

Insider Trading, Outside Search, and Resource Allocation: Why Firms and Society May Disagree on Insider Trading Restrictions

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We show that entrepreneurs may prefer to allow insider trading even when it is not socially optimal. We examine a model in which an insider/manager allocates resources on the basis of his private information and outside information conveyed through the secondary-market price of the firm's shares. If the manager is allowed to trade, he will compete with informed outsiders, reducing the equilibrium quality of outside information. While the benefits to production of outside information are the same for society and entrepreneurs, we show that the social and private costs are different. Thus, entrepreneurs and society may disagree on the conditions under which insider trading restrictions should be imposed.

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A number of papers address the optimality of insider trading regulations. Some researchers argue that allowing insiders to trade on material nonpublic information increases firm value (see, for example, Manne 1966, Carlton and Fischel 1983, Dye 1984, and Fishman and Hagerty 1992), while others show that insider trading reduces firm value (see Manove 1989, Fischer 1992, Ausubel 1990, and Bebchuk and Fershtman 1994). Leland (1992) provided a model in which insider trading may increase or decrease firm value depending upon the nature of the production function. Consequently, whether insider trading is good or bad is an empirical issue. Carlton and Fischel cited seemingly compelling empirical evidence in favor of lifting all mandated insider trading restrictions. They noted that there is no evidence of organizers of firms trying to ban insider trading either before federally mandated restrictions were put in place or during the time they have been in place but not enforced. They concluded, therefore, that any restriction on insider trading imposed from the outside is inefficient and an unwarranted intrusion into the affairs of the firm.

This article, however, presents a model in which the parameter spaces under which entrepreneurs and society wish to restrict insider trading are not identical. Thus, this article shows that the fact that firms do not attempt to ban insider trading themselves is not sufficient empirical evidence to conclude that insider trading is socially desirable.

The model considers a market with an informed manager/insider and an informed outsider. The manager/insider allocates resources within a competitive firm on the basis of the information available to him—including the outsider's information that is conveyed through the secondary-market price of the firm's shares. When the manager/insider is allowed to trade, he competes with the informed outsider. This competition reduces the outsider's expected trading profits and leads to a reduction in the equilibrium quality of the outsider's information.¹ In our model, the reduction in outside search has two effects. First, it reduces the amount of information the insider uses in allocating resources and, second, it affects the liquidity of the secondary market. Both affect the initial offer price. Less outside search lowers the initial offer price by adversely affecting resource allocation and the firm's resulting terminal value. Less outside search, however, increases the initial offer price, since potential liquidity traders, expecting to lose less to outsiders in the secondary market, are willing to pay more for the shares at the offering.

While insider trading reduces the adverse selection initial investors expect to face when trading against the informed outsider, it intro-

¹ Fishman and Hagerty (1992) have a similar result in the context of a model in which insider trading reduces the number of outsiders who obtain signals of fixed precision.

duces adverse selection from the informed insider. However, a key element of the model is that the entrepreneur contracts with the insider regarding the wage. This allows the entrepreneur to capture the insider's expected trading profits by paying a lower contractual wage. Thus, insider trading profits do not reduce the initial offer price. However, since the entrepreneur cannot contract with outsiders, the outsider's profits will reduce the offer price.

Furthermore, we show that the portion of the insider's expected profits that comes from future liquidity buyers does not reduce the initial offer price. Since this portion of the profits reduces the insider's contractual wage, those initial investors who do not sell in the secondary market receive a larger residual amount of the firm because less of the firm's output is paid out as a wage. Thus, liquidity buyers subsidize part of the manager's wage, increasing the initial offer price.²

Given the trade-off between better resource allocation and the relevant portions of the insider's and outsider's trading profits (henceforth referred to as transfers), an entrepreneur favors insider trading whenever the net effect on the initial offer price is positive.³ A social planner, however, is only concerned with the value of the outside information relative to its cost. Although both the entrepreneur and the social planner care about expected terminal value, because the search costs and the amount of the transfers need not be equal, the parameter space under which an entrepreneur prefers to ban insider trading is not necessarily the same as the space under which society prefers to ban it.

This article differs from existing models in the following ways. First, our model has two informed agents, an insider and an outsider, who perform different functions. Distinguishing between the two is important for public policy debates over laws that treat corporate insiders differently than informed agents in general. The distinction is also important because the effect of informed trading on the offer price depends on whether the informed traders are insiders or outsiders. Thus, the results of existing models, which make no distinction between informed insiders and informed outsiders (see, for example, Manove 1989 and Ausubel 1990), may only apply in situations in which managers are not informed. Leland (1992), however, consid-

² If future liquidity buyers come from the same set of agents as the initial investors, this amounts to a neutral transfer to themselves. If future liquidity buyers are from a different set, then the initial investors' welfare is materially improved. The initial offer price is higher in either case.

³ A natural question is why entrepreneurs use insider trading to reduce outside search. An obvious alternative is disclosure, since it too reduces the outsider's trading profits. Disclosure, however, may not be optimal when the information has more value if the details are kept private (see Carlton and Fischel 1983). Also, disclosure may require the costly preparation of documents for public announcements. Finally, disclosures do not generate the insider's wage subsidy that results with insider trading.

ered, as a special case, when the single informed trader is an agent of the firm. Our model contrasts Leland's in that we examine the interaction between informed insiders and outsiders. A second way in which our model differs from existing models is that it differentiates between social and private value. An exception is Fishman and Hagerty (1992)) which showed that a firm may prefer to allow informed trading so as to reduce competition from other firms. In their model, society dislikes insider trading since it leads to suboptimal entry decisions. Our model, however, focuses on resource allocation within firms.

The article is organized as follows. Section 1 presents the details of the model. Section 2 discusses equilibrium resource allocation, terminal values, optimal outsider search, and the secondary market price and specifies the effect insider trading has on the initial offer price. Section 3 compares the private and social benefits of insider trading and characterizes the set of parameters under which there will be disagreement. It also provides some testable implications. Section 4 concludes the article.

1. The Model

1.1 Timing of events and actions

The model consists of three periods. In the first period ($t = 0$), the entrepreneur issues equity to fund a firm consisting of a production technology (the entrepreneur's idea), an input, and a risk-neutral manager. The output of the production technology depends on the amount of input used by the manager at $t = 1$ and the realization of a random state variable at $t = 2$. In the second period ($t = 1$), a secondary market for the securities is open. Also during this period, the manager receives information about the state and then allocates the input to production. In the final period ($t = 2$), the state variable and the output are realized. At this time, the output is sold, the firm is liquidated, and equity holders are paid a liquidating dividend.

At $t = 1$, the manager obtains information about which state will occur at $t = 2$. He receives a private signal while managing the firm, and he infers outside information from the secondary market price. For simplicity, we assume that outside information is possessed by a single risk-neutral informed outsider who receives a signal of the state. Prior to $t = 1$, the outsider incurs a cost to receive the signal and, if profitable, trades in the secondary market at $t = 1$. The cost of the outsider's signal is assumed to be increasing in the quality of the signal. The optimal quality is chosen to maximize expected profits⁴

⁴ We implicitly assume that insiders and outsiders have a comparative advantage at searching different

The secondary market at $t = 1$ is maintained by a risk-neutral, competitive market maker. As in Kyle (1985) and Admati and Pfleiderer (1988), we assume that the market maker only observes the net order flow, ω , and that random liquidity trading by uninformed investors prevents him from perfectly inferring the information of informed traders. As is standard, the market maker quotes a net-order-flow contingent price function, $P_I(\omega)$, such that his expected profits are zero. Thus, $P_I(\omega)$ is simply the conditional expectation of terminal value given the net order flow. Because the market maker cannot differentiate between informed and liquidity trading, the equilibrium price function imposes a liquidity cost on uninformed investors. The size of the liquidity cost depends on the quality of the outsider's information and whether or not insider trading is allowed.

Both uninformed investors and those who will become informed at $t = 1$ (the insider and the outsider) can buy shares in the initial offer at $t = 0$. We assume that uninformed investors are also risk neutral and that the insider and the informed outsider are wealth constrained and cannot buy the whole offering. As such, uninformed investors are the marginal investors in the initial offer market at $t = 0$, and the market-clearing offer price equals their expected cash flow per share.⁵ We assume that each uninformed investor faces the possibility of having to sell a share in the secondary market at $t = 1$. The liquidity cost in the secondary market affects the expected cash flow and, thus, the initial offer price. That is, initial investors, facing the possibility of having to trade for liquidity reasons, will demand a premium in the initial offer market to compensate for the liquidity cost associated with trading against informed agents. Because the liquidity cost depends on whether insider trading is allowed, the offer price depends on the regime. The entrepreneur decides to allow insider trading only if it yields a higher offer price and announces his decision prior to the issue.⁶ This strategy maximizes the rent the entrepreneur earns for his idea.⁷

sources of information. Thus, there are cost savings if agents specialize in searching particular sources. We model this by assuming that the quality of the insider's information is fixed exogenously and that the cost of the insider searching the outsider's source is prohibitively high; thus, he will not search in equilibrium.

⁵ This is similar to the manner in which offer price is determined in Manove (1989) but differs from Rock (1986) in two ways. First, in our model there is no asymmetric information at the time of issue and, second, our issue price is a market-clearing price. Consequently, our offer price is not underpriced as in Rock (1986).

⁶ Unless it is publicly announced whether insider trading is allowed, the offer price will not signal the regime. This is true because those agents who know the regime (the entrepreneur and the insider) do not affect the offer price through their demands. The entrepreneur, however, has no incentive to keep the regime secret, since secrecy would reduce the offer price.

⁷ This objective assumes that the entrepreneur sells the entire issue. The authors also examine the cases in which the entrepreneur maintains an equity state in the firm and show that the results are robust. An appendix that discusses these cases is available from the authors upon request.

The following subsections provide the details on each element of the model.

1.2 Production and resource allocation

The production function of the firm is

$$f(K; \alpha) = Q[\alpha K - (\beta/2)K^2], \quad (1)$$

where a is the random state variable which, unconditionally, takes on one of two equally likely values. Let a_b denote the “bad” state and a_g the “good” state, where $a_g > a_b$. K is the input allocated by the insider, and Q is a scale factor that represents the number of shares issued.⁸ The per-share terminal value of the firm is given by v :

$$v = \{f(K; \alpha) - (rK + W)\}/Q, \quad (2)$$

where W is the contractual wage of the manager/insider (defined as the wage payment that excludes insider trading profits) and rK is the total cost of the input K .

The manager picks K after receiving his own signal and observing $P_1(\omega)$ at $t = 1$. We assume that there is no moral hazard and that the manager maximizes $E^1(v)$, the expected terminal value of the firm given his information set. The first-order conditions imply that the optimal K (denoted K^*) depends on the expectation of the state, denoted a^e , according to

$$K^*(\alpha^e) = (\alpha^e - r)/\beta. \quad (3)$$

The realized terminal value of the firm thus depends on both the expected state at $t = 1$, through $K^*(a^e)$, and the realized terminal state at $t = 2$. Let $v^*(a, a^e)$ denote the value realized when the terminal state is a , and resources are allocated based on Equation (3) given the expectation of the terminal state, a^e . Thus,

$$v^*(\alpha, \alpha^e) = \frac{(\alpha - r)(\alpha^e - r)}{\beta} - \frac{(\alpha^e - r)^2}{2\beta} - w, \quad (4)$$

where $w = W/Q$ is the per-share contractual wage of the manager. It can be easily shown that the closer a^e is to the realized a , the greater the realized terminal value. Thus, information that better predicts a is more valuable. Further, the bigger the difference in the states (i.e., $a_g - a_b$), the more important information becomes. For example, when a^e is the unconditional expectation (i.e., there is no information), the difference between the expected state and the realized state is larger for bigger differences in the states.

⁸ Because each agent can trade only one unit of shares, altering Q permits us to examine the effect of changing the proportion of the firm that each agent can trade (i.e., trade size).

Expectations of a are rational and depend on the information set of the insider. One element of the insider's information set is a signal, θ , which reveals the terminal state perfectly with probability p . With probability $1 - p$, the signal is uninformative and provides no additional information beyond the unconditional distribution of a . We assume that the manager costlessly receives this signal by being on the job.

When θ is uninformative, the insider may infer additional information by observing $P_1(\omega)$. The information the insider obtains from price depends on the quality of the information obtained (and traded on) by the outsider and the manner in which price is determined. With probability q the outsider's signal reveals the state perfectly while, with probability $1 - q$, the signal is uninformative. q measures the quality of the outsider's signal. The outsider must incur a cost, $C(q)$, to obtain a signal of quality q . For simplicity, we assume that $C(q) = Cq$, with $C > 0$.

1.3 The secondary market

Informed agents trade in the secondary market at $t = 1$ to maximize expected terminal wealth.⁹ Specifically, each agent i ($i = I$ or O for the insider/manager and the outsider, respectively) picks a trade, ΔX_i , to solve

$$\text{Max}_{\{\Delta X_i\}} E_i[W_{2i}], \quad (5)$$

where $E_i[\cdot]$ is the expectation operator given the information of agent i at time t , and ΔX_i is agent i 's trade. The terminal wealth, W_{2i} , is $W_{1i} + (X_{0i} + \Delta X_i)(v - P_1)$, where W_{1i} is agent i 's $t = 1$ wealth and X_{0i} is agent i 's initial endowment of the risky asset. We assume that agents can borrow at a zero net interest rate. Positive interest rates can be easily incorporated without altering any qualitative results. Because the price that obtains is a function of the orders submitted [recall $P_1(\omega) = E(v | \omega)$], agents act strategically and submit orders realizing that their trades affect the expected price. Specifically, each agent picks a trade to solve

$$\text{Max}_{\Delta X_i} E_i(W_{2i}) = E_i\{W_{1i} + (X_{0i} + \Delta X_i)[v - P_1(\Delta X_i + \Delta X_o + \Delta X_L)]\}, \quad (6)$$

where $\Delta X_i + \Delta X_o + \Delta X_L$ is the net order flow, ω , with ΔX_i , the insider's

⁹ This objective implicitly assumes that agents consume only in $t = 2$. However, one often-cited reason for allowing managers to trade the securities of their firms is the need to allow managers to liquidate stock holdings that are part of incentive compensation when life-cycle or liquidity concerns arise. The main conclusions of the article will not be affected if the insider also trades for liquidity reasons.

trade; ΔX_O , the outsider's trade; and ΔX_L , the liquidity-motivated trade. We assume that $\Delta X_i \in \{1, 0, -1\}$ for $i = I, O$, and L . Further we assume that, when an agent submits his order, prior to observing the realized $P_1(\omega)$, he does not know the individual orders of others or the net order flow.

Because there is adverse selection, the expected transaction price given a liquidity-motivated sell order is below the unconditional expected terminal value. This difference is the liquidity cost the market maker imposes to compensate for his expected losses to informed traders. The manner in which this liquidity cost affects the initial offer price is discussed in Section 2 below.

1.4 Equilibrium outside search

We assume that the outside searcher decides on the quality of his signal, q , prior to $t = 1$. The outsider picks q to maximize his expected terminal wealth given the cost and the effect of q on his trading profits. The optimal quality, q^* , is such that marginal expected trading profits equal the marginal cost of the signal. That is, q^* solves

$$\frac{dE_o(\pi^o \mid q, R)}{dq} = \frac{dC(q)}{dq} = C, \quad (7)$$

where π^o is the outsider's trading profit and R denotes the regime ($R = A$ when insider trading is allowed and $R = B$ when it is banned). Because prices are different with and without insider trading, the effect q has on the outsider's terminal wealth depends on the regime. We denote the equilibrium quality of the outsider's signal by $q^*(A)$ when insider trading is allowed and $q^*(B)$ when insider trading is banned.¹⁰

1.5 Liquidity costs and the initial offer price

The initial offer market is modeled as follows. At $t = 0$, each agent is symmetrically informed and knows whether he will become an informed trader at $t = 1$ or remain an uninformed investor. Let there be $N(N \leq Q)$ investors who will remain uninformed, each of whom purchases one share in the initial offer market. We refer to these agents as uninformed investors. One of these investors will have to trade in the secondary market at $t = 1$. We refer to that investor as the liquidity trader. The probability that an uninformed investor becomes the liquidity trader is $1/N$. For the liquidity trader, the prob-

¹⁰ As will be seen later, the expected profit function is not linear in q . Consequently, the equilibrium condition (7) may result in inframarginal returns to information collection. Depending on the fixed cost of entry, positive inframarginal returns may lead to entry by more informed outsiders, which would be inconsistent with long-run equilibrium in the search market. An alternative equilibrium condition that implies no entry is total expected profit equals total search cost. As will be obvious later, this condition can be imposed without changing any of the substantive results.

abilities that he must buy, sell, or do nothing are all $1/3$. Thus, the probability that any one of the uninformed initial investors will have to sell his share at $t = 1$ in the secondary market is $1/(3N)$. We assume that the informed agents, the insider and the outsider, do not have to trade for liquidity reasons. These investors will trade in the secondary market only when there is an expected gain given their information. Although these investors may have superior information at $t = 1$, they have no informational advantage in the initial offer market.¹¹ These agents may purchase some of the asset in the offer market, but we assume that they are capital constrained and cannot, collectively or individually, purchase the whole issue.¹²

Since all agents are risk neutral, they are willing to buy for a price that is equal to or less than the expected cash flow from the asset.¹³ The cash flow is either the terminal value, if the agent holds the asset until $t = 2$, or the secondary market price, if the agent must liquidate at $t = 1$. Each agent's $t = 0$ expectation of the security's cash flow depends on whether or not he will become an informed agent. The expected cash flow is higher for agents who will become informed because they will always sell prior to price declines between $t = 1$ and $t = 2$. We assume, however, that there is no price discrimination and that the initial offer price, P_0 , clears the market. Because the informed investors are capital constrained, the aggregate demand curve is a step function with the expected cash flow of uninformed investors establishing the market clearing price in the offer market.

The uninformed investors' expectation at $t = 0$ of the cash flow of a single share, CF, is

$$\begin{aligned} P_0 = E_0[\text{CF}] = & (1/3N) \cdot E[P_1(\omega) \mid \Delta X_L = -1] \\ & + (1/3N) \cdot E[v \mid \Delta X_L = 0] \\ & + (1/3N) \cdot E[v \mid \Delta X_L = 1] \\ & + (1 - (1/N)) \cdot E[v]. \end{aligned} \quad (8)$$

The first term is the probability of being the liquidity trader who has to sell times the expected sales price conditional on his sell order. The second term is the probability of being the liquidity trader who does not trade and retains his initial share until $t = 2$ multiplied by the expected terminal value of the retained share. The third term is the probability of being the liquidity trader who has to buy-but continues to hold his initial share-times the expected terminal value of the retained share. These expectations depend on the trade of the

¹¹ This assumption differs from Leland (1992), which examined how informed trading in the offer market affects the cost of capital.

¹² An alternative assumption is that informed investors are risk averse. This assumption leads to needless complexity in the rest of the model, however.

¹³ For simplicity and without loss of generality, we assume that the discount rate is zero.

liquidity trader because these trades affect the net order flow, which affects the inference of the insider and thus the distribution of terminal value. The final term is the probability of not having to trade (i.e., not becoming the liquidity trader) times the unconditional expected terminal value.

By noting that $E(v) = (1/3)\{E[v | \Delta X_L = -1] + E[v | \Delta X_L = 0] + E[v | \Delta X_L = 1]\}$, the offer price can be written as the expected terminal value minus the probability of a liquidity sale times the expected loss associated with that sale (i.e., the liquidity cost). That is,

$$P_0 = E(v) - \{1/(3N)\}E[v - P_1(\omega) | \Delta X_L = -1]. \quad (9)$$

Thus, at $t = 0$, uninformed investors anticipate the cost of a possible liquidity-motivated sale and pass this cost on to the entrepreneur through a lower initial offer price.

Notice that the liquidity cost associated with a liquidity-motivated purchase does not affect P_0 . This is because a liquidity-motivated purchase entails acquiring another share and thus does not affect the cash flow of an originally purchased share. Consequently, this liquidity cost does not affect the initial offer market price and is, therefore, not passed on to the entrepreneur."

Insider trading affects P_0 in two ways. First, for a fixed q , it affects liquidity costs by altering the information content of net order flow. Second, it affects the equilibrium q , which in turn affects both the liquidity cost (by altering the probability of adverse selection from the outsider) and the expected terminal value (by altering the amount of the information the insider can infer from prices).

We assume that if the entrepreneur is not constrained by any regulation he will choose the regime (i.e., whether or not to allow insider trading) that maximizes the proceeds from the initial offering. Specifically, the entrepreneur chooses a contract (R, W) that specifies the regime and a contractual wage, W , to solve

$$\text{Max}_{(R, W)} QP_0[R, q^*(R)] = QE_0[CF | R, q^*(R)] \quad (10)$$

s.t. (i) $W + E_0(\pi') \geq W^c$, (ii) $q^*(R)$ solves Equation (7).

¹⁴The reason the liquidity costs associated with a liquidity buy do not affect the offer price is that liquidity buyers are not the marginal investors in the secondary market. If they were, prices would be 1- by the amount of the subsidy and the $t = 0$ expected cash flow and the initial offer price would drop similarly. Liquidity buyers are not marginal, since agents cannot differentiate between uninformed trade and informed trades. Consequently, the secondary market clears only when the price is $E[v | \omega]$ —not $E[v | \omega, \Delta X_L = 1] < E[v | \omega]$. If $P_1(\omega)$ is less than $E[v | \omega]$, then the rest of the uninformed investors will buy expecting a gain of $E[v - P_1(\omega)] = E[E[v - P_1(\omega) | \omega]] = E[E(v | \omega) - P_1(\omega) | \omega] > 0$, and there will be excess demand. Similarly, if $P_1(\omega) > E[v | \omega]$, there will be excess supply. Thus, even though the liquidity buyer expects a loss conditional on knowing he is placing an uninformed buy order, the market price must be $E(v | \omega)$. Conceivably, the liquidity buyer could avoid paying the subsidy by buying only initial offerings. However, since liquidity trading typically requires immediate execution, satisfying liquidity buying by trading in infrequent initial offerings is not feasible.

Because the regime affects the functional form of the expected cash flow and the equilibrium q , we write P_0 as a function of the regime and the equilibrium q . The first constraint is the participation constraint for the manager. Because the manager is risk neutral and there is no moral hazard, the manager accepts the job when his expected total compensation, which is the contractual wage plus any expected trading profits, is greater than or equal to the competitive wage, W^C . Here, $E_0(\pi')$ is the expected trade profit of the insider/manager, and $W + E_0(\pi')$ is the total remuneration of the manager. The effect of the regime on the equilibrium signal quality is imposed by the second constraint.

The next section demonstrates exactly how P_0 is affected by insider trading. To do this, we develop closed-form solutions for the equilibrium secondary market price functions, terminal values, and the resulting offer prices with and without insider trading restrictions.

2. Equilibrium Secondary Market Prices, Allocations, and Terminal Values

Typically, secondary market prices do not affect terminal values in market microstructure models. This is not true here, however. Here prices and terminal values must be determined simultaneously because prices both affect and depend on the insider's allocation choice. To determine the feedback between the secondary market and resource allocation, we first determine the information content in prices. We start by conjecturing that the equilibrium price function is invertible in the net order flow. Upon observing the realized price, the insider can infer the net order flow and, because he knows the order he submitted, he can infer the amount of the net order flow due to the outsider and the liquidity trader jointly (hereafter referred to as the *residual net order flow*).

We next conjecture a trading strategy for the informed agents (i.e., the outsider and, when allowed to trade, the insider) that specifies the optimal trade conditional on the signal received. Specifically, we conjecture that informed agents do not trade when their signal is uninformative, do buy when they know that $a = a_g$, and do sell when they know that $a = a_b$. Given this trade strategy, the insider can calculate the probability of observing the residual net order flow given the good state and given the bad state. Then, applying Bayes' theorem, the insider determines the probability of each state contingent on the residual net order flow and forms the conditional expectation of the state. Given this conditional expectation, the manager/insider allocates resources according to Equation (3). Once the state is realized, the terminal value obtains. Of course, when the insider has an

informative signal, prices do not affect terminal value because prices cannot provide any additional information to the insider.

Given the relationship between net order flow and terminal value, it is straightforward to determine $P_I(\omega)$, the expectation of terminal value conditional on the net order flow. Given this price function, we then confirm that our conjectures are consistent with equilibrium. That is, we show that (i) the price is invertible in the net order flow and (ii) the trade strategies of the informed traders are optimal. Appendix A provides all of the details of the construction of the equilibrium. Specifically, closed-form expressions are derived for the distribution of terminal value (see Lemma 1), the optimal trade strategies [Lemma 3(a)], the secondary market prices [Lemma 3(b) and 3(c)], the expected trade profits for the outsider [Equations (A9) and (A10)], and the equilibrium signal quality [Equation (A11)].

The closed-form expressions for equilibrium allow us to analyze the effect insider trading has on terminal value and the liquidity costs that affect P_0 . To focus the discussion, we simplify the expressions that follow by setting the number of investors equal to the number of shares (i.e., $N = Q$). It is also easier to develop intuition when liquidity costs are replaced by expressions involving the expected profits of informed traders. Although total expected liquidity costs equal total expected profits of informed traders, P_0 is affected by only the expected liquidity costs associated with a liquidity-motivated sale. In Appendix A, we convert the relevant expected liquidity costs into a function of potential outsider profits [see Equation (A16)]. Given this conversion, the total amount raised through the initial offering, $QP_0(R, q)$, can be rewritten in terms of trading profits instead of liquidity cost. When insider trading is banned,

$$QP_0(B, q) = QE[v' | B, q] - W^C - \Psi^{OB}(q), \quad (11)$$

where v' is the per-share gross terminal value prior to the contractual wage being paid, the contractual wage (W) is equal to the competitive wage (W^C), and $\Psi^{OB}(q)$ is the portion of the outsider's expected trading profits that corresponds to the liquidity costs for which initial investors require a premium. The closed-form expression of $\Psi^{OB}(q)$ is provided in Section 3 of Appendix A.

When insider trading is allowed, both the insider and the outsider make trading profits and initial investors require a premium for only the portion of the expected profits made at the expense of the liquidity seller. Analogous to Equation (11), the amount raised in the offering if insider trading is allowed is

$$QP_0(A, q) = QE[v' | A, q] - W^A - \Psi^{OA}(q) - \Psi^{IA}(q), \quad (12)$$

where $\Psi^{OB}(q)$ and $\Psi^{IA}(q)$ are the portions of the outsider's and insid-

er's expected profits, respectively, that represent the expected liquidity costs associated with a liquidity-motivated sale and W^A is the contractual wage when insider trading is allowed.

From Equation (12), it appears that higher insider trading profits lower P_0 . But, because there is a no moral hazard and the manager is risk neutral, constraint (i) in the optimization problem (10) will hold with equality in equilibrium. If we define the insider's expected profits from a liquidity seller and buyer by $\Psi^u(q)$ and $\Omega^u(q)$, respectively, then $E_0(\pi') = \Psi^u(q) + \Omega^u(q)$ and $W^A = W^c - [\Psi^u(q) + \Omega^u(q)]$. As such, the contractual wage when insider trading is allowed is less than the contractual wage without insider trading by the amount of the insider's expected profits. Thus, investors who hold until $t = 2$ pay less to the insider in contractual wages and receive a larger residual terminal value. Because initial investors require a premium for only the portion of the insider's expected profits created by a liquidity sale but the insider's contractual wage is reduced by the insider's total expected trading profits, the wage savings exceed the amount of the premium. In effect, investors who hold until $t = 2$ get part of the insider's wage subsidized by a liquidity buyer. Because agents who expect to receive this subsidy are willing to pay more for the asset in the offer market, the entrepreneur extracts the amount of the subsidy by receiving a higher P_0 . Algebraically, by replacing W^A by $W^c - [\Psi^u(q) + \Omega^u(q)]$, Equation (12) becomes

$$QP_0(A, q) = QE[v' | A, q] - W^c + \Omega^u(q) - \Psi^{\alpha u}(q) \quad (13)$$

and the portion of the insider's expected profits due to liquidity-motivated buys, $\Omega^u(q)$ positively affects the amount raised in the initial offering. Closed-form expressions for $\Omega^u(q)$ and $\Psi^{\alpha u}(q)$ are also provided in Section 3 of Appendix A.

By subtracting Equation (13) from Equation (11) and evaluating the expression at the appropriate equilibrium signal qualities [$q^*(A)$ when insider trading is allowed and $q^*(B)$ when it is banned], we can decompose the effect insider trading has on the amount raised in the offering into three components.

$$\begin{aligned} & Q\{P_0[A, q^*(A)] - P_0[B, q^*(B)]\} \\ &= \{\Psi^{\alpha B}[q^*(B)] - \Psi^{\alpha A}[q^*(A)]\} \\ &+ \{E[v' | A, q^*(A)] - E[v' | B, q^*(B)]\} + \{\Omega^u\}. \end{aligned} \quad (14)$$

Each component is discussed separately below.

The first component, $\{\Psi^{\alpha B}[q^*(B)] - \Psi^{\alpha A}[q^*(A)]\}$, is the effect insider trading has on the portion of the outsider's trading profits that the entrepreneur loses through a lower initial offer price. The following proposition shows that the outsider's profits are greater when insider

trading is banned. As such, the entrepreneur may prefer to allow insider trading so as to increase the offer price.

Proposition 1.

(a) For a given quality of outside information q , both the total expected profit of the outsider and the portion of the outsider's profits that affect the offerprice are larger when insider trading is banned. That is, $E_0(\pi^o | B, q) \geq E_0(\pi^o | A, q)$ and $\Psi^{ob}(q) \geq \Psi^{oa}(q)$.

(b) The equilibrium quality of outside information is less when insider trading is allowed than when it is banned. That is $q^*(A) \leq q^*(B)$.

Proof Part (a) follows from tedious but straightforward algebra. Part (b) is proved in Appendix B. ■

The intuition for part (a) is clear. When the insider trades, it is more likely that the net order flow will reveal the state to the market maker. In these cases, no profits are made. Since this is more likely with insider trading, expected profits of the outsider are lower. The same argument holds for the portion of the outsider's profits that lower P_0 . Part (b) follows directly from (a) and the assumption that the marginal cost is C for all q independent of the regime. Because expected profits are lower with insider trading, the marginal benefit curve shifts in with insider trading and intersects the fixed marginal cost curve at a lower quality.

Part (a) of Proposition 1 implies that, for a fixed q , $\{\Psi^{ob}(q) - \Psi^{oa}(q)\}$ is positive and the entrepreneur will reduce the premium by permitting insider trading. Further, because $q^*(B)$ exceeds $q^*(A)$ and the outsider's expected profits are greater for higher q , a secondary effect of allowing insider trading is to reduce the premium further by lowering the equilibrium q . Thus, in equilibrium, $\{\Psi^{ob}[q^*(B)] - \Psi^{oa}[q^*(A)]\}$ is positive.¹⁵

When q is reduced, however, prices are less informative. Thus, when the insider receives an uninformative signal, this adversely affects resource allocation and expected terminal value. This effect is captured by $\{E[v' | A, q^*(A)] - E[v' | B, q^*(B)]\}$. The following proposition shows that this term is negative.

¹⁵ In a Fishman and Hagerty (1992) type model in which multiple outsiders can get a fixed precision signal for a fixed cost, insider trading will increase the aggregate profit of the outsiders in certain cases. This occurs because the number of outsiders is discrete. In our model, however, the "amount" of outside information is modeled as the continuous variable quality. If we were to modify our analysis to allow for multiple outsiders, insider trading would decrease aggregate outsider profits and the qualitative nature of our trade-offs would remain intact.

Proposition 2.

(a) For a given quality of outsider information, q , the unconditional distribution of the gross terminal value of the firm, v' , does not depend on whether or not insider trading is allowed.

(b) The unconditional expectation of terminal value is increasing in the quality of the outsider's information, q .

Proof Part (a) follows from the discussion below. Part (b) is proved in Appendix B. ■

The first part holds because, even though the net order flow is different when insider trading is prohibited, the insider knows how he would have traded and how that would have affected the net order flow. Thus, his allocation decisions, and the resulting terminal values, are identical whether or not he is permitted to trade. The second part of the proposition holds because higher q 's imply that it is less likely that the insider is uninformed after observing $P_1(\omega)$. Whenever the insider's signal is informative, $a^e = a$ and the resulting terminal value is the maximum possible for that state regardless of q (i.e., either v_{gg} or v_{bb} in Appendix A). However, when the insider is uninformed, q affects both the possible terminal values and their probabilities. For example, when the net order flow is 1, a higher q implies that it is more likely that the state is a_g . [See Lemma 1 for $a^e(1)$.] Given that a_g is more likely than a_b , the insider optimally allocates a larger amount of K . If a_g obtains, the terminal value (i.e., v_{g1} in Appendix A) is greater than it would have been if he had allocated less K . If $a = a_b$ obtains, however, the resulting terminal value (i.e., v_{b1} in Appendix A) is lower. Given the assumed quadratic production function, the amount by which the terminal value increases in the good state is less than the amount by which it decreases in the bad state. However, because a_g is more likely for higher q when $\omega = 1$, the net impact on expected terminal value given $\omega = 1$ is positive. Similarly, the expected net effect of a higher q when the net order flow is -1 is also positive.

Note, however, that when the insider is uninformed and the net order is zero, the price is uninformative regardless of q , and the manager allocates the optimal K given that the states are equally likely. In this case, q does not affect the resulting terminal values. Yet, because the probability of getting a net order flow of 0 is decreasing in q , more weight is placed on higher terminal values—those that result from either the insider knowing the state or getting (albeit imperfect) information from order flow. Thus a higher q increases the expected terminal value by reducing the probability that the insider will remain uninformed after observing $P_1(\omega)$.

Proposition 2 implies that the only effect insider trading can have on the expected terminal value is through its effect on equilibrium outsider search, q^* . Because insider trading reduces q^* (see Proposition 1), it reduces the expected terminal value of the firm. Thus, the production influence of insider trading is negative.

The final impact of insider trading is the subsidy of the insider's wage that is provided by a liquidity buyer. Since there is no such subsidy when insider trading is banned, the entrepreneur prefers to allow insider trading so as to capture this subsidy. Notice that, even if there are no information or production effects, this subsidy exists.

Given these three components, the entrepreneur will prefer to allow insider trading when the net effect is positive. For instance, this can happen when the reduction in q from insider trading lowers the expected terminal value by less than the decrease in the portion of the outsider's expected trading profits that affect the offer price. In this case, the entrepreneur will prefer to forego the incremental effect on terminal value from a higher-quality outside signal to avoid the larger incremental leakage in the form of outsider trading profits. Since the entrepreneur also has the incentive to allow insider trading because of the expected subsidy provided by the potential liquidity buyer, it is possible that he may prefer insider trading even when the reduction in the terminal value is more than the reduction in the portion of the outsider's profits that affects the offer price. In the next section, we investigate these interactions further.

3. Social versus Private Benefits from Insider Trading

This section examines society's preference over regimes and shows that the trade-offs faced by a social planner are different from those of the entrepreneur. We assume that the social planner applies the compensation criterion, which implies that the preferred regime is one in which the winners could (but are not required to) compensate the losers so that everyone is better off.¹⁶ In our model, since agents are risk neutral and have utility functions that are linear in wealth only, the socially preferred regime is the one in which expected net social value (ENSV) is maximized. The net social value is the total output of the firm minus (i) production costs, which include input

¹⁶ The compensation criterion is weaker than the Pareto criterion because it does not require that compensation be paid. If compensation is possible without rendering the original allocation infeasible, then a Pareto improvement can be achieved, but only after the compensation is made. Since there is no moral hazard in our model, compensation can occur without distorting the production, trading, and resource allocation decisions, and any regime that satisfies the compensation criterion can be made to satisfy the Pareto criterion. However, those agents who would require compensation under the Pareto criterion (e.g., future liquidity buyers) would be difficult to identify. Consequently, it is hard to envision a transfer scheme that would achieve the Pareto improvement, and we apply the compensation criterion instead.

costs and the insider's competitive wage (the contractual wage *plus* the insider's trading profits), and (ii) the outsider's information search costs. That is, the social planner decides whether or not insider trading is preferred by examining

$$\text{ENSV}(R) \equiv QE_0[v' | R] - [W + E_0(\pi')] - C[q^*(R)]. \quad (15)$$

When $\text{ENSV}(B) > \text{ENSV}(A)$, there exists a reallocation that will make everyone better off by changing from a regime with insider trading to one without it. In that case, society prefers restrictions on insider trading.

Since the entrepreneur will set the contractual wage so that the manager's total expected wage equals the competitive wage [i.e., $W + E_0(\pi') = W^c$] in either regime, and because the distribution of terminal value does not depend on the regime for a fixed q , Equation (15) can be rewritten as

$$\text{ENSV}(R) = QE_0[v' | q^*(R)] - W^c - C[q^*(R)]. \quad (16)$$

Thus, because the manager gets W^c in either regime, ENSV is not affected by how the manager is compensated except to the extent that it affects the quality of the outsider's signal.¹⁷ ENSV depends on the quality of the outsider's signal because q affects the distribution of terminal value and the resources expended on outside search. The social effect of insider trading can thus be decomposed into only two components:

$$\begin{aligned} \text{ENSV}(A) - \text{ENSV}(B) &= Q\{E_0[v' | q^*(A)] - E_0[v' | q^*(B)]\} \\ &\quad - \{C[q^*(A)] - C[q^*(B)]\}. \end{aligned} \quad (17)$$

Propositions 1 and 2 imply that both components are negative. Thus, the social planner faces a trade-off between expected terminal value and search costs. Recall that the entrepreneur faces a more complicated trade-off between expected terminal value, the portion of outsider profits that affects the offer price, and the insider's wage subsidy. Although both consider the effect of insider trading on expected terminal value, the social planner does not care about the subsidy since it is merely a transfer. While the social planner does not care about the outsider's trading profits directly (since they too are transfers), he does care about them to the extent that they affect the equilibrium amount of costly search. However, because the portion of the outsider's profits that affect the offer price are not equal to search costs in equilibrium, the impact of outsider trading profits

¹⁷ For models in which the composition of the insider's compensation directly affects terminal values, see Bagnoli and Khanna (1992), Bebchuk and Fershtman (1994), Dye (1984), Fischer (1992), and Leftwich and Verrecchia (1983). All of these articles consider models with moral hazard.

on the trade-offs faced by the social planner and the entrepreneur differ.¹⁸

General conditions on the parameters that characterize when the entrepreneur and society will agree or disagree on insider trading restrictions can be obtained by setting Equations (14) and (17) equal to zero. By doing this, indifference surfaces in parameter space are defined for the entrepreneur and for society. Given these surfaces, it is straightforward to characterize the set of parameters for which the entrepreneur and society agree or disagree. Analytical expressions of these surfaces are extremely cumbersome, however, and provide little intuition. Explicit solutions for one parameter as an implicit function of the other parameters were not possible in most cases. Thus, we identify these surfaces using numerical methods.

The indifference surfaces are plotted in (a_g, a_b, p) space for different combinations of values for C , β , Q , and N in Figures 1 and 2.¹⁹ The surface for society is labeled *SI*. All points on or below this surface are parameter values for which society prefers to ban insider trading, whereas points above are those for which society prefers to allow it. The surface for entrepreneurs is labeled *EI*. All points on or below this surface are parameters for which the entrepreneur prefers to ban insider trading; the points above are those in which the entrepreneur prefers to allow it. Both the entrepreneur and the society prefer to ban insider trading in the region below both surfaces, labeled $SB \cap EB$. The entrepreneur prefers to allow but society prefers to ban in the region below *SI* but above *EI*, labeled $SB \cap EA$. Finally, both the entrepreneur and society prefer to allow in the region above both surfaces, labeled $SA \cap EA$. Since the entrepreneur's surface is everywhere below society's surface, there is no region in which society prefers to allow insider trading while entrepreneurs prefer to ban it.

As can be seen from Figure 1A, the region in which society prefers to allow insider trading is characterized by either a high p or small differences in a_g and a_b . Specifically, the lower the p -value, the closer together a_g and a_b must be for society to want to allow insider trading. For higher p , society prefers to allow for larger differences in a_g and a_b . This is intuitive because, in all of these cases, outside information is not very valuable. First, when p is high, regardless of the differences in states, the outsider's information is probably already known to the

¹⁸ Note that even when the condition for equilibrium in the search market is that total costs equal total profits, the effect of outsider trading profits on the trade-off differs because the entrepreneur only cares about the portion that affects the offer price while the social planner cares about the total profit. Thus, there remains a potential for disagreement even when the search market is in long-run equilibrium.

¹⁹ The 45-degree line across the (a_g, a_b) plane is due to the assumption that $a_g > a_b$. Thus, parameter values in which $a_g < a_b$ are not in the domain.

insider. In these cases, society discourages redundant information collection by permitting insider trading. Second, when there are small differences in the states, resource allocation decisions have little effect on terminal value. Thus, even when the outsider's information is not likely to be redundant (i.e., for low values of p), outside information has little social value. For both these cases, the small benefit to terminal value does not compensate society for the outsider's information collection costs. Conversely, society will want to ban insider trading and encourage outside search for low p and/or large difference in states.

Now consider a point at which society wants to ban insider trading. If this point is where the entrepreneur prefers to allow insider trading, the transfers derived from insider trading must be larger than the decrease in production. As one moves from this point into the region in which the differences in the states is larger, outside information becomes more valuable. At some point, the value of the outside information will exceed the transfers, and the entrepreneur will prefer to ban insider trading. (Clearly, society continues to want to ban as the differences in states gets larger.) Thus, as is shown in the figures, the entrepreneur's indifference surface is at larger difference in the states. Only at these points is the production effect large enough to overturn the transfers. Notice also that this trade-off depends on p . For high p , the transfers become larger since the insider is more likely to (i) make trading profits, which increases the subsidy, and (ii) compete with the outsider, which reduces the premium required by investors. Further, for high p , the outsider's information is more likely to be redundant and have a small influence on production. In fact, the figures show that for very high p there may not exist a divergence in the states large enough to make the entrepreneur want to encourage outside search by banning insider trading.

Figures 1B and 1C show how the area of disagreement changes with search costs. Clearly, the lower the search cost, the larger the set of parameters for which society wants to ban insider trading and encourage outside search. (Compare Figure 1B to Figures 1A and 1C.) The entrepreneur, however, wants to ban insider trading for a smaller set of parameters since, as search costs fall, both the equilibrium quality of the outsider's signal and the outsider's profits increase. As such, the leakage to the outsider is large, and it takes bigger differences in the states for the outsider's information to be valuable enough for the entrepreneur to ban insider trading. Consequently, for lower search costs, the entrepreneur's surface shifts toward the back of the figure. Since society's indifference surface shifts toward the front of the figure when search costs drop, the area of disagreement gets larger for lower search costs.

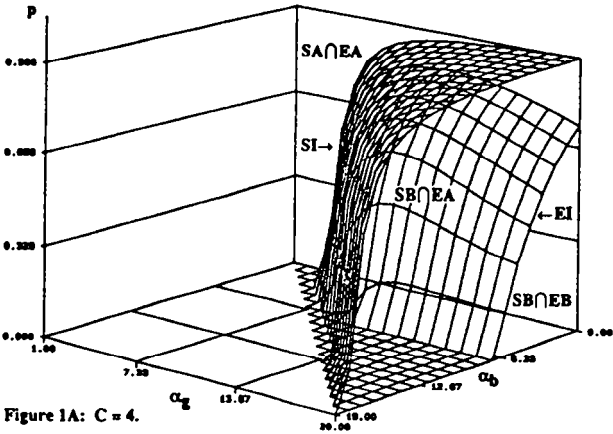


Figure 1A: $C = 4$.

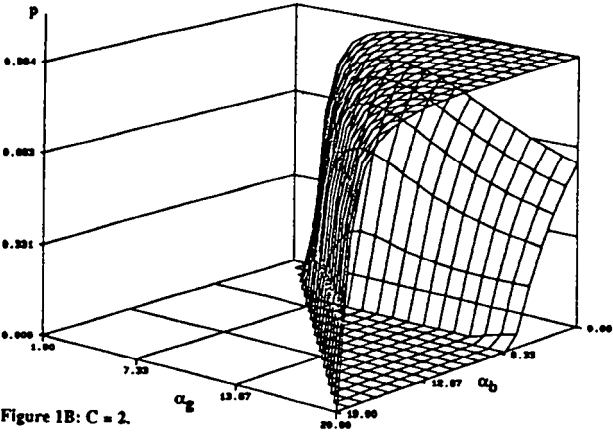


Figure 1B: $C = 2$.

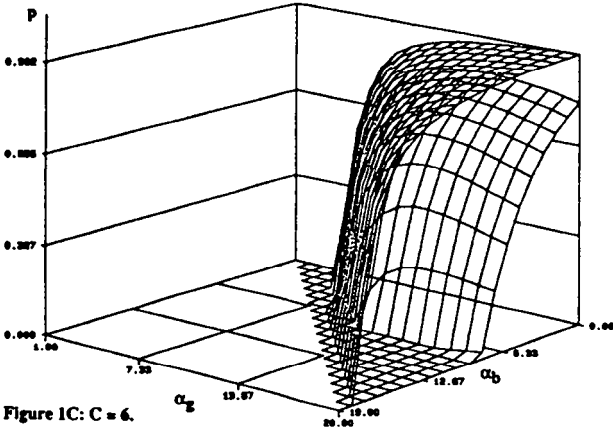


Figure 1C: $C = 6$.

Figures 2A and 2B illustrate the effect of increases and decreases in Q , respectively. By varying Q (and N), we capture the effect of changing the proportion of the firm that informed agents can trade. For the purpose of these figures, we treat N as a fixed proportion of Q , specifically $N = (5/6) Q$.²⁰ Given the assumption that each agent can trade only one share, the larger the Q , the smaller the proportion of the firm that any one agent can trade. Further, for larger Q , the profits from trading one share are smaller relative to the total value of the firm. Figure 2A shows that the surface for the entrepreneur gets proportionally closer to society's surface when Q is increased. This is true because the per-share effect of the outsider's information is independent of Q . As Q increases, the impact of the outsider's information on the total value of the firm is greater. However, since one share now represents a smaller portion of the firm, the unrecoverable trading profit of the outsider decreases with Q . Thus, as Q increases, the transfers become less important relative to the value of the information and the objectives of the entrepreneur and society become more closely aligned. Figure 2B shows that, as expected, the entrepreneur's surface shifts away from society's as Q decreases.

Some testable implications also emerge. For example, there is a relation between volatility and the existence of disagreement between the entrepreneur and society. Note that terminal value volatility increases as the relative difference between a_g and a_b increases and p decreases.²¹ Thus, terminal value variances are highest along the a_g axis (i.e., along the bottom of the right-hand side of the back of the figures) the lowest along a 45-degree line emanating from $a_g = 0$, and $a_b = 0$ when p equals 1. As the 45-degree line sweeps toward the back of the graph, variances increase; as one moves along the 45-degree line toward $p = 0$, variances also increase. Figure 1A implies that, holding p fixed, economies that have higher variances for terminal values are more likely to be under society's indifference surface.

²⁰ Changes in the proportion do not qualitatively affect the results.

²¹ Although p cannot be directly measured, we expect that insiders will have easier access to information than outsiders, and the quality of insiders' information will be high in economies where firms' payoffs are mostly idiosyncratic. In economies in which firms' payoffs are more sensitive to systematic or macro factors, we expect that insiders will not have this advantage and will have relatively low-quality information.

←

Figure 1

Values of p , α_e , and α_s for which society and entrepreneurs want to permit or restrict insider trading for various search costs, C

Each figure shows the indifference surface for the entrepreneur (labeled EI) and society (labeled SI), and the set of parameters for which (1) both society and entrepreneurs prefer to ban (space $SB \cap EB$), (2) both prefer to allow (space $SA \cap EA$), and (3) there is an area of disagreement, with society preferring to ban while entrepreneurs prefer to allow (space $SB \cap EA$). The search costs are $C = 4$ in Figure 1A, $C = 2$ in Figure 1B and $C = 6$ in Figure 1C. For all figures, $Q = 12$, $N = 10$, $\beta = 1$, and $r = 0$.

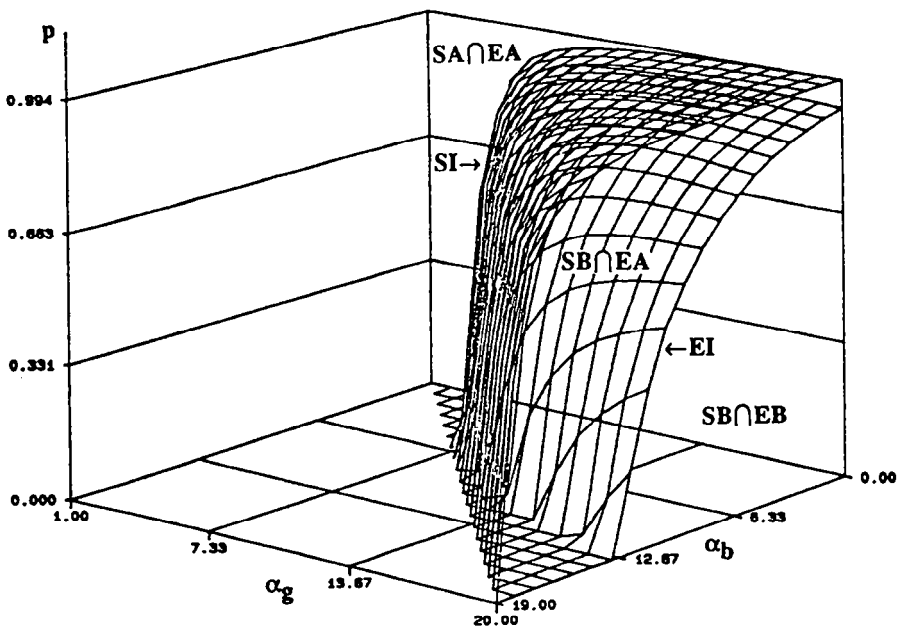


Figure 2A: $Q = 24$ and $N = 20$.

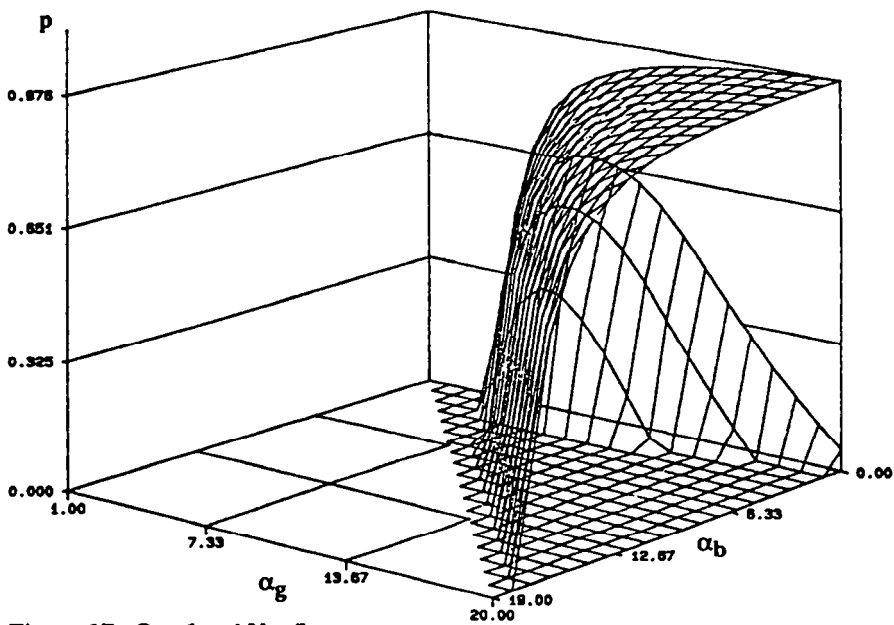


Figure 2B: $Q = 6$ and $N = 5$.

Consequently, social planners in volatile economies are more likely to impose insider trading restrictions to encourage outsider search. Also, controlling for variance, economies with lower p 's are more likely to restrict insider trading.

The effect of C on the surfaces provides another testable implication. In a time series of data in which outside information collection costs, C , are falling, we would expect to see the imposition of socially mandated restrictions on insider trading through time as lower costs result in region $SB \cap EA$ expanding into region $SA \cap EA$ (see Figure 1 B) . Since information collection costs have apparently decreased over the years, this may explain why we have moved from an era of less regulation and enforcement to an era of more regulation and enforcement.

4. Conclusion

In this article, we provide an argument against Carlton and Fischel's claim that, since firms choose not to ban insider trading, federally mandated restrictions are inefficient and should be removed. In our model, an informed manager uses his own information as well as any outside information contained in secondary market prices to improve his resource allocation decisions. If the manager is allowed to trade, he will compete with informed outsiders and reduce the quality of their information. While the benefits to production of outside information are the same for both society and entrepreneurs, we show that the social and private costs are different. As such, there can be a divergence between firms and society with respect to the conditions under which insider trading restrictions should be imposed. Thus, there is a role for public policy.

Appendix A: Construction of the Equilibrium

1. Secondary-market prices and resource allocation

We denote the expectation of a conditional on $P_1(\omega)$ by $a^e(\omega)$. Because $P_1(\omega)$ is an invertible function of ω (as shown below in Lemma 4), it

Figure 2

The effect of changing the number of outstanding shares (Q and N) on the area of disagreement in (a_g, a_b, p) space

Each figure shows the indifference surface for the entrepreneur (labeled EI) and society (labeled SI) and the set of parameters for which (1) both society and entrepreneurs prefer to ban (space $SB \cap EB$), (2) both prefer to allow (space $SA \cap EA$), and (3) there is an area of disagreement, with society preferring to ban while entrepreneurs prefer to allow (space $SB \cap EA$). The number of shares issued is Q , $Q - 24$ in Figure 2A and $Q - 6$ in Figure 2B. The number of shares initially issued to uninformed investors is N ; $N = 20$ in Figure 2A and $N = 5$ in Figure 2B. For all figures, $C = 4$, $\beta = 1$, and $r = 0$.

is appropriate to write the expectation as a function of ω alone. When the insider's own signal is revealing, there is no need for him to infer the outsider's information. When the insider's signal is uninformative, however, his best estimate of a is $a^e(\omega)$. The following lemma specifies the insider's expectations of a conditional on the net order flow when the insider has an uninformative private signal.

Lemma 1.

$$\begin{aligned}\alpha^e(2) &= \alpha_g, \\ \alpha^e(1) &= \frac{q\alpha_g + 2(1-q)\bar{a}}{2-q}, \\ \alpha^e(0) &= \bar{a}, \\ \alpha^e(-1) &= \frac{q\alpha_b + 2(1-q)\bar{a}}{2-q}, \\ \alpha^e(-2) &= \alpha_b,\end{aligned}$$

where $\bar{a} \equiv (\alpha_g + \alpha_b)/2$.

Proof. Let $\mathcal{U}$ denote the space of uninformative signals and $\mathcal{U}^c$ denote the space of informative signals. By the arguments above, $\alpha^e(2) = \alpha_g$ and $\alpha^e(-2) = \alpha_b$. $\alpha^e(1)$, $\alpha^e(0)$, and $\alpha^e(-1)$ only occur when the insider's signal, θ' , is uninformative (i.e., $\theta' \in \mathcal{U}$). As such, the probabilities of the states given below are all conditional on the insider having an uninformative signal. When $\theta' \in \mathcal{U}$, the insider does not trade even if allowed to do so and the expectations are the same whether or not insider trading is allowed.

$\alpha^e(1)$ is derived by applying Bayes' theorem. There are three events in which $\omega = 1$ and $\theta' \in \mathcal{U}$. Note θ^o is the outsider's signal.

i. $\theta' \in \mathcal{U}$, $\theta^o \in \mathcal{U}^c$ and $a = a_g$ (thus, $\Delta X_o = 1$) and $\Delta X_i = 0$. The probability of the first item is $(1-p)$, the second is $q/2$, and the third is $1/3$.

ii. $\theta' \in \mathcal{U}$, $\theta^o \in \mathcal{U}$ and $a = a_g$ (thus, $\Delta X_o = 0$), and $\Delta X_i = 1$. The probability of the first item is $(1-p)$, the second is $(1-q)/2$, and the third is $1/3$.

iii. $\theta' \in \mathcal{U}$, $\theta^o \in \mathcal{U}$ and $a = a_b$ (thus, $\Delta X_o = 0$), and $\Delta X_i = 1$. The probability of the first item is $(1-p)$, the second is $(1-q)/2$, and the third is $1/3$.

Thus, $\Pr(\omega = 1, \theta' \in \mathcal{U}) = (1-p)(q/2)(1/3) + (1-p)[(1-q)/2](1/3) + (1-p)[(1-q)/2](1/3) = (1-p)(2-q)/6$, $\Pr(\alpha = \alpha_g, \omega = 1, \theta' \in \mathcal{U}) = (1-p)(q/2)(1/3) + (1-p)[(1-q)/2](1/3) = (1-p)/6$, and $\Pr(\alpha = \alpha_b, \omega = 1, \theta' \in \mathcal{U}) = (1-p)[(1-q)/2](1/3) =$

$(1 - p)(1 - q)/6$. Applying Bayes' theorem using the above conditional probabilities yields the expression of $\alpha^e(1)$, $\alpha^e(-1)$ and $\alpha^e(0)$ are obtained using the same method as for $\alpha^e(1)$, $\alpha^e(2)$ and $a^e(-2)$ have been discussed already. Q.E.D.

Given this finite set of possible expectations, there are only eight possible terminal values-one for each state and expected state pair. We denote those terminal values as follows: $v_{gg} \equiv v(\alpha_g, \alpha_g)$; $v_{g\omega} \equiv v[\alpha_g, \alpha^e(\omega)]$, for $\omega = 1, 0, -1$; $v_{b\omega} \equiv v[\alpha_b, \alpha^e(\omega)]$ for $\omega = 1, 0, -1$; and $v_{bb} \equiv v(\alpha_b, \alpha_b)$. For example, $v_{g1} \equiv v[\alpha_g, \alpha^e(1)]$ is the terminal value that obtains when the terminal state is a_g and the insider has an uninformative signal but infers the state (albeit imperfectly) from $P_1(1)$. Terminal values v_{gg} and v_{bb} occur either when the insider's signal is informative or when his signal is uninformative, but the order flow is 2 or -2, respectively. We also denote the probability of v_{gg} by p_{gg} ; v_{g1} by p_{g1} ; and so forth. The closed-form expression for the distribution of terminal values is specified in Lemma (2).

Lemma 2. Independent of whether or not insider trading is allowed, the probabilities are

$$\begin{aligned} p_{gg} &= p/2 + (1 - p)q/6; & p_{g1} &= (1 - p)/6; \\ p_{g0} &= (1 - p)/6; & p_{g-1} &= (1 - p)(1 - q)/6; \\ p_{b1} &= (1 - p)(1 - q)/6; & p_{b0} &= (1 - p)/6; \\ p_{b-1} &= (1 - p)/6; & p_{bb} &= p/2 + (1 - p)q/6. \end{aligned}$$

Proof. As has been argued previously, the probabilities are independent of whether insider trading is allowed because the insider knows how he would trade if he were allowed to do so. We show how to determine the probabilities for only v_{gg} and v_{gl} here. The other probabilities are determined in a similar manner and are straightforward for the reader to verify.

The terminal value v_{gg} occurs when either (i) $\theta' \in \mathcal{U}^c$ and $\alpha = \alpha_x$ or (ii) $\theta' \in \mathcal{U}$ but $\Delta X_L = 1$, $\Delta X_O = 1$ (i.e., when the outsider knows $a = a_g$ and buys), and $\omega = 2$. The first event occurs with probability $p/2$ while the second event occurs with probability $(1 - p)(q/2)(1/3)$. Thus,

$$\begin{aligned} \Pr(v_{gg}) &= p/2 + (1 - p)(q/2)(1/3) \\ &= p/2 + (1 - p)(q/6). \end{aligned} \tag{A1}$$

The terminal value v_{gl} occurs only when $\theta' \in \mathcal{U}$ and $\omega = 1$. The event $\theta' \in \mathcal{U}$ happens with probability $1 - p$. Given that $\theta' \in \mathcal{U}$, the

event $\omega = 1$ occurs when (i) the outsider is informed and buying (i.e., $\theta^o \in \mathcal{U}^c$, $\alpha = \alpha_g$, and $\Delta X_o = 1$) and the liquidity trader is doing nothing (i.e., $\Delta X_L = 0$) or (ii) the outsider is uninformed and not trading (i.e., $\theta^o \in \mathcal{U}$ and $\Delta X_o = 0$) but the liquidity trader is buying (i.e., $\Delta X_L = 1$). Event (i) occurs with probability $(q/2)(1/3)$ while event (ii) occurs with probability $(1 - q)/2(1/3)$. Thus,

$$\begin{aligned} \Pr(v_{g1}) &= (1 - p)\{(q/2)(1/3) + [(1 - q)/2](1/3)\} \\ &= (1 - p)/6. \end{aligned} \quad \begin{matrix} (A2) \\ \text{Q.E.D.} \end{matrix}$$

To quantify the effect of q on liquidation value, one must derive equilibrium secondary market prices. The following lemma specifies both equilibrium trades and prices in the secondary market when insider trading is allowed and when it is prohibited.

Lemma 3.

(a) Regardless of whether insider trading is allowed, a buy order is optimal when the agent's signal reveals $a = a_g$, a sell order is optimal when the agent's signal reveals $a = a_b$, and no trade is optimal when the agent's signal is uninformative.

(b) When insider trading is allowed, the equilibrium price function is as follows:

$$\begin{aligned} P_1(3) &= P_1(2) = v_{gg}, \\ P_1(1) &= \frac{pv_{gg} + (1 - p)v_{g1} + (1 - p)(1 - q)v_{b1}}{1 + (1 - p)(1 - q)}, \\ P_1(0) &= \frac{p(1 - q)v_{gg} + (1 - p)v_{g0} + (1 - p)v_{b0} + p(1 - q)v_{bb}}{2(1 - pq)}, \\ P_1(-1) &= \frac{pv_{bb} + (1 - p)v_{b-1} + (1 - p)(1 - q)v_{g-1}}{1 + (1 - p)(1 - q)}, \text{ and} \\ P_1(-3) &= P_1(-2) = v_{bb}. \end{aligned}$$

(c) When insider trading is prohibited, the equilibrium price function is as follows:

$$\begin{aligned} P_1(2) &= v_{gg}, \\ P_1(1) &= \frac{pv_{gg} + (1 - p)v_{g1} + (1 - p)(1 - q)v_{b1} + p(1 - q)v_{bb}}{2 - q}, \\ P_1(0) &= \frac{pv_{gg} + (1 - p)v_{g0} + (1 - p)v_{b0} + pv_{bb}}{2}, \end{aligned}$$

$$P_1(-1) = \frac{pv_{bb} + (1-p)v_{b-1} + (1-p)(1-q)v_{g-1} + p(1-q)v_{gg}}{2-q},$$

and

$$P_1(-2) = v_{bb}.$$

Proof of Lemma 3(a). It is necessary to show that, when $\theta' \in \mathcal{U}^c$, it is optimal to buy when $a = a_g$ and sell when $a = a_b$. That is, it is necessary to show, for $i = I$ and O , that

$$\begin{aligned} \text{(i)} \quad & E(\pi' | \alpha^e = \alpha_g, \Delta X_i = 1) > E(\pi' | \alpha^e = \alpha_g, \Delta X_i = 0) \text{ and} \\ & E(\pi' | \alpha^e = \alpha_g, \Delta X_i = 1) > E(\pi' | \alpha^e = \alpha_g, \Delta X_i = -1), \\ \text{and (ii)} \quad & E(\pi' | \alpha^e = \alpha_b, \Delta X_i = -1) > E(\pi' | \alpha^e = \alpha_b, \Delta X_i = 0) \text{ and} \\ & E(\pi' | \alpha^e = \alpha_b, \Delta X_i = -1) > E(\pi' | \alpha^e = \alpha_b, \Delta X_i = 1). \end{aligned}$$

Because $E(\pi' | \alpha^e = \alpha_b, \Delta X_i = 0) = 0$, $E(\pi' | \alpha^e = \alpha_g, \Delta X_i = 1) > E(\pi' | \alpha^e = \alpha_g, \Delta X_i = -1)$, and $E(\pi' | \alpha^e = \alpha_b, \Delta X_i = -1) > E(\pi' | \alpha^e = \alpha_b, \Delta X_i = 1)$ for $i = I$ or O , to prove (i) and (ii), it is sufficient to show

$$E(\pi' | \alpha^e = \alpha_g, \Delta X_i = 1) > 0 \text{ and} \quad (\text{A3})$$

$$E(\pi' | \alpha^e = \alpha_b, \Delta X_i = -1) > 0. \quad (\text{A4})$$

We now prove that Equation (A3) holds when insider trading is allowed. The proof for Equation (A4) when insider trading is allowed and the proofs for Equations (A3) and (A4) when insider trading is prohibited are left to the reader.

The expected profit given $a^e = a_g$ and $\Delta X_i = 1$ can be easily shown to be $E(\pi' | \alpha^e = \alpha_g, \Delta X_i = 1) = (1/3)\{p[v_{gg} - P_1(1)] + (1-p)[v_{g1} - P_1(1)] + (1-p)[v_{g0} - P_1(0)]\}$ which the reader can verify is positive. Q.E.D.

Proof of Lemma 3(b). Whenever $\omega = 3$ or 2 , the insider knows the terminal state is a_g (either directly or by inferring from price) and allocates accordingly. Thus, whenever $\omega = 3$ or 2 , the terminal value is v_{gg} . The market maker knows this and quotes a price function where $P_1(2) = P_1(3) = v_{gg}$. Similarly, for $\omega = -3$ and -2 , the market maker sets $P_1(-3) = P_1(-2) = v_{bb}$. The terminal values are ambiguous when $\omega = 1, 0$, or -1 , however, and the market maker quotes the price function as $P_1(\omega) = E(v | \omega)$. Thus,

$$\begin{aligned} P_1(\omega) = & \Pr(v_{gg} | \omega)v_{gg} + \Pr(v_{g1} | \omega)v_{g1} + \Pr(v_{g0} | \omega)v_{g0} \\ & + \Pr(v_{g-1} | \omega)v_{g-1} + \Pr(v_{b1} | \omega)v_{b1} + \Pr(v_{b0} | \omega)v_{b0} \\ & + \Pr(v_{b-1} | \omega)v_{b-1} + \Pr(v_{bb} | \omega)v_{bb}, \end{aligned} \quad (\text{A5})$$

where $\Pr(v_{s\omega} | \omega) = \Pr(v_{s\omega}, \omega) / \Pr(\omega)$ for $s = g, b$ and $\omega = 1, 0, -1$.

Note that $\Pr(v = v_{s1}, \omega = 0) = \Pr(v = v_{s1}, \omega = -1) = \Pr(v = v_{s0}, \omega = 1) = \Pr(v = v_{s0}, \omega = -1) = \Pr(v = v_{s-1}, \omega = 1) = \Pr(v = v_{s-1}, \omega =$

0) = 0 since the only time terminal value is not v_{gg} or v_{bb} is when the insider must infer α from price.

The probabilities $\Pr(v_{sw}, \omega)$ for each possible sand ω pair are derived first. Then the sum of each is used to obtain $\Pr(\omega)$ and the resulting conditional probabilities are calculated and used in Equation (A5) for each ω .

$$\Pr(v_{gg}, \omega = 1) = (p/2)[(1 - q)(1/3) + q(1/3)] = p/6, \quad (A6)$$

where $p/2$ is the probability that the insider knows $a = a_g$. The insider must know $a = a_g$ directly from his signal since, if he had an uninformative signal, v_{gl} would obtain. The term $(1 - q)(1/3)$ is the probability that $\theta^o \in \mathcal{U}$ (and thus, $\Delta X_o = 0$) and $\Delta X_L = 1$ and $q(1/3)$ is the probability that $\theta^o \in \mathcal{U}^c$ (and thus, $\Delta X_o = 1$) and $\Delta X_L = 0$. Similarly,

$$\begin{aligned} \Pr(v_{gl}, \omega = 1) &= [(1 - p)/2][(1 - q)(1/3) + q(1/3)] \\ &= (1 - p)/6 \end{aligned} \quad (A7)$$

where $(1 - p)/2$ is the probability $\theta' \in \mathcal{U}$ and $\alpha = \alpha_g$. Note that $\theta' \in \mathcal{U}$ must hold, since if the insider had received an informative signal, v_{gg} would obtain. The term $(1 - q)(1/3)$ is the probability that $\theta^o \in \mathcal{U}$ (and thus, $\Delta X_o = 0$) and $\Delta X_L = 1$, and $q(1/3)$ is the probability that $\theta^o \in \mathcal{U}^c$ (and thus, $\Delta X_o = 1$) and $\Delta X_L = 0$. Finally,

$$\begin{aligned} \Pr(v_{bl}, \omega = 1) &= [(1 - p)/2][(1 - q)(1/3)] \\ &= (1 - p)(1 - q)/6 \end{aligned} \quad (A8)$$

where, again $\theta' \in \mathcal{U}$. Here $\theta^o \in \mathcal{U}$ must hold since there is no way to get a net order flow of 1 when $\theta' \in \mathcal{U}$ (and thus $\Delta X_L = 0$) and $\theta^o \in \mathcal{U}^c$ (and thus $\Delta X_o = -1$) when $\Delta X_L \in \{1, 0, -1\}$. Thus, this is the probability that the insider and the outsider do not trade, the liquidity traders are buying, and $\alpha = \alpha_b$.

Summing over probabilities and simplifying yields $\Pr(\omega = 1) = [1 + (1 - p)(1 - q)]/6$. Thus, $\Pr(v_{gg} | \omega = 1) = p/[1 + (1 - p)(1 - q)]$, $\Pr(v_{gl} | \omega = 1) = (1 - p)/[1 + (1 - p)(1 - q)]$, $\Pr(v_{bl} | \omega = 1) = [(1 - p)(1 - q)]/[1 + (1 - p)(1 - q)]$, and $P_1(1)$ is as given in the lemma.

The expression for $P_1(-1)$ can be determined by replacing a_g for a_b and a_b for a_g . The expression for $P_1(0)$ is obtained using the same method as for $P_1(1)$ and can be easily verified by the reader. Q.E.D.

Proof of Lemma 3(c). The price function without insider trading is obtained using the same method as in the proof of Lemma 3(b).

Q.E.D.

2. Expected profits of informed traders and optimal signal quality

Given the equilibrium trades, terminal values, and secondary market price function, the equilibrium quality of the outsider's signal can be determined. The first step is to determine the outsider's expected profits. When insider trading is prohibited, the expected profit is

$$\begin{aligned}
 E_0(\pi^o \mid q, R = B) &= (q/6) \{ \{ p[v_{gg} - P_1(1)] + p[v_{gg} - P_1(0)] \\
 &\quad + (1 - p)[v_{g1} - P_1(1)] + (1 - p)[v_{g0} - P_1(0)] \} \\
 &\quad - \{ (1 - p)[v_{b0} - P_1(0)] + (1 - p)[v_{b-1} - P_1(-1)] \\
 &\quad + p[v_{bb} - P_1(0)] + p[v_{bb} - P_1(-1)] \} \} \\
 &= (Hq/6)[(4 - 3q)/(2 - q)], \tag{A9}
 \end{aligned}$$

where $H \equiv (\alpha_g - \alpha_b)(\bar{\alpha} - r)/\beta$. Expression (A9) is simply the probability-weighted sum of possible realized profits. Each part of the expression [e.g., $(pq/6)(v_{gg} - P_1(1))$] is a profit that obtains by trading on the difference between terminal value and secondary market price times the probability of that profit. For example $v_{gg} - P_1(1)$ is the profit obtained when the insider knows the terminal state is a_g and the net order flow is $\omega = 1$. This profit occurs only when the outsider buys, the liquidity trader does not trade, and the insider has an informative signal.²² The probability is $pq/6 = pq(1/2)(1/3)$, where p is the probability that the insider receives an informative signal, q is the probability that the outsider receives an informative signal, $1/2$ is the probability that the state is a_g , and $1/3$ is the probability that the liquidity trader is selling. Each of the other expressions are obtained in the same manner. Substituting expressions from Lemmas (2) and (3) and simplifying yields the final equality in Equation (A9).

Similarly, the outsider's expected profits when insider trading is allowed are given by

$$\begin{aligned}
 E_0(\pi^o \mid q, R = A) &= (q/6) \{ \{ p[v_{gg} - P_1(1)] + (1 - p)[v_{g1} - P_1(1)] \\
 &\quad + (1 - p)[v_{g0} - P_1(0)] \} \\
 &\quad - \{ (1 - p)[v_{b0} - P_1(0)] + (1 - p)[v_{b-1} - P_1(-1)] \}
 \end{aligned}$$

²² If the insider has an uninformative signal, then v_{g1} is the best outcome possible given a net order flow of 1. Further, this case does not happen when the insider is informed and buying, the liquidity trader is not trading, and the outsider is uninformed and not trading, since the outsider realizes no profits unless he trades.

$$+ p[v_{gg} - P_1(-1)]\}} \\ = (Hq/6)[2 - p - (1 - z)/(1 + z)], \quad (\text{A10})$$

with $z \equiv (1 - p)(1 - q)$.

Given the expected profit functions for the outsider, the equilibrium quality of the outsider's signal can be determined. It can be shown that, in both regimes, Equation (7) in the text implies a quadratic equation in q . Let π_{0R} , π_{1R} , and π_{2R} denote the coefficients of the quadratic equation $\pi_{0R}q^2 + \pi_{1R}q + \pi_{2R} = 0$, for each regime ($R = A$ and B). The coefficients when insider trading is allowed (i.e., $R = A$) are

$$\pi_{0A} = (1 - p)^2, \quad \pi_{1A} = -2(1 - p)(2 - p), \quad \text{and} \\ \pi_{2A} = (2 - p)^2 - \frac{2(2 - p)}{3 - p - (6C/A)},$$

while the coefficients when insider trading is banned (i.e., $R = B$) are

$$\pi_{0B} = 1, \quad \pi_{1B} = -4, \quad \text{and} \quad \pi_{2B} = \frac{8(A - 3C)}{3(A - 2C)}.$$

By examining the second-order condition, the optimal q is the smaller of the two roots of these equations. That is,

$$q^{R*} = \frac{-\pi_{1R} - (\pi_{1R}^2 - 4\pi_{0R}\pi_{2R})^{1/2}}{2\pi_{0R}}. \quad (\text{A11})$$

Although the discriminant is always positive (i.e., the root is real) when insider trading is banned, it may be negative when insider trading is allowed. For it to be positive when $R = A$,

$$8(1 - p)^2(2 - p)/D > 0, \quad (\text{A12})$$

where $D \equiv 3 - p - 6C/H$ and $H \equiv (\alpha_g - \alpha_b)(\bar{\alpha} - r)/\beta$. Since $8(1 - p)^2(2 - p) > 0$ for $p \in [0, 1]$, Equation (A12) holds when $D > 0$. When $D < 0$, however, the marginal cost exceeds marginal profits for all q and the optimal q is $q^* = 0$. The condition for the extrema to be maxima is that the second derivative be negative. The second derivative is $[q(1 - p) - (2 - p)](1 - p)$, which the reader can verify is negative for all p and $q \in [0, 1]$. Therefore, any solution $q^* \in [0, 1]$ is a maxima.

The following lemma characterizes how p effects optimal q .

Lemma 4.

(a) When insider trading is allowed, the optimal q is decreasing in p .

(b) When insider trading is prohibited, the optimal q is independent of p .

Proof of Lemma 4(a).

Given Equation (A9), the first-order condition, $\partial E(\pi^o)/\partial q - C = 0$ is

$$[q(1 - p) - (2 - p)]^2 - 2(2 - p)/D - C = 0. \quad (A13)$$

The total differential of Equation (A13) is

$$2L[(1 - p)dq + (1 - q)dp] - [2(2 - p)/D^2 - 2/D]dP = 0, \quad (A14)$$

where $L \equiv q(1 - p) - (2 - p) < 0$ Equation (A14) implies

$$\frac{dq}{dp} = \frac{-(1 - q)}{(1 - p)} - \frac{1}{L(1 - p)D} + \frac{(2 - p)}{(1 - p)D^2L}.$$

Because $L < 0$ and $D > 0$ (for the solution to be real), $dq/dp < 0$ implies

$$-D[LD(1 - q) - 1] + (2 - p) > 0. \quad (A15)$$

Since $LD(1 - q) - 1 < 0$ (because $L < 0$, $D > 0$, and $q \in [0, 1]$) the first term in Equation (A15) is positive. Since $p \in [0, 1]$, the second term is also positive and, thus, the sum of the two terms is positive.

Q.E.D.

Proof of Lemma 4(b). Inspection of q^* without insider trading shows that p does not appear at all.

Q.E.D.

3. The portion of informed agents' expected profits that affects the initial offer price

Only a portion of the expected profits discussed above translates into liquidity costs for a liquidity-motivated seller. When the outsider is informed and the liquidity trader is selling, the liquidity trader loses directly to the outsider. When the outsider knows $a = a_b$, the net order flow is -2, the price equals the terminal value v_{bb} , and the loss to the liquidity trader is zero. When the outsider knows $a = a_g$, however, the net order flow is zero and the liquidity trader sells to the outsider for $P_1(0)$. In this case, the resulting terminal value is either v_{go} (in the event that the insider is uninformed) or v_{gg} (in the event that the insider is informed) and the liquidity cost is equal to the outsider's profit. When the outsider receives an uninformative signal, the liquidity seller still incurs a loss, though not directly to the outsider. Since the market maker cannot distinguish between a net order flow of -1 due to only the outsider selling (knowing that $a = a_b$ or due to only a liquidity sale, the liquidity seller will still bear a liquidity cost. For the market maker to get zero expected profits, the liquidity cost associated with only a liquidity sale must equal the

outsider's profits when the outsider is selling and the liquidity trader is not trading. Thus, the total cost of a liquidity-motivated sale as a function of potential outsider profits is

$$\Psi^{OB} = (q/6)\{p[v_{gg} - P_1(0)] + (1-p)[v_{g0} - P_1(0)] + (1-p)[P_1(-1) - v_{b-1}] + p[P_1(-1) - v_{bb}]\} \quad (A16)$$

where the first two terms are the direct losses and the second two terms are the indirect losses imposed on the liquidity seller. By comparison with Equation (A9) above, these profits represent the profits in only half the states in which the outsider makes profits. The rest of the profits affect the liquidity cost of a liquidity-motivated buy order and, as argued above, do not affect P_O .

The reader can easily verify that the proportion of the outsider's expected profit that affects the offer price when insider trading is allowed is

$$\begin{aligned} \Psi^{OA} = (q/6)\{ & (p/2)[v_{gg} - P_1(1)] + (1-p)[v_{g0} - P_1(0)] \\ & + (1-p)[P_1(-1) - v_{b-1}] + (p/2)[P_1(-1) - v_{bb}]\}. \end{aligned} \quad (A17)$$

Similarly, the component of the insider's expected profits that affects the offer price is

$$\begin{aligned} \Omega^A = (p/6)\{ & (q/2)[v_{gg} - P_1(1)] + (1-q)[v_{gg} - P_1(1)] \\ & + (1-q)[P_1(-1) - v_{bb}] + (q/2)[P_1(-1) - v_{bb}]\}. \end{aligned} \quad (A18)$$

Appendix B: Proposition Proofs

Proof of Proposition 1(b). A comparison of Equations (A9) and (A10) yields the following relationship between the outsider's expected profits in the two regimes.

$$E_0(\pi^O \mid q, B) = E_0(\pi^O \mid q, A) + \delta(q), \quad (B1)$$

where

$$\delta(q) \equiv \frac{Aq}{\beta} \left(p + \frac{1-z}{1+z} - \frac{q}{2-q} \right).$$

When $p = 0$, then $\delta(q) = 0$ and $\partial\delta(q)/\partial q = 0$. Thus,

$$\partial E(\pi^O \mid B)/\partial q = \partial E(\pi^O \mid A)/\partial q, \quad \text{and} \quad (B2)$$

$$q^*(B, \Omega, p = 0) = q^*(A, \Omega, p = 0), \quad (B3)$$

where Ω is a vector of all the model's parameters except p . by Lemma 4(a),

$$q^*(A, p = 0) \geq q^*(A, p) \quad \text{for all } p \in [0, 1], \quad (\text{B4})$$

and by Lemma 4(b),

$$q^*(B, p = 0) = q^*(B, p) \quad \text{for all } p \in [0, 1]. \quad (\text{B5})$$

Equations (B3) and (B4) imply

$$q^*(B, \Omega, p = 0) = q^*(A, \Omega, p = 0) \geq q^*(A, \Omega, p), \quad (\text{B6})$$

while Equations (B5) and (B6) imply

$$q^*(B, \Omega, p) = q^*(B, \Omega, p = 0) \geq q^*(A, \Omega, p). \quad (\text{B7})$$

Therefore, $q^*(B) \geq q^*(A)$ for all Ω and p . Q.E.D.

Proof of Proposition 2(b).

$$\begin{aligned} \frac{\partial E(v)}{\partial q} &= \frac{(1-p)}{6} [(v_{gg} - v_{g-1}) + (v_{bb} - v_{b1})] \\ &\quad + \left(p_{g1} \frac{\partial v_{g1}}{\partial q} + p_{b1} \frac{\partial v_{b1}}{\partial q} \right) + \left(p_{b-1} \frac{\partial v_{b-1}}{\partial q} + p_{g-1} \frac{\partial v_{g-1}}{\partial q} \right). \end{aligned}$$

Because $(v_{gg} - v_{g-1}) > 0$ and $(v_{bb} - v_{b1}) > 0$, it is enough to show that

$$(i) \quad p_{g1} \frac{\partial v_{g1}}{\partial q} + p_{b1} \frac{\partial v_{b1}}{\partial q} \geq 0 \quad \text{and}$$

$$(ii) \quad p_{b-1} \frac{\partial v_{b-1}}{\partial q} + p_{g-1} \frac{\partial v_{g-1}}{\partial q} \geq 0.$$

Condition (i) holds because

$$\begin{aligned} \frac{\partial v_{g1}}{\partial q} &= \frac{\partial \alpha^e(1)}{\partial q} \frac{(\alpha_g - v)}{\beta} - \frac{[\alpha^e(1) - v] \partial \alpha^e(1)}{\beta \partial q} \\ &= \frac{\partial \alpha^e(1)}{\partial q} \frac{[\alpha_g - \alpha^e(1)]}{\beta}, \\ \frac{\partial v_{b1}}{\partial q} &= \frac{\partial \alpha^e(1)}{\partial q} \frac{(\alpha_b - v)}{\beta} - \frac{[\alpha^e(1) - r] \partial \alpha^e(1)}{\beta \partial q} \\ &= \frac{\partial \alpha^e(1)}{\partial q} \frac{[\alpha_b - \alpha^e(1)]}{\beta} \end{aligned}$$

and

$$p_{g1} \frac{\partial v_{g1}}{\partial q} + p_{b1} \frac{\partial v_{b1}}{\partial q} = \frac{1}{\beta} \frac{\partial \alpha^*(1)}{\partial q} \{p_{g1}[\alpha_g - \alpha^*(1)] + p_{b1}[\alpha_b - \alpha^*(1)]\}.$$

Substituting expressions for the probabilities and conditional expectations of a derived above yields

$$\frac{(1-p)}{6\beta} \frac{\partial \alpha^*(1)}{\partial q} \{[\alpha_g + (1-q)\alpha_b] - [\alpha_g + (1-q)\alpha_b]\} = 0.$$

The proof of (ii) is similar to the proof of (i) and is left to the reader. Q.E.D.

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