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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 one or more *independent* traders. 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. The profit impact of these two effects are countervailing. When there are a sufficient number of other informed traders, the profit impact from enhanced information dominates. Hence, the insider has incentives to leak some of his private information. We label this rational information leakage and discuss its implications for the regulation of insider trading.

Keywords: Information leakage, insider trading, securities regulations.

JEL Classifications: G14, G18, D82.

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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* where information is selectively revealed to a subset of investors. 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 (2013) suggest that leaked information can explain the increased short-sale trading 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 informed individuals would be motivated to leak their private information.[1] The standard intuition holds that some privately informed individuals, e.g., corporate executives and board members hindered from actively trading in their firms' shares, share or sell 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 and compensated as hedge fund consultants (Zuckerman and Pulliam 2010). Similarly, sell-side analysts who cannot otherwise trade on the information they generate can indirectly profit from their work by pre-releasing (or tipping)

[1] Of course, private information can also be stolen by (or involuntarily leaked to) individuals intent on exploiting 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).

their analyst recommendations to those clients who generate significant commission revenues.

In this paper, we argue that informed traders' incentives to leak information extend beyond the above standard logic. In particular, we show that an informed investor (e.g., an insider who is allowed to trade actively) may voluntarily reveal some of his private information to unrelated or *independent* third parties and yet benefit from this leakage even in the absence of explicit payments, commissions, or claims to the other party's trading profits.

To illustrate an informed trader's rationale to leak information as parsimoniously as possible, 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. To characterize information leakage where information is selectively revealed to a small subset of investors, we assume that the insider provides a garbled version of his information to a single (unaffiliated) informed trader whom we label as a *designated trader*.[2] We assume that the insider can commit to a noisy information leakage system and that the extent of noise in that leaked information is common knowledge. We find that leaking information to the designated trader (without receiving compensation in return) has countervailing effects on the insider's expected trading profits. The negative 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 positive effect is more subtle; leaking information increases the insider's information advantage concerning the execution price of the asset relative to everyone else. This is because trades that rely on the leaked information render the asset price 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.

Clearly, when the profit impact of the negative effect dominates the profit impact of the positive effect, the insider has no incentive to leak information. Conversely, when the positive effect dominates the negative effect, information leakage is *rational*. Overall, information leakage benefits the insider, the single designated trader and liquidity traders at the expense

[2] We also consider a more general model in Section 4.1 where the insider reveals a garbled version of his information to all other informed traders, not just one. Although revealing information to a large group of traders is less descriptive of the notion of "information leakage," the insider's motivation is similar nonetheless to his motivation to leak information to a single designated trader.

of other informed traders. The liquidity traders benefit because information leakage reduces the overall level of information asymmetry amongst market participants rendering the market deeper for trade. In turn, the single designated trader benefits mainly because he gains an information advantage vis-à-vis other informed traders.[3] Moreover, we find that information leakage is rational if and only if there are a sufficient number of other informed traders. The intuition is straightforward. Because the insider's benefit accrues only at the expense of other informed traders, a sufficiently large population of other traders is required to render information leakage profitable.

Our finding that the insider benefits at the expense of other informed traders who are not privy to the leaked information 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 collectively reduce their information collection efforts as the marginal benefit of doing so declines due to information leakage. Finally, our model demonstrates that information leakage can enhance market depth and can dampen liquidity traders' losses. This latter result complements Leland's (1992) finding that more insider trading can benefit uninformed liquidity traders by making the market more liquid.

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 that informed investors cannot benefit from sharing information 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, and/or when other traders are relatively well informed.

Finally, our paper contributes to the debate on how to regulate insider trading. Sharing

[3] When the insider reveals some information to all other informed traders (as in Section 4.1), all will trade optimally on the information even though no one enjoys an information advantage over another. In this case, the insider and the liquidity traders benefit at the expense of all other informed traders despite the fact that the information that is revealed improves all informed traders' understanding of firm value.

of information amongst a subset of investors, whether through leakage, tipping or other broader forms of selective disclosure, has been a critical concern of capital market regulators and has attracted significant attention from academics over several decades (SEC 2000). The wealth transfers from some traders to others highlighted in our model illustrate that those who diligently collect and process information (e.g., informed traders who are not privy to the leaked information) are not appropriately rewarded for their efforts. Thus, understanding this rational mechanism for information sharing highlights the need to focus on the underlying incentives rather than simply building a Chinese Wall such as the Regulation Fair Disclosure.

Although 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 the huge information selling literature.[4] For instance, our model has elements in common with both Fishman and Hagerty (1995) and Cheynel and Levine (2012) but differs from both technically as well as practically in terms of the empirical contexts to which it applies. In Fishman and Hagerty (1995), the insider also profits at the expense of other traders but the source of such profits is not due to an information advantage that comes from strategic information leakage. Instead, the profits derive from the sale of information to previously uninformed traders who compete against other informed traders. In Cheynel and Levine (2012), the profits also derive from the sale of information (as in Fishman and Hagerty) but the focus is on non-trading analysts selling non-fundamental information (e.g., information about supply noise) to all potential traders. Although such non-fundamental information gives some traders an information advantage over the execution price of the asset (as in our model), the Cheynel and Levine model is not designed to address an insider's strategic decision to leak fundamental information to a single or select few other traders.[5]

Given that information leakage is a form of "selective disclosure", our paper is also related to accounting studies examining the implication of public disclosures using strategic

[4] This literature was started by a series of studies conducted by Admati and Pfleiderer (1986, 1988, 1990) and Allen (1990). Other notable work includes Benabou and Laroque (1992), Fishman and Hagerty (1995), Veldkamp (2006), Cespa (2008), Garcia and Vanden (2009), Garcia and Sangiorgi (2011), and Cheynel and Levine (2012), among many others.

[5] The general idea that noise or non-fundamental information is a source of information advantage is also illustrated in van Bommel (2003) and Brunnermeier (2005), both of which use a dynamic model to show that an informed trader can profit from the price overshooting caused by non-fundamental information.

Kyle-type models (e.g., Bushman and Indjejikian 1995, Huddart, Hughes, and Levine 2001). For instance, Bushman and indjejikian (1995) demonstrate that disclosing some public 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. Specifically, our analysis in Section 4.2 suggests that, among all informed traders, the insider prefers to leak the information to the less informed.

The remainder of the paper is organized as follows. Section 2 describes the model setup and equilibrium. Section 3 shows the rationality of information leakage, outlining the conditions that must prevail for the insider to leak private information. Section 4 shows the robustness of our results to some alternative settings, and 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 $\tilde{\varepsilon} \sim N(0,1)$.[6] There are two types of risk-neutral informed traders: (1) a well-informed investor (e.g., insider) who privately observes $\tilde{\varepsilon}$; and (2) two groups of informed traders (N_1 and N_2) who observe private signals about $\tilde{\varepsilon}$ as follows:

$$\tilde{y}_{1,j} = \tilde{\varepsilon} + \tilde{\eta}_{1,j} \text{ where } \tilde{\eta}_{1,j} \sim N\left(0, h_1^{-1}\right) \text{ (with } h_1 > 0\text{) for } j = 1, \ldots, N_1, \tag{1}$$

$$\text{and } \tilde{y}_{2,j} = \tilde{\varepsilon} + \tilde{\eta}_{2,j} \text{ where } \tilde{\eta}_{2,j} \sim N\left(0, h_2^{-1}\right) \text{ (with } h_2 > 0\text{) for } j = 1, \ldots, N_2. \tag{2}$$

Descriptively, the insider in our model can be thought of as a hedge fund manager or

[6] The normalization that $\tilde{\varepsilon}$ has a zero mean and a unit standard deviation is without loss of generality. Instead, if we assume $\tilde{\varepsilon} \sim N(\bar{\varepsilon}, 1/e)$ (with $\bar{\varepsilon} \in \mathbb{R}$ and $e > 0$), then all our results would hold as long as we reinterpret the information precisions (h and z) as signal-to-noise ratios.

corporate executive with superior information about a firm's prospects, while the $N_1 + N_2$ informed traders in our model can be thought of as institutional investors that may 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 to all traders in one group (say group 1). That is, in addition to $\tilde{y}_{1,j}$, traders in group 1 receive a signal of the form

$$\tilde{y}_{L,j} = \tilde{\varepsilon} + \tilde{\zeta}_j, \text{ with } \tilde{\zeta}_j \sim N(0, 1/z) \text{ and } z \geq 0 \text{ for } j = 1, \ldots, N_1. \tag{3}$$

We note that the precision z of $\tilde{\zeta}_j$ dictates the extent to which the insider leaks information where $z = 0$ corresponds to no information leakage and $z \to \infty$ corresponds to full leakage. Clearly, $\tilde{\zeta}_j$ is in the insider's information set because he observes $\tilde{\varepsilon}$ and the leaked signals $\tilde{y}_{L,j}$. Indeed, the insider's knowledge of $\tilde{\zeta}_j$ is central to our results because such knowledge confers an informational advantage relative to all other market participants.

To illustrate the insider's rationale to leak information as parsimoniously as possible, for the remainder of this section and throughout Section 3 we assume that $N_1 = 1$ and $h_1 = h_2 = h$. That is, we assume the insider leaks information to a single trader who is otherwise equally well informed as the other N_2 traders prior to observing the leaked signal. For greater clarity, we denote the trader privy to the leaked information as trader D for *designated trader*. Accordingly, we write trader D's signal $\tilde{y}_{1,j}$ as $\tilde{y}_D$, the leaked information $\tilde{y}_{L,j} = \tilde{\varepsilon} + \tilde{\zeta}_j$ as $\tilde{y}_L = \tilde{\varepsilon} + \tilde{\zeta}$, and other traders' private signals $\tilde{y}_{2,j} = \tilde{\varepsilon} + \tilde{\eta}_{2,j}$ as $\tilde{y}_j = \tilde{\varepsilon} + \tilde{\eta}_j$. This simplification notwithstanding, in Appendix A1, we consider a more general model where $N_1 \neq 1$. In addition, in Section 4 we address the insider's motivation to leak information to multiple traders as well as his motivations in the event that $h_1 \neq h_2$.

The market is also populated by risk-neutral liquidity traders whose net order is represented by

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

and a risk-neutral market maker who only observes the aggregate market order flow and sets the price. Finally, we assume that all the underlying random variables $\{\tilde{\varepsilon}, \tilde{\zeta}, \tilde{u}, \tilde{\eta}_D, \tilde{\eta}_1, ..., \tilde{\eta}_{N_2}\}$

are mutually independent and the statistical properties of all random variables are common knowledge.

2.2 Equilibrium

As in Kyle (1985) and the subsequent literature, we restrict attention to equilibria in which the price is linear in order flow and each trader's strategy is linear in the statistics characterizing that trader's information. Specifically, the market maker sets the price according to the weak efficiency rule:

$$\tilde{p} = E\left(\tilde{\varepsilon}|\tilde{\omega}\right) = \lambda\tilde{\omega}, \tag{5}$$

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

$$\tilde{\omega} = \tilde{x}_I + \tilde{x}_D + \sum_{j=1}^{N_2} \tilde{x}_j + \tilde{u}, \tag{6}$$

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, respectively.

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

$$\max_{\tilde{x}_i} E\left[\left(\tilde{\varepsilon} - \tilde{p}\right)\tilde{x}_i | \mathcal{I}_i\right],$$

where $\mathcal{I}_i$ is his information set.

The first-order condition is

$$E\left[\left.\frac{\partial\left(\tilde{\varepsilon} - \tilde{p}\right)}{\partial\tilde{x}_i}\tilde{x}_i + \left(\tilde{\varepsilon} - \tilde{p}\right)\right| \mathcal{I}_i\right] = 0, \tag{7}$$

which, by $\tilde{p} = \lambda\tilde{\omega} = \lambda\left(\tilde{x}_I + \tilde{x}_D + \sum_{j=1}^{N_2} \tilde{x}_j + \tilde{u}\right)$, implies that the optimal order flow is

$$\tilde{x}_i^* = \frac{1}{2\lambda}\left[E\left(\tilde{\varepsilon}|\mathcal{I}_i\right) - \lambda\sum\nolimits_{k\neq i} E\left(\tilde{x}_k^*|\mathcal{I}_i\right)\right]. \tag{8}$$

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

$$\pi_i = E\left\{E\left[\left(\tilde{\varepsilon} - \tilde{p}\right)\tilde{x}_i^* | \mathcal{I}_i\right]\right\} = \lambda Var\left(\tilde{x}_i^*\right). \tag{9}$$

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:

$$\begin{bmatrix} \tilde{x}_I = \alpha_I \tilde{\varepsilon} + \alpha_L \tilde{y}_L \\ \tilde{x}_D = \beta_D E\left(\tilde{\varepsilon}|\tilde{y}_D, \tilde{y}_L\right) + \beta_L \tilde{y}_L \\ \tilde{x}_j = \gamma E\left(\tilde{\varepsilon}|\tilde{y}_j\right) \end{bmatrix}, \tag{10}$$

where coefficients α_I, α_L, β_D, β_L and γ are endogenously determined. The coefficients α_I and β_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 α_L and β_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 α_I, α_L, β_D, β_L and γ as follows:

$$\begin{bmatrix} 2\alpha_I + \frac{h}{1+h+z}\beta_D + \frac{N_2 h}{1+h}\gamma = \frac{1}{\lambda} \\ 2\alpha_L + \frac{z}{1+h+z}\beta_D + \beta_L = 0 \\ 2\beta_D + \alpha_I + \frac{N_2 h}{1+h}\gamma = \frac{1}{\lambda} \\ \alpha_L + 2\beta_L = 0 \\ \alpha_I + \alpha_L + \frac{h+z}{1+h+z}\beta_D + \beta_L + \left[2 + \frac{(N_2-1)h}{1+h}\right]\gamma = \frac{1}{\lambda} \end{bmatrix}. \tag{11}$$

Combining (11) with $\lambda = \frac{Cov(\tilde{\varepsilon},\tilde{\omega})}{Var(\tilde{\omega})}$ gives a system of six equations and six unknowns (λ, α_I, α_L, β_D, β_L and γ). Solving this system yields the following proposition.

Proposition 1 *The equilibrium price function is*

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

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

$$\begin{aligned}
\tilde{x}_I &= \alpha_I \tilde{\varepsilon} + \alpha_L \tilde{y}_L, \\
\tilde{x}_D &= \frac{h\beta_D}{1+h+z}\tilde{y}_D + \left(\frac{z\beta_D}{1+h+z} + \beta_L\right)\tilde{y}_L, \\
\tilde{x}_j &= \frac{h\gamma}{1+h}\tilde{y}_j,
\end{aligned}$$

where $j = 1, 2, \ldots, N_2$, *and where*

$$\begin{aligned}
\lambda &= \frac{\sqrt{C_2}}{\sigma_u C_1}, \alpha_I = \frac{3(h+2)(h+2z+2)}{C_1\lambda}, \alpha_L = -\frac{2z(h+2)}{C_1\lambda} \\
\beta_D &= \frac{3(h+2)(h+z+1)}{C_1\lambda}, \beta_L = \frac{z(h+2)}{C_1\lambda}, \gamma = \frac{(h+1)(3h+4z+6)}{C_1\lambda},
\end{aligned}$$

with

$$C_1 = N_2 h(3h+4z+6) + 3(h+2)(3h+4z+4),$$

$$C_2 = N_2 h(h+1)(3h+4z+6)^2 + (h+2)^2\left[2(3h+4z)^2 + 45h + 68z + 36\right].$$

Proof. See Appendix A1. ■

Four notable observations emerge from Proposition 1. First, we note that the insider's trading strategy depends explicitly on the leaked information $\tilde{y}_L = \tilde{\varepsilon} + \tilde{\zeta}$ (i.e., $\alpha_L \neq 0$) despite the fact that the insider observes $\tilde{\varepsilon}$, and $\tilde{y}_L$ is simply a garbled version of $\tilde{\varepsilon}$. 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 $\alpha_L + \left(\frac{z\beta_D}{1+h+z} + \beta_L\right) = \frac{2z(h+2)}{C_1\lambda}$.

Second, we note that the insider's $\tilde{y}_L$-based trading strategy (i.e., α_L) is negative while trader D's $\tilde{y}_L$-based trading strategy, $\left(\frac{z\beta_D}{1+h+z} + \beta_L\right)$, 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 $z = 0$, $\tilde{x}_D = \tilde{x}_j$; otherwise, when $z > 0$, trader D trades more than the other N_2 informed traders in the sense that $Var(\tilde{x}_D) > Var(\tilde{x}_j)$, which can be shown by direct computation (see also Lemma 1 below).

Finally, we note that for a given λ, increasing z decreases γ, which means that information leakage causes the other informed traders to trade less aggressively on their own information. As we illustrate in the next section, this is an important consequence of information leakage and will prove central to our results.

3 Rational Information Leakage

In this section, we address the insider's rationale for leaking information. We begin by first characterizing the ex ante profits of the designated trader and other N_2 informed traders. Substituting the trading strategies $\tilde{x}_D$ and $\tilde{x}_j$ described in Proposition 1 into the traders' respective profit expressions in (9), we have:

$$\pi_D(z,h,N_2) = \frac{\sigma_u (h+2)^2 \left(9h + 16z + (3h+4z)^2\right)}{C_1\sqrt{C_2}} \tag{12}$$

$$\pi_j(z,h,N_2) = \frac{\sigma_u h (h+1)(3h+4z+6)^2}{C_1\sqrt{C_2}} \tag{13}$$

$$\text{and } \pi_D + N_2\pi_j = \pi_j \left(N_2 + 1 + \frac{8z\left[(5h+4)(h+2) + 2z(3h+4)\right]}{h(h+1)(3h+4z+6)^2} \right) \tag{14}$$

where $j = 1, 2, \ldots, N_2$ and C_1 and C_2 are defined in Proposition 1.

Expressions (12) through (14) suggest that $\pi_D \geq \pi_j$. This follows because the leaked signal, $\tilde{y}_L$, provides the designated trader additional information concerning the asset's payoff unavailable to the other N_2 traders. Indeed, we can show that as $\tilde{y}_L$ becomes increasingly more precise (i.e., as z increases), the designated trader's profit increases while the profit of the other N_2 traders decreases. As a result, if N_2 is large, information leakage decreases the profit of designated trader and the other N_2 informed traders combined. We summarize these observations in the following lemma.

Lemma 1 *The expected profit of the designated trader is increasing in the precision of the leaked information. The expected profits of the other N_2 informed traders are decreasing in the precision of leaked information. Finally, for large N_2, we have $\frac{\partial(\pi_D + N_2\pi_j)}{\partial z} \leq 0$.*

Proof. Direct computation. ■

To analyze the insider's motivation for leaking information we begin by recasting the insider's demand, $\tilde{x}_I = \alpha_I \tilde{\varepsilon} + \alpha_L \tilde{y}_L$ in Proposition 1, as a trading strategy based on two distinct pieces of information; information about the asset's fundamental value $\tilde{\varepsilon}$ and information about the non-fundamental component $\tilde{\zeta}$ of the leaked signal $\tilde{y}_L = \tilde{\varepsilon} + \tilde{\zeta}$. That is,

$$\tilde{x}_I = (\alpha_I + \alpha_L)\,\tilde{\varepsilon} + \alpha_L \tilde{\zeta}. \tag{15}$$

Intuitively, we expect information leakage to dampen the insider's demand corresponding to the fundamental component because sharing information with other traders (here the designated trader D) weakens the insider's information advantage about $\tilde{\varepsilon}$. At the same time, expression (15) suggests that information leakage generates a trading opportunity for the insider, one that is based on information about the non-fundamental component $\tilde{\zeta}$. The intuition is straightforward. Because price is sensitive to $\tilde{y}_L$-based trades, the insider's knowledge of both $\tilde{\varepsilon}$ and $\tilde{y}_L$ (and by default $\tilde{\zeta}$) generates an informational advantage about the asset's execution price, $\tilde{p}$.

Substituting (15) into the insider's ex ante profit expression in (9) yields

$$\pi_I(z, h, N_2) = \frac{\sigma_u (h+2)^2 (3h + 4z + 6)^2}{C_1 \sqrt{C_2}} + \frac{4z\sigma_u (h+2)^2}{C_1 \sqrt{C_2}}, \tag{16}$$

where the two terms in (16) correspond to the $\tilde{\varepsilon}$-sensitive and $\tilde{\zeta}$-sensitive trades in (15) respectively, and C_1, C_2 are as defined earlier. Intuitively then, we expect information leakage to lower the insider's profit corresponding to the fundamental component but increase the insider's profit corresponding to the non-fundamental component (because leakage is the mechanism that generates $\tilde{\zeta}$-sensitive trades in the first place).[7] Therefore, the insider's decision *whether* to leak information and *how much* information to leak depends on the relative importance of these two effects.

Expression (15) illustrates how information leakage gives the insider an informational advantage about the asset's execution price. At the same time, Lemma 1 shows that such

[7] Leaking generates an informational advantage about the asset's execution price as long as the insider does not reveal his private information, $\tilde{\varepsilon}$, perfectly. With perfect leakage (i.e., $z \to \infty$) the designated trader is as equally well informed as the insider and hence price is no longer sensitive to $\tilde{\zeta}$. This implies that perfect leakage is never optimal for the insider.

leakage benefits the designated trader and harms the other N_2 traders. Therefore, taken together, these results imply that if the insider were to profit from his information advantage about the asset's execution price, the profits would accrue at the expense of the other N_2 traders. To illustrate this somewhat differently, we recast the insider's profit in (16) as a fraction (or percentage) of total market profit as follows:

$$\begin{aligned} \pi_I(z,h,N_2) &= \frac{Var(\tilde{x}_I)}{Var(\tilde{x}_I)+Var(\tilde{x}_D)+N_2 Var(\tilde{x}_j)} \times \lambda\sigma_u^2 \\ &= \frac{1}{1+\frac{[Var(\tilde{x}_D)+N_2 Var(\tilde{x}_j)]}{Var(\tilde{x}_I)}} \times \lambda\sigma_u^2, \end{aligned} \tag{17}$$

where $\lambda\sigma_u^2$ represents the expected costs borne by liquidity traders (or equivalently the combined trading profits of informed traders), and $\frac{[Var(\tilde{x}_D)+N_2 Var(\tilde{x}_j)]}{Var(\tilde{x}_I)}$ represents the trading aggressiveness of the insider (or his market share) relative to the N_2+1 informed traders. In contrast to expression (16) which characterizes the insider's profit in relation to the two sources of insider information, expression (17) suggests that the profit impact of information leakage can also be understood in terms of its consequences to the other market participants, namely the liquidity traders and N_2+1 informed traders.

Consider first the effect of leakage on λ holding the effects on the other N_2+1 traders constant. As we will show in Proposition 3 below, an increase in z typically improves market liquidity (i.e., λ^{-1}) which reduces the losses incurred by liquidity traders. From (17), it follows that a lower λ reduces the profits to be shared by all informed traders including the insider. This implies that the insider's profit from information leakage must be at the expense of the other N_2+1 traders.

Next, consider the effect of leakage on the designated trader through the term $\frac{Var(\tilde{x}_D)}{Var(\tilde{x}_I)}$. From Lemma 1, this term can be computed as $\frac{Var(\tilde{x}_D)}{Var(\tilde{x}_I)} = \left[1+\frac{9(3h+4z+4)}{(3h+4z)^2+9h+16z}\right]^{-1}$, which is unambiguously increasing in z. Hence, ceteris paribus, information leakage decreases the insider's profit in (17) via $\frac{Var(\tilde{x}_D)}{Var(\tilde{x}_I)}$.

Lastly, we consider the effect of leakage on $\frac{Var(\tilde{x}_j)}{Var(\tilde{x}_I)} = \left[\frac{(h+2)^2}{h(h+1)} + \frac{(h+2)^2}{h(h+1)}\frac{4z}{(3h+4z+6)^2}\right]^{-1}$ which remains the only potential avenue for the insider to benefit from information leakage. The first component in $\frac{Var(\tilde{x}_j)}{Var(\tilde{x}_I)}$ represented by the term $\frac{(h+2)^2}{h(h+1)}$ corresponds to the trading aggressiveness of the insider relative the other N_2 informed traders with respect to the asset's fundamental value $\tilde{\varepsilon}$ (i.e., corresponds to the first term in expression (15)). This term is unaffected by z because information leakage does not alter the insider's relative information advantage vis-a-vis the other N_2 informed traders with respect to the asset's fundamental value $\tilde{\varepsilon}$. In contrast, the second component in $\frac{Var(\tilde{x}_j)}{Var(\tilde{x}_I)}$ represented by the term $\frac{(h+2)^2}{h(h+1)}\frac{4z}{(3h+4z+6)^2}$, which corresponds to the insider's aggressiveness with respect to non-fundamental information $\tilde{\zeta}$, is increasing in z for small z (when $z < \frac{3h+6}{4}$). This implies that $\frac{Var(\tilde{x}_j)}{Var(\tilde{x}_I)}$ is decreasing in z (for small z) and hence information leakage increases the insider's profit via $\frac{Var(\tilde{x}_j)}{Var(\tilde{x}_I)}$. Finally, we note that the impact of leakage on other informed traders is particularly robust for large N_2.

Taken together, the preceding discussion suggests that the insider's benefit from information leakage (if any) comes at the expense of the other informed traders. Formally, then, if $z^* = \max\{0, \arg\max_z \pi_I(z,h,N_2)\}$ represents the insider's optimal choice of z, we say that information leakage is *rational* if $\arg\max_z \pi_I(z,h,N_2) > 0$. We have:

Proposition 2 ***[Rational Information Leakage]*** *Information Leakage to a single designated trader is rational if and only if*

$$N_2 > \hat{N}_2(h) \equiv \frac{(13h^2+44h+28)+(h+2)\sqrt{529h^2+1004h+484}}{4h(h+1)};$$

that is, $z^* > 0$ if and only if N_2, the number of other informed traders, is sufficiently large.

Proof. See Appendix A2. ■

If N_2 is greater than $\hat{N}_2$, the optimal z^* can be solved for explicitly as the solution to a cubic polynomial described in Appendix A2. The intuition is better captured in Figure 1 which plots the function $\hat{N}_2(h)$ with a solid curve in the plane of (h, N_2). 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_2 is greater than $\hat{N}_2(h)$.

[INSERT FIGURE 1 HERE]

Proposition 2 (and Figure 1) suggest that information leakage is more likely when (i) there are more informed traders in the market (N_2 is large) and/or (ii) other informed traders' are relatively well informed about the underlying asset (h 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_2 is large) and/or if these traders are more aggressive due to their more precise signals (h is large), the benefit of leaking information is large and it is potentially rational for the insider to leak some of his information.

Taken together, Lemma 1 and Proposition 2 suggest that rational information leakage benefits the insider (and the designated trader) at the expense of other informed traders. Of course, this affects the overall liquidity of the market because, as we noted earlier, the aggregate expected profit of all informed traders, $\pi_I + \pi_D + N_2\pi_j$, equals the expected cost borne by liquidity traders, namely $\lambda\sigma_u^2$. Indeed, for N_2 large enough, and in particular greater than $\hat{N}_2(h)$, we conjecture that markets are more liquid and there is less information asymmetry in the market (i.e., λ is lower) because the N_2 informed traders trade less aggressively on their private information when there is information leakage. In turn, a lower λ implies that information leakage dissipates the aggregate profit of the other informed traders and the designated trader combined, i.e., $\pi_D + N_2\pi_j$ is lower with information leakage that without.[8] We have:

Proposition 3 *Rational information leakage to a designated trader (i) benefits liquidity traders (i.e., renders markets more liquid) and (ii) reduces the aggregate profits of informed traders who are not insiders. That is, if* $z^* > 0$, *then* $\lambda(z, h, N_2)|_{z=z^*} < \lambda(z, h, N_2)|_{z=0}$ *and* $(\pi_D + N_2\pi_j)|_{z=z^*} < (\pi_D + N_2\pi_j)|_{z=0}$.

Proof. See Appendix A3.1. ■

An important implication of Proposition 3 is that information leakage benefits uninformed market participants (e.g., liquidity traders) but harms informed investors who are otherwise not privy to inside information. A practical consequence is that informed investors have less

[8] This result prevails even if the insider leaks information to all informed traders, not just to one designated trader (see Section 4.1). In this case, all traders will optimally trade on the information even though they would be better off if they were to jointly commit not to trade on the leaked information.

of an incentive to collect and process information which may have important implications for the efficient functioning of capital markets.

Rational information leakage also has implications for assessing the informational efficiency of market price. For instance, with leakage we expect the price of the risky asset to be more efficient because more of the insider's information is eventually impounded in price. In the context of our model, if we define price informativeness as $\frac{1}{Var(\tilde{\varepsilon}|\tilde{p})}$, the precision of the risky asset payoff conditional on its price, then we expect $\frac{1}{Var(\tilde{\varepsilon}|\tilde{p})}$ evaluated at all values of $z^* > 0$ to be greater than $\frac{1}{Var(\tilde{\varepsilon}|\tilde{p})}$ evaluated at $z = 0$. We have:

Proposition 4 *Markets are more informationally efficient with rational information leakage than without. That is,* $\frac{\partial \frac{1}{Var(\tilde{\varepsilon}|\tilde{p})}}{\partial z} > 0$.

Proof. See Appendix A3.2. ■

4 Model Extensions

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

4.1 Leaking Information to All Informed Traders

In this subsection, we consider the possibility that the insider leaks information to all other informed traders in the marketplace rather than a single trader labeled earlier as the designated trader. To address this question, we adapt the general model introduced in Section 2.1 and solved for in Appendix A1 by setting $N_2 = 0$ so that all remaining ($N_1 > 1$) informed traders are privy to the leaked information.[9] Given this structure, we define *rational information leakage* as before; namely, we say that information leakage is rational if z^*, the precision of all leaked signals, is greater than zero. We have:

Proposition 5 *Information leakage to all informed traders is rational if and only if*

$$N_1 > \hat{N}_1(h) \equiv \frac{(h+2)(17h+14) + (h+2)\sqrt{529h^2 + 1004h + 484}}{4h(h+1)};$$

[9] In contrast, recall that in Sections 2 and 3 we have $N_1 = 1$ and $N_2 > 0$.

that is, $z^* > 0$ if and only if N_1, the number of informed traders who receive leaked information from the insider is sufficiently large.

Proof. See Appendix A4.1. ■

We note that the necessary and sufficient condition for information leakage in Proposition 5, i.e., $\hat{N}_1(h)$, mirrors the corresponding condition in Proposition 2 (i.e., $\hat{N}_2(h)$) where the insider leaks information to a single designated trader. In particular, we note that $\hat{N}_1(h) = \hat{N}_2(h) + 1$ because in the model considered in Section 3 we have $N_2 + 1$ informed traders (other than the insider) while in the current model we have N_1 informed traders. More importantly, the correspondence between Propositions 2 and 5 implies that the rationale for information leakage depends on the size of the informed trader population rather than on the presence of a single designated trader or a subset of the population that may receive leaked information.

To elaborate on the importance of the size of the informed trader population, we note that when all traders are privy to leaked information, the profitability of their trades reflect two countervailing forces. While an individual trader benefits from the leaked information much like he would if he were the sole designated trader in Section 3, he is also harmed by the presence of other traders also privy to leaked information, much like the other informed traders in Section 3. When $N_1 > \hat{N}_1$, the second effect dominates so that all informed traders are worse off despite the fact that the information that is revealed improves their understanding of firm value.[10]

The preceding discussion suggests that if the insider rationally leaks information to all other informed traders, his benefit accrues at the expense of those same traders. Moreover, we find that when the insider optimally leaks information to all other informed traders, markets are more liquid and there is less information asymmetry (i.e., λ is lower). Taken together, these findings mirror our earlier results in Proposition 3 where information leakage was limited to a single designated trader. We have:

[10] The N_1 traders can benefit in the aggregate if they all commit to refrain for using the leaked information in their trading decisions. However, such a commitment is not credible for an individual trader who, ceteris paribus, stands to benefit from leaked information. In equilibrium, all traders will trade on the leaked information to their aggregate detriment.

Proposition 6 *Rational information leakage to all informed traders (i) benefits liquidity traders (i.e., renders markets more liquid) and (ii) reduces the aggregate profits of informed traders who are not insiders. That is, if* $z^* > 0$*, then* $\pi_I(z, h, N_1)|_{z=z^*} > \pi_I(z, h, N_1)|_{z=0}$ *and* $N_1\pi_j|_{z=z^*} < N_1\pi_j|_{z=0}$.

Proof. See Appendix A4.2. ■

4.2 Insider's Choice of Designated Traders

Our model in Section 3 characterized the insider's strategy as a decision about how much information to leak to a single designated trader (or to all traders as in Section 4.1) who is, a priori, equally informed as the other informed traders in the marketplace. In this subsection, we consider the possibility that an insider's strategy is to decide not only "how much" information to leak but also "to whom" to leak the information (i.e., the choice of designated traders).

To address this question we revisit the general formulation of our model described in Section 2.1 (and illustrated in Appendix A1) where N_1, respectively N_2 traders observe private signals about $\tilde{\varepsilon}$ with precisions h_1 and h_2 respectively. Assuming that $h_1 \neq h_2$, the insider's decision as "to whom" to leak to rests on whether the insider benefits more from leaking information to group 1 than from leaking information to group 2. That is, if informed traders are differentially informed prior to gaining access to leaked information, will the insider exhibit a preference as to whom (or to which group) to leak the information?

Following our discussion in Section 3, we expect the insider to benefit more from leaking information to less well informed traders than leaking to better informed ones. The intuition is straightforward. Recall that information leakage confers an information advantage about execution price to the insider because trades based on leaked information renders price sensitive to the noise components of the leaked signals. Less well informed traders rely more on leaked information than their own private signals in formulating their strategies. This implies that if the insider leaks information to the less well informed, then price is more sensitive to the noise in leaked information. Consequently the insider gains more of an information advantage about the asset's execution price.

Formalizing this intuition calls for a comparison of the insider's profit evaluated at z_1^* (the optimal leakage precision in the event that information is leaked to group 1) with the insider's profit evaluated at z_2^* (the optimal leakage precision in the event that information is leaked to group 2). Unfortunately, absent closed-form expressions for z_1^* and z_2^*, the complexity of the profit expressions precludes a general comparison. However, in the event that the insider's choice is limited to selecting a single designated trader from either group 1 or group 2, we can formally derive the following proposition:

Proposition 7 *Assume $h_1 > h_2$ and $N_1 + N_2$ is sufficiently large. If the insider's choice is to select a single designated trader from either group 1 or group 2, then the insider prefers a designated trader from the less well informed group (group 2).*

Proof. See Appendix A4.3. ■

Beyond Proposition 7, numerical simulations suggest that the insider's preference to leak information to the less well informed holds more generally. For example, if the insider's choice is to select either group 1 or group 2 and leak information to all members in that group, then the insider prefers the less well informed group (group 2). Figure 2 illustrates a typical example with the following parameters: $\sigma_u = 1000$, $h_1 = 2$, $h_2 = 0.5$ and $N_1 = N_2 = 20$. For this example, we find that when the insider leaks information to the better informed group, his maximum profit (at $z^* = 0.37$) is 19.35 while if he leaks information to the less well informed group, his maximum profit (at $z^* = 0.27$) is 19.92. Hence, the insider prefers to leak information to the less well informed group.

[INSERT FIGURE 2 HERE]

4.3 Other Extensions and Variation

4.3.1 Endogenous Number of Other Informed Traders

Our results in Section 3 were based on the assumption that there are a fixed number (i.e., $N_2 + 1$) of other informed traders. To assess how information leakage might affect N_2 if N_2 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_2^* of other informed traders is determined by $\pi_j(z, h, N_2^*) = C$. With endogenous entry, we find that information leakage drives out some informed traders from the market because leakage reduces π_j (Lemma 1). Hence, N_2^* decreases.

With N_2^* determined endogenously, we find that the insider is more likely to leak information than if the same N_2^* was exogenously specified. Formally, if the total derivative $\frac{d\pi_I(z,h,N_2^*)}{dz} = \frac{\partial\pi_I(z,h,N_2^*)}{\partial z} + \frac{\partial\pi_I(z,h,N_2^*)}{\partial N_2}\frac{dN_2^*}{dz}$ measures the insider's incentive to leak information taking into account the effect of z on N_2, then we can show that $\frac{d\pi_I(z,h,N_2^*)}{dz} > \frac{\partial\pi_I(z,h,N_2^*)}{\partial z}$. This follows because more informed traders reduce the insider's profit ($\frac{\partial\pi_I(z,h,N_2^*)}{\partial N_2} < 0$) and information leakage crowds out some informed traders ($\frac{dN_2^*}{dz} < 0$). Hence, the optimal information leakage z with endogenous entry exceeds the optimal z^* characterized earlier in Proposition 2.

4.3.2 Sale of Information to the Designated Trader

Our results thus far assumed that the insider voluntarily leaks private information to one or more other traders without any fee or direct compensation in return. In light of prior literature that examines the direct sale of information in financial markets (discussed earlier in the introduction), 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.

With the ability to sell information as well as trade, the objective of the insider now is to maximize $(\pi_I + \pi_D - \pi_j)$, where $\pi_D - \pi_j$ represents the price charged by the insider set in a manner that exploits all the informational rents. Alternatively, we can think of the term $(\pi_I + \pi_D)$ as the joint (or collusive) profits of the insider and the designated trader and π_j as the designated trader's reservation profit if he were to abstain from purchasing information from the insider. Given this objective, if we let z_{sale} represent the optimal amount of information sold by the insider, i.e., $z_{sale} = \max\{0, \arg\max_z [\pi_I(z, h, N_2) + \pi_D(z, h, N_2) - \pi_j(z, h, N_2)]\}$, then it follows easily that $z_{sale} \geq z^*$, which means that the insider's motivation to share his information is further enhanced if he were also compensated for it.[11]

[11] To see this, note that $\frac{\partial(\pi_I(z,h,N_2)+\pi_D(z,h,N_2)-\pi_j(z,h,N_2))}{\partial z} \geq \frac{\partial\pi_I(z,h,N_2)}{\partial z}$ for all z because $\frac{\partial\pi_D(z,h,N_2)}{\partial z} \geq$

In the absence of any regulatory restrictions, the sale of private information for a fee is no doubt tempting. However, we suggest that, as a practical matter, a direct sale of private information may be a less profitable venture than leakage of private information, 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.

5 Summary and Discussion

In this paper we examine an informed investor's (e.g., 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 investor's information advantage about the asset's value, it enhances his information advantage about the asset's execution price relative to other informed traders in the marketplace. 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.

0 and $\frac{\partial \pi_j(z,h,N_2)}{\partial z} \leq 0$ by Proposition 1. Hence, $z_{sale} \geq z^* = \max\{0, \arg\max_z \pi_I(z,h,N_2)\}$ where the inequality is strict if $z^* > 0$.

In the context of our model, if we interpret the informed investor 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 informed investor in our model as a brokerage firm whose analysts share with their clients some of the information they collect and process, then the impropriety of information leakage is less apparent. The impropriety is even less apparent if the information is shared without any direct compensation in return. 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 information sharing 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.[12]

Notwithstanding the legalities of insider trading and the SEC's enforcement efforts, there is a plethora of evidence to suggest that selective disclosures, information leakage and insider trading are 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 Christophe *et al.* (2010) find that short sellers tend to short more shares ahead of analyst sell recommendations. While our model doesn't exactly capture the institutional settings underlying some of these studies, their 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 or sharing information very low (see also SEC's insider trading website). The chance of detection and prosecution by the SEC is likely even lower if the insider leaks information to an unrelated individual (or a small number of traders) who can disavow a duty of trust. Finally, in the event of prosecution, an independent beneficiary of leaked information 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

[12] For 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".

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, and when these traders are better informed about the underlying asset value. Hence, assuming that private information is most salient for firms with high cash flow volatility (e.g., growth firms), our results suggest that the leakage problem is likely most evident in the trading of growth or high cash volatility 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.

Appendix. Proofs

A1. Proof of Proposition 1

Standard computations show that in the general setup laid out at the beginning of Section 2, there exists an equilibrium in which the equilibrium price function is

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

and the trading strategies are:

$$\begin{aligned}
\tilde{x}_I &= \alpha_I \tilde{\varepsilon} + \alpha_L \sum\nolimits_{j=1}^{N_1} \tilde{y}_{L,j}, \\
\tilde{x}_{1,j} &= \beta_D E\left(\tilde{\varepsilon} | \tilde{y}_{1,j}, \tilde{y}_{L,j}\right) + \beta_L \tilde{y}_{L,j}, \text{ for } j = 1, ..., N_1, \\
\tilde{x}_{2,j} &= \gamma E\left(\tilde{\varepsilon} | \tilde{y}_{2,j}\right), \text{ for } j = 1, ..., N_2,
\end{aligned}$$

where

$$\begin{aligned}
\lambda &= \frac{\sqrt{C_2}}{\sigma_u C_1}, \alpha_I = \frac{(h_2+2)(3h_1+2(N_1+2)z+6)}{C_1\lambda}, \alpha_L = -\frac{2(h_2+2)z}{C_1\lambda}, \\
\beta_D &= \frac{3(h_2+2)(h_1+z+1)}{C_1\lambda}, \beta_L = \frac{(h_2+2)z}{C_1\lambda}, \gamma = \frac{(h_2+1)(3h_1+4z+6)}{C_1\lambda},
\end{aligned}$$

with

$$\begin{aligned}
C_1 &= N_2h_2(3h_1+4z+6) + N_1(h_2+2)(3h_1+4z) + 2(h_2+2)(3h_1+4z+6), \\
C_2 &= N_2h_2(h_2+1)(3h_1+4z+6)^2 + N_1(h_2+2)^2\left[9h_1+20z+(3h_1+4z)^2\right] \\
&\quad + (h_2+2)^2(3h_1+4z+6)^2.
\end{aligned}$$

Hence, from expression (9) in Section 2.2, the respective profits of the insider, of a trader j in group 1 who receive leaked information, and of a trader j in group 2 who do not, are:

$$\begin{aligned}
\pi_I(z,h_1,h_2,N_1,N_2) &= \frac{\sigma_u(h_2+2)^2\left[(3h_1+4z+6)^2+4N_1z\right]}{C_1\sqrt{C_2}}, \\
\pi_{1,j}(z,h_1,h_2,N_1,N_2) &= \frac{\sigma_u(h_2+2)^2\left[16z+9h_1+(3h_1+4z)^2\right]}{C_1\sqrt{C_2}}, \text{ for } j=1,...,N_1, \\
\pi_{2,j}(z,h_1,h_2,N_1,N_2) &= \frac{\sigma_u h_2(h_2+1)(3h_1+4z+6)^2}{C_1\sqrt{C_2}}, \text{ for } j=1,...,N_2.
\end{aligned}$$

Proposition 1 follows by substituting $N_1 = 1$ and $h_1 = h_2 = h$.

A2. Proof of Proposition 2

For π_I given by (16), direct computation shows:

$$\frac{\partial \log(\pi_I)}{\partial z} = \frac{f(z,h,N_2)}{Const_1^+},$$

where $Const_1^+$ is a positive function of (z,h,N_2), and

$$f(z,h,N_2) = A_3z^3 + A_2z^2 + A_1z + A_0,$$

with

$$
\begin{aligned}
A_3 &= -\frac{64\left[N_2 h\left(2N_2h^2+2N_2h+29h^2+98h+80\right)+57\left(h+2\right)^3\right]}{27\left(h+2\right)^3},\\
A_2 &= -\frac{16\left[N_2 h\left(6N_2h^2+6N_2h+213h^2+683h+514\right)+3\left(159h+233\right)\left(h+2\right)^2\right]}{27\left(h+2\right)^2},\\
A_1 &= \frac{4\left[6N_2^2h^2\left(h+1\right)-N_2h\left(165h^2+517h+362\right)-\left(h+2\right)\left(441h^2+1293h+952\right)\right]}{9\left(h+2\right)},\\
A_0 &= 2h^2\left(h+1\right)N_2^2-h\left(44h+13h^2+28\right)N_2-\left(45h^3+202h^2+292h+144\right).
\end{aligned}
$$

To solve for $f\left(z,h,N_2\right)=0$, we consider two cases:

Case 1: $A_0 \leq 0$

If $A_0 \leq 0$, then we easily show that $A_1 < 0$. This means that all four coefficients of the cubic polynomial $f\left(z,h,N_2\right)$ are negative which in turn implies that the cubic polynomial has no positive real roots (by Descarte's "rule of signs"). So, $f\left(z,h,N_2\right) < 0$ for all $z > 0$, which means that profit $\pi_I\left(\cdot,h,N_2\right)$ achieves its maximum at $z^* = 0$.

Case 2: $A_0 > 0$

If $A_0 > 0$, then the coefficients of the cubic polynomial $f\left(z,h,N_2\right)$ have one sign change regardless of the sign of A_1. Hence, by Descarte's "rule of signs," the cubic polynomial $f\left(z,h,N_2\right)$ has one (unique) positive real root. That is, profit $\pi_I\left(\cdot,h,N_2\right)$ is unimodal in z, first increasing and then decreasing in z. Therefore, $A_0 > 0$ is a necessary and sufficient condition for rational information leakage, i.e., $z^* > 0$.

To show the conditions under which $A_0 > 0$, we note that A_0 is a quadratic polynomial in N_2 with a positive root given by

$$
\hat{N}_2 = \frac{\left(13h^2+44h+28\right)+\left(h+2\right)\sqrt{529h^2+1004h+484}}{4h\left(h+1\right)}.
$$

Hence, $N_2 > \hat{N}_2$ is a necessary and sufficient condition for rational information leakage. And the optimal z^* solves the cubic polynomial $f(z,h,N_2)$.

A3. Proof of Propositions 3 and 4

A3.1. Proof of Proposition 3

It suffices to prove part (i) (i.e., that rational information leakage implies that liquidity traders benefit) because part (ii) follows from part (i). To see this, note that if $z > z^*$, we must have $\pi_I (z, h, N_2)|_{z=z^*} > \pi_I (z, h, N_2)|_{z=0}$, since the insider is choosing z to maximize $\pi_I (z, h, N_2)$. If we can show $\lambda (z, h, N_2)|_{z=z^*} < \lambda (z, h, N_2)|_{z=0}$ in part (i), then it must also be the case that $(\pi_D + N_2\pi_j)|_{z=z^*} < (\pi_D + N_2\pi_j)|_{z=0}$ because $\lambda\sigma_u^2 = \pi_I + \pi_D + N_2\pi_j$. To prove that is lower with information leakage than without, we use the expression for λ in Proposition 1 to show:

$$
\begin{aligned}
& \left(\frac{\lambda (z, h, N_2)}{\lambda (0, h, N_2)}\right)^2 - 1 \\
= & \frac{-4z \times g (z, h, N_2)}{(N_2h^2 + 2h^2 + N_2h + 5h + 4) (30h + 24z + 3N_2h^2 + 6N_2h + 12hz + 9h^2 + 4N_2hz + 24)^2},
\end{aligned}
$$

where

$$
\begin{aligned}
& g (z, h, N_2) \\
= & 4 \left[4 (N_2 - 2) h^2 + (2N_2 - 3) h^3 + \left(N_2^2h^3 + 4N_2h + 4h + 16\right)\right] z \\
& + (h + 2)^2 (N_2h - 9h + 4) (3h + N_2h + 4) .
\end{aligned}
$$

So, $\lambda (z, h, N_2)|_{z=z^*} < \lambda (z, h, N_2)|_{z=0}$ if and only if $g (z^*, h, N_2) > 0$ (when $z^* > 0$).

Note that when $z^* > 0$, we have $N_2 > \hat{N}_2 = \frac{\left(13h^2+44h+28\right)+(h+2)\sqrt{529h^2+1004h+484}}{4h(h+1)}$, which implies that $(N_2h - 9h + 4) > 0$, because

$$
N_2 > \hat{N}_2 > \frac{13h (h + 1) + \sqrt{529}h (h + 1)}{4h (h + 1)} = 9 > 9 - 4h^{-1} \Rightarrow N_2h - 9h + 4 > 0.
$$

Also, $N_2 > 9 \Rightarrow [4 (N_2 - 2) h^2 + (2N_2 - 3) h^3 + (N_2^2h^3 + 4N_2h + 4h + 16)] > 0$, and as a result, we have $g (z^*, h, N_2) > 0$ (for $z^* > 0$).

A3.2. Proof of Proposition 4

Applying Bayes' rule delivers

$$Var\left(\tilde{\varepsilon}|\tilde{p}\right)=Var\left(\tilde{\varepsilon}|\tilde{\omega}\right)=1-\frac{Cov\left(\tilde{\varepsilon},\tilde{\omega}\right)}{Var\left(\tilde{\omega}\right)}Cov\left(\tilde{\varepsilon},\tilde{\omega}\right)=1-\lambda Cov\left(\tilde{\varepsilon},\tilde{\omega}\right),$$

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

Substituting the expressions for traders' optimal trading strategies into the total order flow $\tilde{\omega}$, we can show:

$$\begin{aligned}\lambda Cov\left(\tilde{\varepsilon},\tilde{\omega}\right) &= \frac{N_2h\left(3h+4z+6\right)+2\left(h+2\right)\left(3h+4z+3\right)}{3\left(h+2\right)\left(h+z+1\right)}\beta_D\lambda \\ &= \frac{N_2h\left(3h+4z+6\right)+2\left(h+2\right)\left(3h+4z+3\right)}{C_1}.\end{aligned}$$

Direct computation yields:

$$\frac{\partial\log\left(\lambda Cov\left(\tilde{\varepsilon},\tilde{\omega}\right)\right)}{\partial z}=\frac{24\left(h+2\right)^2}{C_1\left(N_2h\left(3h+4z+6\right)+2\left(h+2\right)\left(3h+4z+3\right)\right)}>0.$$

A4. Proofs of Propositions in Section 4

A4.1. Proof of Proposition 5

Setting $N_2=0$ and $h_1=h$ in the expression of π_I in Appendix A1, we obtain

$$\pi_I\left(z,h,N_1\right)=\frac{\sigma_u\left(1+\frac{4N_1z}{(3h+4z+6)^2}\right)}{\left(2+\frac{N_1(3h+4z)}{3h+4z+6}\right)\sqrt{1+N_1\frac{9h+20z+(3h+4z)^2}{(3h+4z+6)^2}}}.$$

Direct computation shows

$$\frac{\partial\pi_I\left(z,h,N_1\right)}{\partial z}\propto A_3z^3+A_2z^2+A_1z+A_0,$$

where

$$
\begin{aligned}
A_3 &= -64\left(2N_1^2+25N_1+30\right),\\
A_2 &= -16\left(5N_1^2+6N_1^2h+226N_1+201N_1h+270h+468\right),\\
A_1 &= 12\left[h\left(6h+5\right)N_1^2-\left(362h+177h^2+160\right)N_1-18\left(h+2\right)\left(15h+22\right)\right],\\
A_0 &= 27\left[2h^2\left(h+1\right)N_1^2-h\left(h+2\right)\left(17h+14\right)N_1-6\left(5h+6\right)\left(h+2\right)^2\right].
\end{aligned}
$$

Note that A_0 is a quadratic function in N_1, and it is positive if and only if

$$N_1 > \hat{N}_1\left(h\right) \equiv \frac{\left(h+2\right)\left(17h+14\right)+\left(h+2\right)\sqrt{529h^2+1004h+484}}{4h\left(h+1\right)}.$$

Similarly, A_1 is also a quadratic function of N_1, and it is positive if and only if

$$N_1 > \bar{N}_1\left(h\right) \equiv \frac{\left(362h+177h^2+160\right)+\sqrt{\left(362h+177h^2+160\right)^2+4h\left(6h+5\right)18\left(h+2\right)\left(15h+22\right)}}{2h\left(6h+5\right)}.$$

We can easily establish $\hat{N}_1 < \bar{N}_1$. Specifically, we multiply the numerator and the denominator of $\hat{N}_1$ by 3 and show that they are respectively smaller and greater than their counterparts of $\bar{N}_1$. As a result, if $A_0 < 0$, or if $N_1 < \hat{N}_1$, then we must have $N_1 < \bar{N}_1$ and hence $A_1 < 0$. It follows that $z^* > 0$ because the cubic polynomial $A_3z^3 + A_2z^2 + A_1z + A_0$ above has one real root.

A4.2. Proof of Proposition 6

As was the case for the proof of Proposition 3, we only need to prove part (i). Setting $N_2 = 0$ and $h_1 = h$ in the expression of λ in Appendix A1, we obtain

$$\lambda\left(z,h,N_1\right) = \frac{\sqrt{1+N_1\frac{9h+20z+\left(3h+4z\right)^2}{\left(3h+4z+6\right)^2}}}{\sigma_u\left(2+N_1\frac{3h+4z}{3h+4z+6}\right)}.$$

Direct computation delivers

$$\begin{aligned}&\left(\frac{\lambda(z,h,N_1)}{\lambda(z,h,N_1)}\right)^2-1\\ =\quad & -\frac{4N_1z\left[4\left(4N_1+N_1^2h-4h\right)z+\left(2h+N_1h+4\right)\left(N_1h+4-10h\right)\right]}{\left(4h+N_1h^2+N_1h+h^2+4\right)\left(6h+8z+3N_1h+4N_1z+12\right)^2}.\end{aligned}$$

As a result, it is sufficient to show $4\left(4N_1+N_1^2h-4h\right)z^*+\left(2h+N_1h+4\right)\left(N_1h+4-10h\right)>0$ (when $z^*>0$) to establish Proposition 6.

When $z^*>0$, by Proposition 5, we know

$$N_1>\frac{(h+2)(17h+14)+(h+2)\sqrt{529}h}{4h(h+1)}=\frac{(h+2)(20h+7)}{2h(h+1)}.$$

So, $N_1h>\frac{(h+2)(20h+7)}{2(h+1)}$, and hence $N_1h+4-10h>\frac{(h+2)(20h+7)}{2(h+1)}+4-10h=\frac{1}{2}\frac{35h+22}{h+1}>0$. Also, by $N_1>\frac{(h+2)(20h+7)}{2h(h+1)}>10$, we have $\left(4N_1+N_1^2h-4h\right)>\left(4N_1+96h\right)>0$. Therefore, we have $4\left(4N_1+N_1^2h-4h\right)z^*+\left(2h+N_1h+4\right)\left(N_1h+4-10h\right)>0$.

A4.3. Proof of Proposition 7

To prove the insider's choice of a designated trader, we recast our model slightly as follows. Let the designated trader hail from informed trader group $a\in\{1,2\}$ and label the other informed group as group b. Then, following Appendix A1, the trading strategies will be:

$$\begin{bmatrix}\tilde{x}_I=\alpha_I\tilde{\varepsilon}+\alpha_L\tilde{y}_L\\ \tilde{x}_D=\beta_DE\left(\tilde{\varepsilon}|\tilde{y}_D,\tilde{y}_L\right)+\beta_L\tilde{y}_L\\ \tilde{x}_{a,j}=\gamma_aE\left(\tilde{\varepsilon}|\tilde{y}_{a,j}\right)\\ \tilde{x}_{b,j}=\gamma_bE\left(\tilde{\varepsilon}|\tilde{y}_{b,j}\right)\end{bmatrix},$$

where the coefficients are endogenously determined as before.

Following the earlier derivation of the insider's profit in Appendix A1, we have

$$\pi_{I,a}(z)=\frac{X_a(z)}{Y_a(z)\sqrt{W_a(z)}},$$

where

$$X_a(z) = 1 + \frac{4z}{(4z + 3h_a + 6)^2},$$

$$Y_a(z) = 2 + \frac{8z}{(4z + 3h_a + 6)(h_a + 2)} + \frac{N_a h_a}{h_a + 2} + \frac{N_b h_b}{h_b + 2},$$

$$\begin{aligned} W_a(z) &= 1 + \frac{4z}{(4z + 3h_a + 6)^2}\left[5 + \frac{(3h_a + 4)(2h_a + 4z) + 4h_a}{(h_a + 2)^2}\right] \\ &\quad + \frac{N_a h_a (h_a + 1)}{(h_a + 2)^2} + \frac{N_b h_b (h_b + 1)}{(h_b + 2)^2}. \end{aligned}$$

Now, let z_1^* and z_2^* be the optimal information leakage when the designated trader hails from group 1 (with private precision h_1) and group 2 (with private precision h_2) respectively. If $N_1 + N_2$ is sufficiently large, then following Proposition 2 both z_1^* and z_2^* are positive. Now let $\pi_{I,1}^* \equiv \pi_{I,1}(z_1^*)$ and $\pi_{I,2}^* \equiv \pi_{I,2}(z_2^*)$ be the optimal profits. Our objective is to show that $\pi_{I,1}^* < \pi_{I,2}^*$ when $h_1 > h_2$. We note that $\pi_{I,2}^* > \pi_{I,2}(z_1^*)$ by the definition of the optimum. That is leaking z_2^* to a designated trader from group 2 dominates leaking any other z (including the z_1^* that would have been optimal for group 1). Hence, if we can show that $\pi_{I,2}(z_1^*) > \pi_{I,1}^*$, then we have a sufficient proof of $\pi_{I,2}^* > \pi_{I,2}(z_1^*) > \pi_{I,1}^*$.

We have:

$$\begin{aligned} \pi_{I,2}(z_1^*) - \pi_{I,1}(z_1^*) &= \frac{X_2(z_1^*)}{Y_2(z_1^*)\sqrt{W_2(z_1^*)}} - \frac{X_1(z_1^*)}{Y_1(z_1^*)\sqrt{W_1(z_1^*)}} \\ &= \frac{X_1(z_1^*)}{Y_2(z_1^*)\sqrt{W_2(z_1^*)}}\left[\frac{X_2(z_1^*)}{X_1(z_1^*)} - \frac{Y_2(z_1^*)}{Y_1(z_1^*)}\sqrt{\frac{W_2(z_1^*)}{W_1(z_1^*)}}\right] \end{aligned}$$

and we can show the following:

$$\frac{X_2(z_1^*)}{X_1(z_1^*)} = 1 + \frac{12z_1^*(h_1 - h_2)}{(4z_1^* + 3h_2 + 6)\left[(4z_1^* + 3h_1 + 6)^2 + 4z_1^*\right]}\left[2 + \frac{3(h_1 - h_2)}{(4z_1^* + 3h_2 + 6)}\right],$$

$$\frac{Y_2(z_1^*)}{Y_1(z_1^*)} = 1 + \frac{\frac{8z_1^*(h_1 - h_2)}{(4z_1^* + 3h_2 + 6)(h_1 + 2)(h_2 + 2)}\left[1 + \frac{3(h_2 + 2)}{(4z_1^* + 3h_1 + 6)}\right]}{2 + \frac{8z_1^*}{(4z_1^* + 3h_1 + 6)(h_1 + 2)} + \frac{N_1 h_1}{h_1 + 2} + \frac{N_2 h_2}{h_2 + 2}},$$

and

$$\frac{W_2(z_1^*)}{W_1(z_1^*)} = 1 + \frac{4z_1^*(h_1-h_2)K(z_1^*,h_1,h_2)}{1+\frac{4z_1^*}{(4z_1^*+3h_1+6)^2}\left(5+\frac{(3h_1+4)(2h_1+4z_1^*)+4h_1}{(h_1+2)^2}\right)+\frac{N_1h_1(h_1+1)}{(h_1+2)^2}+\frac{N_2h_2(h_2+1)}{(h_2+2)^2}},$$

where $K(z_1^*, h_1, h_2)$ is a positive number which depends on (z_1^*, h_1, h_2) but does not depend on N_1 or N_2.

Note that $\frac{X_2(z_1^*)}{X_1(z_1^*)} > 1$ and is independent of N_1 and N_2. In contrast, both $\frac{Y_2(z_1^*)}{Y_1(z_1^*)}$ and $\frac{W_2(z_1^*)}{W_1(z_1^*)}$ are decreasing in N_1 and/or N_2. Moreover, $\frac{Y_2(z_1^*)}{Y_1(z_1^*)}\sqrt{\frac{W_2(z_1^*)}{W_1(z_1^*)}}$ approaches 1 for large N_1 and/or N_2. Hence, $\frac{X_2(z_1^*)}{X_1(z_1^*)} - \frac{Y_2(z_1^*)}{Y_1(z_1^*)}\sqrt{\frac{W_2(z_1^*)}{W_1(z_1^*)}} > 0$ for sufficiently large $N_1 + N_2$. This completes the proof.

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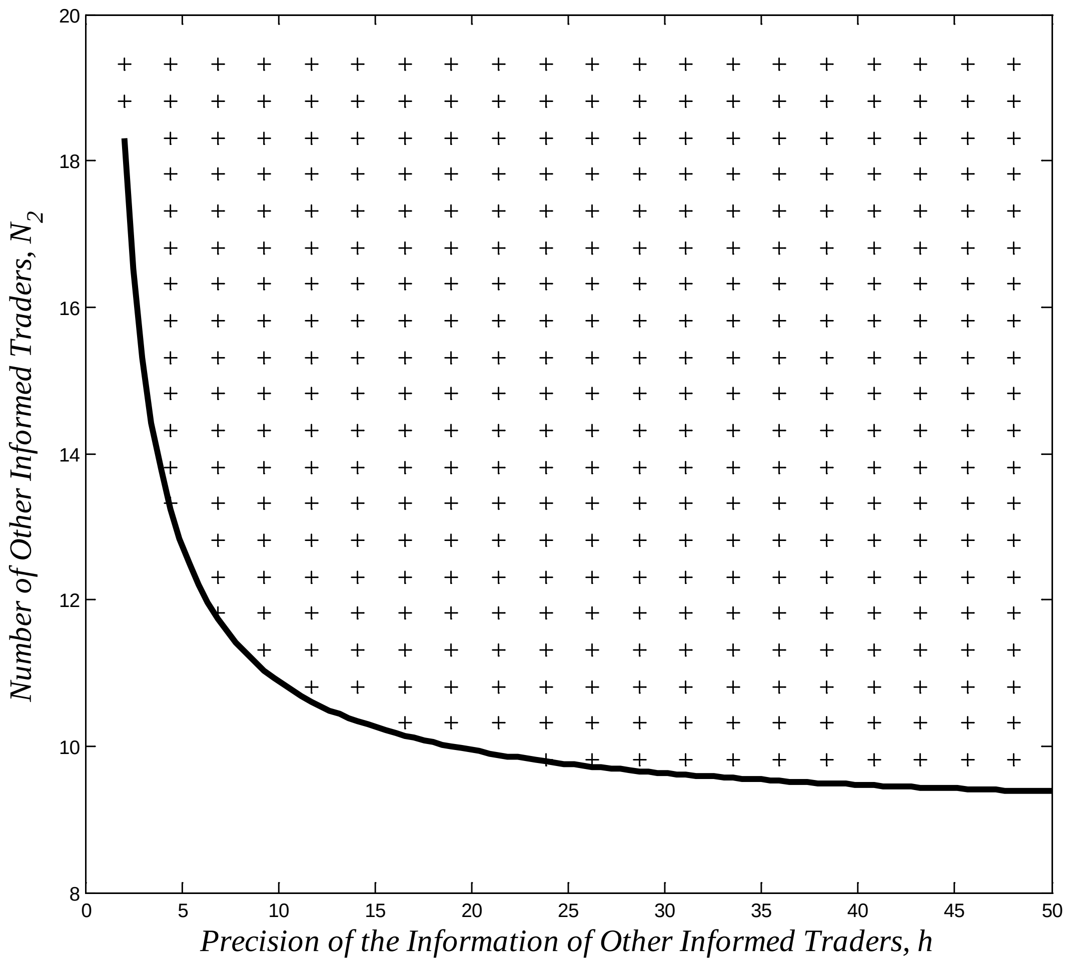
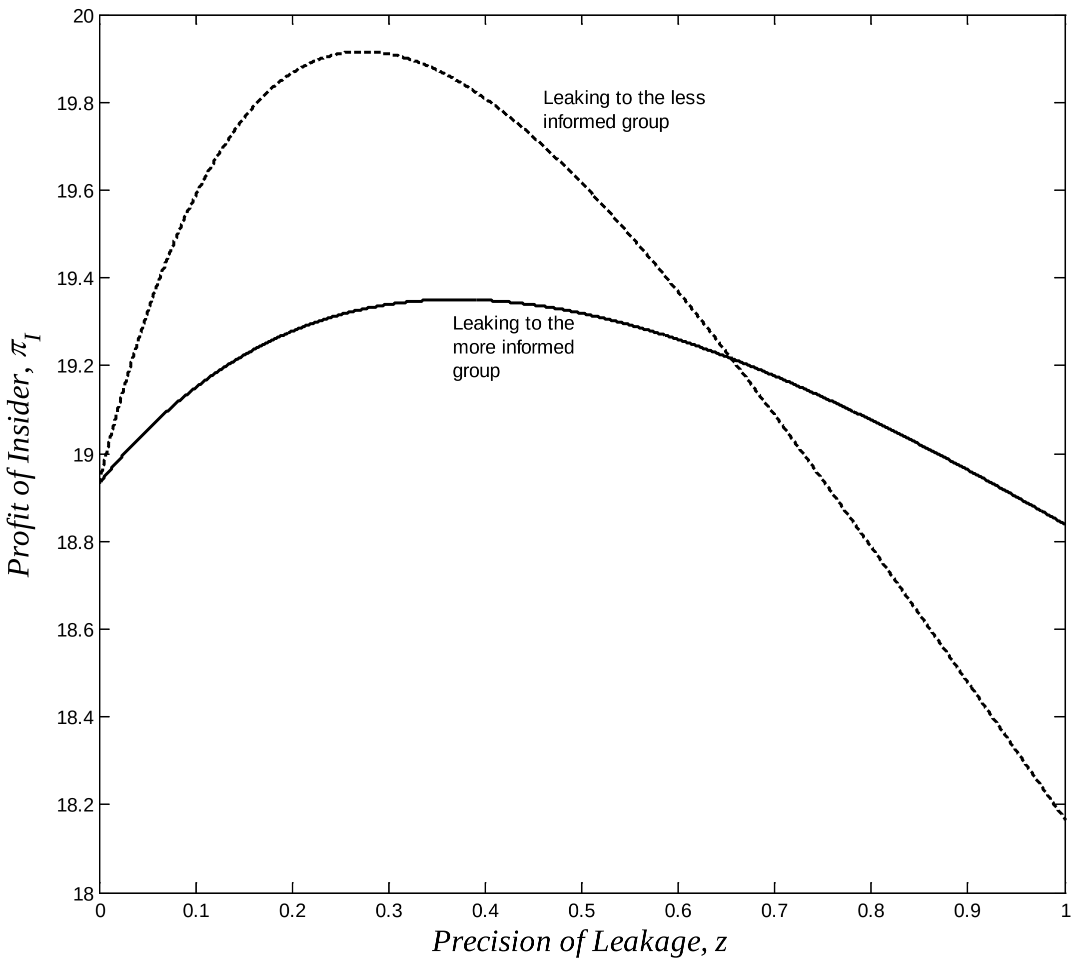
Figure 1 The Region of Rational Information Leakage



Notes. The symbol "+" indicates the region for which the number of other informed traders N_2 exceeds the threshold value $\widehat{N}_2(h)$, where h represents the precision of other informed trader's private information. The solid curve represents the "information leakage frontier".

Figure 2 Insider's Choice of Designated Traders



Notes. This figure shows the insider's profit as a function of the precision of the leaked information z in the presence of two groups of differentially informed traders. We assume the insider can choose to leak information to the entire better-informed group (solid curve) or to the entire less-informed group (dashed curve). Both groups have 20 traders: $N_1 = N_2 = 20$. The traders in group 1 receive private signals with precision of $h_1 = 2$, while the traders in group 2 receive private signals with precision of $h_2 = 0.5$. The variance of noise trading is $\sigma_u = 1000$.