Delta_1 \Delta_2}. 
\]  

(45)
where

\[ S_I = \left( 1 + \frac{e}{e + h + z} + \frac{z}{3(e + h + z)} \right)^2 + \left( \frac{2}{3} \frac{z}{e + h + z} \right)^2 \frac{e}{z}. \]  

(46)

Therefore,

\[ \frac{\partial \log (\pi_I)}{\partial z} = \frac{\partial}{\partial z} \left[ \log (\sigma_u e^{-1/2}) + \log (S_I) - \log (\Delta_1) - \log (\Delta_2) \right] = \frac{1}{S_I} \frac{\partial S_I}{\partial z} - \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z}. \]

Direct computation shows that

\[ \frac{\partial S_I}{\partial z} = \left[ \frac{2(1 + \frac{e}{e + h + z} + \frac{z}{3(e + h + z)})}{(e + h + z)} e - \frac{z}{3(e + h + z)^2} \right] + 2 \left( \frac{2}{3} \frac{e}{e + h + z} \right) \frac{2}{3} \frac{z}{(e + h + z)^2} - \left( \frac{e}{3(e + h + z)^2} \right). \]  

(47)

So, evaluating \( S_I, \Delta_1, \Delta_2, \frac{\partial S_I}{\partial z}, \frac{\partial \Delta_1}{\partial z}, \) \( \frac{\partial \Delta_2}{\partial z} \) at \( z = 0 \) in equations (46), (34), (33), (47), (42) and (43), and then plugging them into \( \left[ \frac{1}{S_I} \frac{\partial S_I}{\partial z} - \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z} \right] \), we have

\[ \left[ \frac{1}{S_I} \frac{\partial S_I}{\partial z} - \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z} \right]_{z=0} = \left( \frac{2 \left( \frac{e}{e + h + z} \right)^3 + N^2 \left( \frac{h}{e} \right)^2}{N^2 - \left[ 13 \left( \frac{h}{e} \right)^3 + 44 \left( \frac{h}{e} \right)^2 + 28 \frac{h}{e} \right] N - \left[ 45 \left( \frac{h}{e} \right)^3 + 202 \left( \frac{h}{e} \right)^2 + 292 \frac{h}{e} + 144 \right] \right), \]  

(48)

The denominator of the above equation is positive, but the sign of the numerator is ambiguous. Define the numerator as

\[ F \left( N, \frac{h}{e} \right) \triangleq \left[ 2 \left( \frac{h}{e} \right)^3 + N^2 \left( \frac{h}{e} \right)^2 \right] N^2 - \left[ 13 \left( \frac{h}{e} \right)^3 + 44 \left( \frac{h}{e} \right)^2 + 28 \frac{h}{e} \right] N - \left[ 45 \left( \frac{h}{e} \right)^3 + 202 \left( \frac{h}{e} \right)^2 + 292 \frac{h}{e} + 144 \right]. \]  

(49)

If we treat \( (h/e) \) as a parameter, then \( F (N, h/e) \) is a quadratic function of \( N \). In order to determine the sign of \( F (N, h/e) \), we need to calculate the root of \( N \) in the equation of \( F (N, h/e) = 0 \).

Setting \( F (N, h/e) = 0 \), we find that the unique positive root of \( N \) as a function of \( (h/e) \) is:

\[ \hat{N} \left( \frac{h}{e} \right) \triangleq \left[ 13 \left( \frac{h}{e} \right)^3 + 44 \left( \frac{h}{e} \right)^2 + 28 \frac{h}{e} \right] + \sqrt{4 \left[ 2 \left( \frac{h}{e} \right)^3 + 2 \left( \frac{h}{e} \right)^2 \right] \left[ 45 \left( \frac{h}{e} \right)^3 + 202 \left( \frac{h}{e} \right)^2 + 292 \frac{h}{e} + 144 \right]} \]

\[ \left( \left[ 13 \left( \frac{h}{e} \right)^3 + 44 \left( \frac{h}{e} \right)^2 + 28 \frac{h}{e} \right] \right)^2 \]  

(50)

By factoring the term under the square root, we can further simplify \( \hat{N} \left( \frac{h}{e} \right) \) as:

\[ \hat{N} \left( \frac{h}{e} \right) = \left[ 13 (h/e)^2 + 44 (h/e) + 28 \right] + (h/e + 2) \sqrt{529 (h/e)^2 + 1004 (h/e) + 484} \]

\[ 4 (h/e) (h/e + 1). \]  

(50)

Thus, \( F (N, h/e) > 0 \) if and only if \( N > \hat{N} \left( \frac{h}{e} \right) \); that is, \( \left. \frac{\partial \pi_I(z, e, h, N)}{\partial z} \right|_{z=0} > 0 \) if and only if \( N > \hat{N} \left( \frac{h}{e} \right) \).

In addition, we can show that the function \( \hat{N} \left( \frac{h}{e} \right) \) is decreasing in \( (h/e) \), because direct computa-
tion shows that the first order derivative of the function $\hat{N}(x) = \frac{(13x^2+44x+28)+(x+2)\sqrt{529x^2+1004x+484}}{4x(x+1)}$ is

$$
\hat{N}'(x) = -\frac{1}{4} \left[ \frac{[4x(x+1)]^2}{2940x + 56x\sqrt{1004x + 529x^2 + 484} \cdot 31x^2 \sqrt{1004x + 529x^2 + 484}}{+28\sqrt{1004x + 529x^2 + 484} + 2994x^2 + 1031x + 968} \right] < 0.
$$

### A4 Information Leakage, Price Informativeness and Market Liquidity

Applying Bayes’ rule delivers

$$
Var(\hat{z}|\hat{p}) = \frac{1}{e} \frac{Cov(\hat{z}, \hat{w})}{Var(\hat{w})} = \frac{1}{e} - \lambda Cov(\hat{z}, \hat{w}),
$$

where the last equality follows from $\lambda = \frac{Cov(\hat{z}, \hat{w})}{Var(\hat{w})}$. Thus, $\frac{\partial \{1/Var(\hat{z}|\hat{p})\}}{\partial z} > 0$ if and only if $\frac{\partial \{Cov(\hat{z}, \hat{w})\}}{\partial z} > 0$.

By the expression of $\hat{w}$ (given by equation (30)) and the fact that $\beta_D \lambda = \frac{1}{\Delta_2}$ (implied by Proposition 1):

$$
\lambda Cov(\hat{z}, \hat{w}) = \frac{\lambda A_\epsilon \beta_D}{e} = \frac{A_\epsilon}{\Delta_2 e}.
$$

Then, by equations (27), (29) and (33), we have:

$$
A_\epsilon = \frac{2}{3e + h + z} + \frac{h}{e + h + z} - 2 + \Delta_2.
$$

Therefore,

$$
\lambda Cov(\hat{z}, \hat{w}) = \frac{2}{3} \frac{(1 - e + h + z) + h}{e + h + z} - 2 + \frac{1}{e},
$$

and as a result:

$$
\frac{\partial \{\lambda Cov(\hat{z}, \hat{w})\}}{\partial z} > 0 \iff \frac{\partial}{\partial z} \left[ \frac{2}{3} \left(1 - \frac{e + h + z}{e + h + z} + \frac{h}{e + h + z} - 2\right) \right] > 0.
$$

Direct computation shows that

$$
\frac{\partial}{\partial z} \left[ \frac{2}{3} \left(1 - \frac{e + h + z}{e + h + z} + \frac{h}{e + h + z} - 2\right) \Delta_2 e \right] = \frac{8}{3} \frac{1}{(h + z + e)^2 \Delta_2} > 0.
$$

So, information leakage improves price informativeness; that is, $\frac{\partial \{1/Var(\hat{z}|\hat{p})\}}{\partial z} > 0$.

We next examine the impact of information leakage on market illiquidity $\lambda$. By equation (31), $\lambda = \frac{\Delta_1}{\sigma_{\hat{w}}^2 \Delta_2}$. Thus,

$$
\frac{\partial \log(\lambda)}{\partial z} = \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z}.
$$

Evaluating $\Delta_1$, $\Delta_2$, $\frac{\partial \Delta_1}{\partial z}$ and $\frac{\partial \Delta_2}{\partial z}$ at $z = 0$ in equations (34), (33), (42) and (43), respectively, and
then plugging those values into equation (51), we have
\[
\left. \frac{\partial \log (\lambda)}{\partial z} \right|_{z=0} = \left. \left[ \frac{1}{\Delta_1} \frac{\partial \Delta_1}{\partial z} - \frac{1}{\Delta_2} \frac{\partial \Delta_2}{\partial z} \right] \right|_{z=0}
\]
\[
= \frac{2}{9} \frac{e (Nh - 9h + 4e)}{N^2h^3 + eN^2h^2 + 5Nh^3 + 12eNh^2 + 8e^2Nh + 6h^3 + 23h^2 + 32e^2h + 16e^3}
\]

So, \( \frac{\partial \lambda}{\partial z} \bigg|_{z=0} < 0 \) (i.e., \( \frac{\partial \log (\lambda)}{\partial z} \bigg|_{z=0} < 0 \)) if and only if
\[
Nh - 9h + 4e > 0 \iff N > 9 - 4 (h/e)^{-1}.
\]  
By equation (50):
\[
\hat{N} \left( \frac{h}{e} \right) = \frac{13 (h/e)^2 + 44 (h/e) + 28}{4 (h/e) (h/e + 1)} + (h/e + 2) \sqrt{529 (h/e)^2 + 1004 (h/e) + 484}
\]
\[
> \frac{13 (h/e) (h/e + 1) + 5 \sqrt{529 (h/e) (h/e + 1)}}{4 (h/e) (h/e + 1)} = 9 > 9 - 4 (h/e)^{-1}.
\]

Therefore, if \( N = \hat{N} \), then \( \frac{\partial \lambda}{\partial z} \bigg|_{z=0} < 0 \).
Figure 1 The Region of Rational Information Leakage

This figure uses “+” to indicate the region for which the number of other informed traders $N$ exceeds the threshold value $\bar{N}(h/e)$, which is a function of the other informed trader’s signal-to-noise ratio $(h/e)$. The solid curve is identified as “information leakage frontier”.

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
0
50
100
150
200
250

Signal-to-Noise Ratio, $(h/e)$

Number of Other Informed Traders, $N$
This figure shows the implications of information leakage for the insider’s profit when the number of the other informed traders takes a value of 10 (Panel (a)) or 50 (Panel (b)). The other parameter values are $e = h = \sigma_u = 1$. 
This figure shows the insider’s profit as functions of precision of leakage $z$ when there are two groups of informed traders and when he can choose to leak information to a trader from the more informed group (blue, solid curve) or from the less informed group (red, dashed curve). The more informed group has $N_1 = 25$ traders with precision of $h_1 = 2$, while the less informed group has $N_2 = 26$ traders with precision of $h_2 = 0.5$. The other parameter values are $e =\sigma_u = 1$. 