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PRIVATE INFORMATION, MARKET EFFICIENCY AND INSIDER TRADING: A RATIONAL EXPECTATIONS APPROACH*

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Abstract

1. INTRODUCTION

Competitive rational expectations equilibrium models of securities markets formalize the notion that prices reflect private information possessed by market participants [see, for example, Admati (1985), Danthine (1978), Diamond and Verrecchia (1981), Grossman (1976) and (1978), Grossman and Stiglitz (1985), and Verrecchia (1982)]. In order to maintain tractability, many of these models employ normality assumptions to describe uncertainty. While these models have proved to be rich in terms of insights about the process by which prices aggregate private information, the distributional assumptions make them difficult to empirically test. Most of the existing tests involve only the broadest predictions of the models, often limited only to tests of whether prices converge to the security's value and a heuristic description of the speed of convergence [see Huberman and Schwert (1985), Kandel, Ofer and Sarig (1991), Plott and Sunder (1982), and Sunder (1990)]. Consequently, some of the interesting, but more subtle, predictions of these models have not been subjected to empirical testing, particularly the restrictions these models place on second moments.

In this paper, we develop a simple rational expectations model of a securities market involving lognormally distributed random variables. We assume that agents have mean-variance preferences and we derive security prices in a large competitive market. We define the notions of quality of information, importance of information, and price informativeness in a manner consistent with the existing literature. Then we show that our model's predictions regarding the relationships among these market attributes is qualitatively the same as predicted by extant models involving normal distributions. Finally, we test these predictions using data on insider trading.

There are two reasons why normality assumptions are convenient in rational expectations models of securities markets. First, posterior beliefs based on observations of jointly normal random variables are easy to characterize because only the posterior mean depends on the realized value of the information variable. Therefore only one dimension of individual's posterior beliefs depends on the realized value of the individual's information. Since demands typically depend on both dimensions (mean and variance) of posterior beliefs, this feature of normal distributions facilitates the aggregation required by market clearing conditions. Second, the set of jointly normal random variables is closed under addition. Therefore, normality is preserved when market clearing conditions (which are inherently additive) are imposed. Both of these conveniences are absent in our model involving lognormal random variables. However, we are able to recover a price that is a log-linear function of normal random variables by considering an economy in which the number of agents is arbitrarily large, and the aggregate supply of the security is finite. As the economy grows, the per-capita risk borne by agents tends to zero.[1]

The benefit of our approach is that continuously-compounded equilibrium rates of return are normally distributed.This enables us to express market attributes such as price informativeness, and quality and importance of private information in terms of *return* moments. Moreover, the predicted relations between these attributes is linear, so straightforward statistical techniques can be used to estimate them and to test the model's predictions. Our tests have an appealing intuitive interpretation independent of our parametric model. The expression for price informativeness in terms of return moments is a measure of the speed of price adjustment to a piece of information. This is because it measures the extent to which the eventual return associated with the information is completed by some earlier point in time. The importance of information measures how well the information forecasts eventual returns. The model's prediction that price informativeness and the importance of information are directly related is equivalent to saying that prices react sooner to information whose eventual impact on returns is stronger. Therefore, independent of the model, our empirical testing procedure can be viewed more generally as a method to test this hypothesis.

Discuss the data and results in broad terms here...

The model is presented in the Section 2. Section 3 discusses the testing procedure and empirical results. Section 4 concludes the paper.

2. THE MODEL

We consider an economy composed of individual traders who have mean-variance preferences over terminal wealth and who behave competitively. Conditional on their private information and any information they infer from prices, individuals choose utility-maximizing portfolios consisting of a riskless and a risky asset. There are no constraints on buying or selling the assets. For convenience, we normalize the price of the riskless asset to unity (i.e., the riskless asset serves as the numeraire), and we normalize the riskless interest rate to zero. The risky asset is assumed to have a lognormally-distributed random payoff. Its

[1] See Bhattacharya and Pfleiderer (1988) for a model of a professionally managed mutual fund with a similar feature.

equilibrium price is determined by equating the risky asset's aggregate demand and supply.

2.1 Market Equilibrium

Let $X \in [0, \infty)$ denote the supply of the risky asset whose payoff is

$$\tilde{V} = V_o \exp\left\{\tilde{\theta} + \tilde{\eta}\right\}$$

where V_o is a known constant, and $\tilde{\theta}$ and $\tilde{\eta}$ are normal random variables having zero means and variances of σ_θ^2 and σ_η^2, respectively. There are m mean-variance utility maximizers, indexed by i. Individual i observes (costless) private information in the form $V_o \exp\left\{\hat{\theta}_i\right\}$ where $\hat{\theta}_i$ is the realization of the random variable

$$\tilde{\hat{\theta}}_i = \tilde{\theta} + \tilde{Z} + \tilde{\epsilon}_i$$

where $\tilde{Z}$ and $\tilde{\epsilon}_i$ are normal random variables having zero means and variances of σ_z^2 and σ_ϵ^2, respectively. For simplicity we assume that $\tilde{\theta}$, $\tilde{\eta}$, $\tilde{Z}$, $\tilde{\epsilon}_1, \ldots, \tilde{\epsilon}_m$ are mutually independent.

For notational convenience, define the following conditional moments that describe individual i's posterior beliefs

$$\overline{V}_i \equiv E\left[\tilde{V}|\hat{\theta}_i, P\right]$$
$$\sigma_i^2 \equiv \text{Var}\left[\tilde{V}|\hat{\theta}_i, P\right]$$

where P is the equilibrium price of the risky asset. Given our distributional assumptions, more explicit expressions for these moments are

$$\overline{V}_i = V_o \exp\left\{\bar{\mu}_i + \frac{1}{2}\delta^{-1}\right\}$$
$$\sigma_i^2 = \overline{V}_i^2 \exp\left\{\delta^{-1}\right\} \quad (1)$$

where

$$\delta^{-1} \equiv \text{Var}\left[\tilde{\theta} + \tilde{\eta}|\hat{\theta}_i, P\right]$$
$$\bar{\mu}_i \equiv E\left[\tilde{\theta} + \tilde{\eta}|\hat{\theta}_i, P\right].$$

In contrast to jointly normal variates, *both* the conditional mean and conditional variance of the lognormal variate $\tilde{V}$ depend on the realization of $\tilde{\hat{\theta}}_i$. We assume that agents conjecture that the equilibrium price is a log-linear function of $\tilde{\theta}$ and $\tilde{Z}$, then show that there exists a unique log-linear function for which this conjecture is fulfilled.[2]

Suppose individuals in a large market conjecture that the price function is of the form

$$\tilde{P} = K \exp\left\{B\tilde{\theta} + G\tilde{Z}\right\}$$

where K, B, and G are constants determined in equilibrium. Under this supposition,

$$\delta^{-1} = \text{Var}\left[\tilde{\theta} + \tilde{\eta} \mid \theta + Z + \epsilon_i, B\theta + GZ\right],$$

which is independent of the realizations of the random variables and i, and

$$\begin{aligned}\bar{\mu}_i &= E\left[\tilde{\theta} + \tilde{\eta} \mid \theta + Z + \epsilon_i, B\theta + GZ\right] \\ &= \phi_1 (\theta + Z + \epsilon_i) + \phi_2 (B\theta + GZ) \\ &= (\phi_1 + \phi_2 B)\,\theta + (\phi_1 + \phi_2 G)\,Z + \phi_1 \epsilon_i\end{aligned}$$

where ϕ_1 and ϕ_2 are given by Bayesian updating formulas involving normal variates.

Each individual, i, maximizes the mean-variance utility of his terminal wealth $\tilde{W}_i$

$$U_i(\tilde{W}_i) = \text{E}_i\left[\tilde{W}_i\right] - \frac{\alpha}{2}\text{Var}_i\left[\tilde{W}_i\right] \qquad \text{where} \qquad \tilde{W}_i = x_i(\tilde{V} - P) + w_i,$$

w_i is the value of i's endowment, α is the risk-aversion coefficient, and the expectation and variance are evaluated conditional on i's information, $\hat{\theta}_i$, and the security's price which is taken as given.[3] This implies that agent i's demand for the risky asset is

$$x_i = \frac{\overline{V}_i - P}{\alpha\sigma_i^2}.$$

Equating aggregate supply and aggregate demand yields

$$X = \sum_{i=1}^{m} \frac{\overline{V}_i}{\alpha\sigma_i^2} - P\sum_{i=1}^{m} \frac{1}{\alpha\sigma_i^2}$$

[2] Alternatively, we could assume that the conjectured price is also a function of an arbitrary linear combination of the $\tilde{\epsilon}_i$'s and $\tilde{\eta}$. With this starting point, we can show that the weight on this linear combination in the equilibrium price is zero.

[3] The expression for terminal wealth, $\tilde{W}_i$ is derived from a substitution involving the budget constraint. Terminal wealth is the sum of the payoffs from the portfolio, $x_i\tilde{V} + y_i 1$. The budget constraint requires that the cost of the portfolio does not exceed the value of i's endowment, $x_i P + y_i 1 \leq w_i$. Since utility is monotone in riskless wealth, this constraint is binding at the optimum. Therefore, regarding it as an equality, and using it to substitute for $y_i 1$ in $x_i\tilde{V} + y_i 1$ yields $\tilde{W}_i = x_i(\tilde{V} - P) + w_i$.

or, using (1), the market clearing condition can be restated as

$$\alpha \exp\{\delta^{-1}\}\frac{X}{m} = \frac{1}{m}\sum_{i=1}^{m}\left(\overline{V}_i\right)^{-1} - P\cdot\frac{1}{m}\sum_{i=1}^{m}\left(\overline{V}_i\right)^{-2}.$$

Define the following (almost sure) limits

$$\overline{\mathbf{V}}_1 = \lim_{m\to\infty}\frac{1}{m}\sum_{i=1}^{m}\left(\overline{V}_i\right)^{-1} \qquad \overline{\mathbf{V}}_2 = \lim_{m\to\infty}\frac{1}{m}\sum_{i=1}^{m}\left(\overline{V}_i\right)^{-2} \qquad \mathbf{X} = \lim_{m\to\infty}\frac{X}{m}.$$

If these limits exist, the market clearing price in a large market is[4]

$$P = \left(\frac{\overline{\mathbf{V}}_1}{\overline{\mathbf{V}}_2}\right) - \frac{\alpha \exp\left\{\delta^{-1}\right\}\mathbf{X}}{\overline{\mathbf{V}}_2}. \tag{2}$$

Since we hold aggregate supply, X, fixed as the market grows, $\mathbf{X} = 0$. The other limits are given in Lemma 1.

Lemma 1. *The (almost sure) limits $\overline{\mathbf{V}}_1$ and $\overline{\mathbf{V}}_2$ exist and are given by*

$$\overline{\mathbf{V}}_1 = V_o^{-1}\exp\left\{\frac{1}{2}\left(\phi_1^2\sigma_\epsilon^2 - \delta^{-1}\right)\right\}\exp\left\{-\left(\phi_1 + \phi_2 B\right)\theta - \left(\phi_1 + \phi_2 G\right)Z\right\}$$

$$\overline{\mathbf{V}}_2 = \overline{\mathbf{V}}_1^2\exp\left\{\phi_1^2\sigma_\epsilon^2\right\}.$$

Proof: See Appendix.

Substituting these limits into (2) yields

$$\begin{aligned} P &= \frac{1}{\overline{\mathbf{V}}_1\exp\left\{\phi_1^2\sigma_\epsilon^2\right\}} \\ &= \frac{V_o\exp\left\{\frac{1}{2}\left(\delta^{-1} - \phi_1^2\sigma_\epsilon^2\right)\right\}}{\exp\left\{\phi_1^2\sigma_\epsilon^2\right\}}\exp\left\{\left(\phi_1 + \phi_2 B\right)\theta + \left(\phi_1 + \phi_2 G\right)Z\right\} \end{aligned} \tag{3}$$

which is of the conjectured form with

$$\begin{aligned} K &= V_o\exp\left\{\frac{1}{2}\delta^{-1} - \frac{3}{2}\phi_1^2\sigma_\epsilon^2\right\} \\ B &= \left(\phi_1 + \phi_2 B\right) \qquad G = \left(\phi_1 + \phi_2 G\right). \end{aligned} \tag{4}$$

Tedious calculations involving Bayesian updating formulas show that

$$\phi_1 = 0 \qquad \text{and} \qquad \phi_2 = \frac{\sigma_\theta^2}{G\left(\sigma_\theta^2 + \sigma_z^2\right)}. \tag{5}$$

Solving (4) and (5) yields

$$B = G = \frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_z^2} \qquad \text{and} \qquad \phi_2 = 1.$$

Note that the values of parameters in the conjectured price function are uniquely determined. Proposition 1 is obtained by substituting these values into equation (3).

[4] More precisely, if these limits exist then the REE price converges almost surely to P as $m \to \infty$.

Proposition 1. *In a large market ($m \to \infty$) there exists a rational expectations equilibrium price*

$$\tilde{P} = V_o \exp\left\{\frac{1}{2}\delta^{-1} + \frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_z^2}\left(\tilde{\theta} + \tilde{Z}\right)\right\}$$

that is unique in the log-linear class.

The expression for $\tilde{P}$ is the expectation of $\tilde{V}$ conditional on the average signal. This result highlights the role of the equilibrium price as an aggregator of private information [see also Grossman (1976) and (1978), Hellwig (1980), and Diamond and Verrecchia (1981)].

It will be useful to have an expression for the equilibrium price that results from trading when agents do not possess private information. This price can be obtained by solving for the market clearing price that results from individuals' optimization with beliefs conditioned only on the price, then taking the limit as $m \to \infty$; or by taking the limit of $\tilde{P}$ as $\sigma_z \to \infty$. Noting that $\delta^{-1} \to (\sigma_\theta^2 + \sigma_\eta^2)$ as $\sigma_z^2 \to \infty$ yields the expression in Proposition 2.

Proposition 2. *In the absence of private information the market clearing price of the risky asset in a large market ($m \to \infty$) is*

$$\tilde{P}_o = V_o \exp\left\{\frac{1}{2}\left(\sigma_\theta^2 + \sigma_\eta^2\right)\right\}.$$

2.2 Market Attributes

Consider three points in time relative to the release of private information. Time 0 is prior to agents observing their private information, time T is the date upon which the security's payoff is realized (or the component of the payoff related to private information is realized), and time t is any time between time 0 and time T. The market clearing prices at time 0 and time t correspond to $\tilde{P}_o$ and $\tilde{P}$ in the context of the model. The price at T corresponds to $\tilde{V}$ in the context of the model. We define the continuously compounded returns over the sub-periods $(0, t)$ and (t, T), and the return over the entire period $(0, T)$, as follows

$$\tilde{r}_{o,t} \equiv \ln\left(\tilde{P}/\tilde{P}_o\right)$$
$$\tilde{r}_{t,T} \equiv \ln\left(\tilde{V}/\tilde{P}\right)$$
$$\tilde{R}_T \equiv \ln\left(\tilde{V}/\tilde{P}_o\right).$$

The returns $\tilde{r}_{o,t}$ and $\tilde{r}_{t,T}$ apply to the first and second (non-overlapping) sub-periods. The return $\tilde{R}_T$ is realized over the entire period. We often refer to $\tilde{r}_{o,t}$ as the short-horizon return, and to $\tilde{R}_T$ as the long-horizon return, associated with the information $\tilde{\hat{\theta}}$.

Assume, for the moment, that $\sigma_z = 0$. In this case, (ignoring additive constants) one can show that

$$\tilde{r}_{o,t} = \tilde{\theta} \tag{6}$$

$$\tilde{r}_{t,T} = \tilde{\eta} \tag{7}$$

$$\tilde{R}_T = \tilde{\theta} + \tilde{\eta}. \tag{8}$$

The third equation holds by assumption. The first two equations, however, are implications of the maximizing behavior posited by the model, and capture the main prediction of pricing in a rational expectations equilibrium: The information that agents have, and only that information, is reflected in the market clearing price. The alternatives to this implication are that $\tilde{r}_{o,t}$ or $\tilde{r}_{t,T}$ are constants, $\tilde{r}_{o,t}$ depends on $\tilde{\eta}$, or $\tilde{r}_{t,T}$ depends on $\tilde{\theta}$. Each of these alternatives is inconsistent with the, hypothesis that prices reflect value-relevant information, and only the information, that agents possess at the time the price prevails.

Define the quality of information as $Q \equiv \frac{\sigma_\theta^2}{\sigma_\theta^2+\sigma_z^2}$, the importance of information as $I \equiv \frac{\sigma_\theta^2}{\sigma_\theta^2+\sigma_\eta^2}$, and price informativeness, Δ, as the *squared* correlation between $\tilde{r}_{o,t}$ and $\tilde{R}_T$.[5] The quality of information measures the proportion of variation in the average signal that is due to value-relevant information. The importance of information measures the proportion of the eventual price change that is associated with the information. Price informativeness measures the correlation between the eventual price change associated with the information and the price change that occurs based on agents' private information. Since we have (momentarily) assumed that $\sigma_z^2 = 0$, the quality of information is unity. Using (6), (7) and (8), we see that the model implies

$$\Delta = \frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_\eta^2} = I. \tag{11}$$

The interpretation of this is that the larger the eventual impact an event will have on the security price relative to other factors, the more complete will be the price reaction based on agents' having private information about the event. When information is of the highest quality (as when $\sigma_z^2 = 0$), the completeness of the price reaction is determined entirely by the importance of information.

[5]See Diamond and Verrecchia (1981), Grossman and Stiglitz (1980), and Verrecchia (1982) for similar definitions.

Now we relax our assumption that $\sigma_z = 0$. In this case, (again ignoring additive constants) one can show that

$$\tilde{r}_{o,t} = \left(\frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_z^2}\right)(\tilde{\theta} + \tilde{Z}) \tag{10}$$

$$\tilde{r}_{t,T} = \left(\frac{\sigma_z^2}{\sigma_\theta^2 + \sigma_z^2}\right)\tilde{\theta} + \tilde{\eta} - \left(\frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_z^2}\right)\tilde{Z} \tag{11}$$

$$\tilde{R}_T = \tilde{\theta} + \tilde{\eta}. \tag{12}$$

Using these expressions, one can show that

$$\Delta = Q \cdot I. \tag{13}$$

Holding Q constant, the interpretation of (13) is similar to the interpretation of (9). The difference is that the completeness of the initial price response is determined by both the importance and the quality of agents' private information. The quality indicates the extent to which the average private signal is value-relevant. When $\sigma_z = 0$, all of the variation in the private signal is value-relevant; when $\sigma_z > 0$, only a proportion, Q, of the variation in the private signal is value-relevant.

So far, the theory predicts that the relation between Δ and I are proportional, and that the proportionality constant can be interpreted as the quality of private information possessed by agents prior to its being publicly revealed. It turns out that this relationship is modified slightly if returns are affected by "noise" in the market. To see this, suppose that returns have an additive noise component—perhaps due to liquidity-motivated trading or market frictions. Then, instead of (10), (11) and (12), we have

$$\tilde{r}_{o,t} = \left(\frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_z^2}\right)(\tilde{\theta} + \tilde{Z}) + \tilde{\xi}_1$$

$$\tilde{r}_{t,T} = \left(\frac{\sigma_z^2}{\sigma_\theta^2 + \sigma_z^2}\right)\tilde{\theta} + \tilde{\eta} - \left(\frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_z^2}\right)\tilde{Z} + \tilde{\xi}_2$$

$$\tilde{R}_T = \tilde{\theta} + \tilde{\eta} + \tilde{\xi}_1 + \tilde{\xi}_2.$$

where $\tilde{\xi}_1$ and $\tilde{\xi}_2$ are i.i.d. random variables that capture variation due to noise. We define the importance of information in this context as

$$I_\theta \equiv \frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_\eta^2 + 2\sigma_\xi^2}$$

where $\sigma_\xi^2 = \text{Var}\left[\tilde{\xi}_1\right] = \text{Var}\left[\tilde{\xi}_2\right]$. Using these expressions, one can show that

$$\Delta = I_\xi + QI_\theta. \tag{14}$$

where $I_\xi = \frac{\sigma_\xi^2}{\sigma_\theta^2+\sigma_\eta^2+2\sigma_\xi^2}$. By analogy with the definition of the importance of information, we call I_ξ the importance of noise. Thus, in the context of the model, the informativeness of the equilibrium price is a linear function of the importance of information where the intercept is the importance of noise and the slope is the quality of information.

2.3 Empirical Implementation

The remainder of the paper focuses on estimating Δ and I_θ and developing an empirical test of equation (14). We illustrate the procedure in the context of trades made by insiders in the common stock of their own firms by regarding insiders' trades as a reflection of value-relevant information, $\tilde{\theta}$. This context is convenient for our tests for two reasons. First, we can identify when the information becomes available. Second, individual investors can obtain private information about insiders' trades in advance of the trades being publicly disclosed.

To test the restriction imposed by (14), we relate cross-sectional variation in Δ to cross-sectional variation in I_θ. Since Q is defined as the quality of the average private signal, it is fair to assume that Q is constant across insider trades because each insider trade involves the same kind of information (sign of trade, size of trade, etc.). Furthermore, all such trades are reported and processed within a uniform disclosure mechanism. Consequently, at a given point in time relative to an insider's trade, the quality of private information possessed by outsiders should not be firm-specific. By contrast, we would expect the importance of information to have a firm-specific value. This is because the importance of information measures the association between insider trading and long-horizon returns, and earlier studies have shown that insiders' profits are systematically related to firm specific attributes [see, for example, Seyhun (1986)].

We use the R-square from a regression of R_T on θ for each firm as an estimate of I_θ. This is because

$$R\text{-square} \equiv \frac{\text{SSR}}{\text{SST}} = \frac{\text{SST - SSE}}{\text{SST}} = \frac{\text{Var}\left[\tilde{R}_T\right] - \text{Var}\left[\tilde{R}_T|\theta\right]}{\text{Var}\left[\tilde{R}_T\right]} = \frac{\sigma_\theta^2}{\sigma_\theta^2+\sigma_\eta^2+2\sigma_\xi^2} \equiv I_\theta$$

where the second-to-last equality is implied by the model. In our context, θ is a vector of variables capturing the information contained in insider trades (sign, size, etc.); and $\tilde{R}_T$ represents the return over a period starting with an insider trade (time 0) and ending at some future date (time T). To obtain this R-square for each firm, we regress a time series of returns on a vector of variables that describes the insider trade associated each return.

To estimate Δ for each firm, we compute the sample correlation between the short-horizon $(0, t)$ returns and the long-horizon $(0, T)$ returns from a time series of paired short- and long-horizon returns corresponding to periods in which there is insider trading activity.

It is important to emphasize that the R-square and squared sample correlation do not have the mathematical relationship specified in (14) independent of the model. This relation arises as a consequence of the maximizing behavior the model describes. Observe that the R-square measures the strength of the association between insider trading and long-horizon returns. By contrast, the correlation measures the similarity between short-horizon and long-horizon returns. Independent of the model, the strength of this similarity need not depend on the association between insider trading and long-horizon returns. The content of the model is that if agents have private information about insider trading during the first sub-period, and if they behave optimally (i.e., in accordance with the model) the similarity between short-horizon and long-horizon price changes following insider trading is stronger, the stronger is the association between insider trading and long-horizon returns.

A refinement of our arguments is relevant for the empirical tests. We might regard the relation in (14) as dependent upon the endpoint of the short-horizon returns

$$\Delta_t = I_\xi + Q_t I_\theta$$

holding time 0 and time T fixed. The larger is t, the more time has passed since the insider's trade. The association between long-horizon returns and insider trading, I_θ, or the effect of noise on returns, I_ξ, are not affected by the choice of t, but the quality of the average private signal, Q_t, is likely to be affected by such a choice.[6] If the quality of private information about insider trades declines (increases) as time passes after the trades' execution then the model predicts that slope estimates are smaller (greater) when estimated using a larger value for t. Consequently, for each T we use, we replicate our tests using different choices of t.

3. Empirical Tests

3.1 Data

The insider trading data used on this study come from a tape prepared by the Securities and Exchange Commission. The data set contains insiders' transactions in all public firms from 1975 to 1989. Included in the data set are insider's name, relation to the firm, date

[6] Q_t should still be cross-sectionally constant, however, for the same reason as discussed above.

of trade, date of reporting, date of publication, price of securities traded, and number of shares traded. This study uses only the open market sales and purchases by insiders, as these are the most informative transactions. Monthly stock returns come from the tapes of the Center for Research in Security Prices of the University of Chicago.

Table I shows the distribution of insiders' transactions from 1975 to 1989. In each year, there are more than 10,000 buy and sell transactions. The number of firms trading in a calendar year ranges from approximately 2900 to 4500. On average, the number of sales and the number of shares sold by insiders exceed the corresponding purchase activity. Insiders in most firms receive stock options as part of their compensation and sell these shares which accounts for the higher insider selling. Table 1 shows that neither the number of firms nor the number of transactions show a strong trend between 1975 and 1989. However, insiders do trade increasing numbers of shares per transaction over this period.

To measure the information content of insider trading in firm i in month t, we use three variables: i) the net number of transactions by insiders, denoted as $NET_{i,t}$; ii) the net number of shares traded by insiders, denoted as $NS_{i,t}$ and iii) the direction of insiders' transactions, denoted as $DIRECTION_{i,t}$. These insider trading variables are defined as follows:

$$NET_{i,t} = \sum_{j=1}^{N_{i,t}} H_{j,i,t} \tag{1}$$

where $N_{i,t}$ denotes the total number of transactions in firm i in month t, and the variable $H_{j,i,t}$ equals 1 if transaction j in firm i in month t is a purchase, and -1 if a sale. $DIRECTION_{i,t}$ equals 1 if $NET_{i,t}$ is positive and -1 if $NET_{i,t}$ is negative. The net number of shares traded, $NS_{i,t}$ is computed as in (1) except that $H_{j,i,t}$ is first multiplied by the number of shares traded in transaction j. Since the information content of insiders' information is not expected to increase linearly with the number of shares traded, we take the natural logarithm of NS, while preserving the sign for sales and purchases. All three measures of insider trading equal zero for those months when there are no transactions by insiders.

3.2 Importance of Information and Price Informativeness

Importance of insider trading information is measured over three holding periods, 2, 4, and 6 months. For each firm from 1975-1989, we compute holding period returns over nonoverlapping 2-, 4-, and 6-month periods. Figure 1 shows our measurement convention time line for all three horizons.

To illustrate the measurement of these variables, consider the case of 4-month holding periods from Figure 1.

We examine the first two months for insider trading activity; the net number of transactions and net number of shares traded over the two month interval is computed by summing insider trading activity in months one and two. Next, we compute the holding period return over the subsequent 4 months. We then move forward 4-months, and repeat the procedure until the end of 1989. This procedure ensures that observations of the dependent variable in our regressions are measured from non-overlapping intervals. For a firm to be included in our sample, we require that there be at least five periods over which there is non-zero insider trading activity.[7]

Table II summarizes the results of the regressions for estimating the importance of insider trading information for each firm. To estimate the importance of information, we regress the holding period returns on our three insider trading variables across periods of insider trading on a firm-by-firm basis,

$$R_T = a_o + a_1 \; DIRECTION + a_2 \; NET + a_3 \; SG \ln(1 + |NS|)$$

where R_T is the T-month holding period return, and SG is the sign of NS, the net number of shares traded by insiders. The vertical bars around NS denote absolute value. Note that the sign of NS is preserved because SG is defined as -1 when the net number of shares traded is negative and +1 when the net number of shares traded is positive. The holding period, T, takes on the values 2, 4, and 6. There are 3,772, 3,580 and 2,457 firms that meet the data availability requirements for the three holding periods, respectively.

The results of the regressions are shown in Table II. For all three holding periods, the average coefficient estimates on NET and NS are positive. For the 2-month holding period,

[7] We also require that there be a certain amount of monthly returns data available on CRSP. For a firm to be used for the 2-month holding period tests, it must have a minimum of 40 sets of 2-month returns, not necessarily consecutive. For a firm to be used for the 4-month (6-month) holding period tests, it must have a minimum of 20 sets of 4-month (6-month) returns, not necessarily consecutive.

the regression coefficients are not significant due to large standard errors of the estimates. The regression coefficients for the 4-month and 6-month holding periods are statistically significant. Furthermore, the net number of shares traded by insiders becomes more significant as an explanatory variable as the holding period increases from 2 months to 6 months. After taking into account net number of transactions and the net number of shares traded, the direction of insiders' trading activity (buy or sell) is rendered insignificant.

The estimates in Table II enable an assessment of the economic significance of insider trading activity for subsequent stock returns. Holding all else constant, a 1,000 share purchase by insiders is associated with a 3.3 percent increase in stock prices over a 4-month horizon (a coefficient estimate of 0.0048 times ln (1001) which is 6.9) and a 5.2 percent increase in stock prices over a 6-month horizon (0.0075 times 6.9). Hence, stock prices movements are directly related to past insider trading activity. Stock prices tend to rise following insiders' purchases and fall following insiders' sales, thereby giving rise to the positive regression coefficients. The degree to which stock prices eventually respond to insider trading activity, as measured by the R-square from this regression, is our measure of the importance of insider trading information.

Table II also shows that insider trading activity (including periods of no insider transactions) over 180 months explains a significant proportion of the variation in subsequent stock returns on a *firm-by-firm* basis. For the 2-month horizon, the mean R-square of the regressions equals 4.6 percent. The mean R-square increases to 9.3 percent and 11.7 percent for the 4-month and 6-month horizons, respectively.

Our theoretical results suggest measuring price informativeness, or equivalently the degree of information efficiency, as the correlation coefficient between early stock returns and the eventual stock returns following a period of insider trading. Hence, for a 4-month holding period, the degree of information efficiency, $DELTA_2$, is measured as the correlation coefficient between the 2-month and 4-month holding period returns following an insider trading period.[8] Additional measures of information efficiency are computed for all intermediate points up to T months. For the 4-month holding period, the correlations between the 1-month and 4-month holding period returns following an insider trading period is denoted as $DELTA_1$, and correlations between the 3-month and 4-month holding period returns is denoted as $DELTA_3$. A particular firm's stock price is characterized as more informative, or informationally efficient, if more of the return following insider trad-

[8] In terms of Figure 1, $DELTA_2$ is the correlation between the return over months three and four, and the return over months three through six.

ing activity occurs sooner rather than later. At one extreme, if prices respond fully and instantaneously to insider trading activity (a step function), then the correlation coefficient (or *DELTA*) will equal one. Conversely, if the initial return following insider trading activity is consistently in the wrong direction, compared to the eventual return, then the correlation coefficient will be negative. Thus, DELTA_t is a speed-of-adjustment index because it measures the average similarity between short-term price changes following insider trading activity and the eventual price change associated with such activity.

Table III shows the distribution of estimated values of $\mathit{IMPORTANCE}_T$, for $T = 2$, 4, and 6-month holding periods, and DELTA_1, DELTA_2, and DELTA_3 for the mid-points of the holding periods. The DELTA_t variables exhibit a large amount of variation, from negative values to 0.99. The mean value of *DELTA* is between 0.62 and 0.68. The estimated values of $\mathit{IMPORTANCE}_T$ also exhibit a large amoung of variation. The values range from a minimum of 0.000 to a maximum of 0.472, 0.666, and 0.645 for the three horizons, respectively. The mean values of *IMPORTANCE* are 0.046, 0.093, and 0.117 for three horizons, respectively. Hence, insider trading activity is able to explain a nontrivial proportion of the variation in stock returns on a firm-by-firm basis.

The central prediction of our theory is that the degree of information efficiency, *DELTA*, is positively related to the importance of information. Table IV shows results from regressions of *DELTA* on *IMPORTANCE* and the natural log of firm size, where size is measured as the average value of equity between 1975 and 1989. Since we use estimated values of *IMPORTANCE*, the regression of *DELTA* on *IMPORTANCE* is subject to an errors-in-variables problem which would cause the slope coefficient to be biased toward zero. To mitigate the errors-in-variables problem, we group all observations into 100 groups based on decile ranks of *IMPORTANCE* and *Size* and run the regression using within-group means.

The first two models in Table IV examine a 2-month horizon and 1-month intermediate point. There is a strong positive relation between *IMPORTANCE* of information and *DELTA*, our measure of the degree of information efficiency. The regression coefficient estimate equals 0.323 with a t-statistic of 3.74, which is significant at the one percent level. Inclusion of firm size as an additional explanatory variable does not affect the relation between *IMPORTANCE* and *DELTA*. These results are consistent with our theory. More important information is reflected earlier in stock prices.

The next group of regressions in Table IV examines the relation between *IMPORTANCE*, measured over a 4-month horizon, and degree of information efficiency for intermediate points of 1, 2, and 3 months. Once again, there is a strong positive relation between *IMPORTANCE* and *DELTA* for all intermediate points. These results our consistent with the predictions of our theory. As before, including the firm size variable does not affect the relation between *IMPORTANCE* and *DELTA*.

The final group of regressions in Table IV examines *IMPORTANCE* measured over a 6-month horizon and *DELTA* for intermediate points of 1 to 5 months. The relation between *IMPORTANCE* and *DELTA* is significantly positive for intermediate points beyond two months. These results are consistent with the theory. They indicate that insider trading activity that is more strongly related to six-month returns is reflected more clearly in price changes that occur by the third, fourth and fifth month following the insider trading activity. When the intermediate point is defined as one or two months, however, there appears to be no relation between the importance of information and correlation between one or two-month stock returns and six-month stock returns. This indicates that the components of six-month stock returns that are more strongly related to insider trading are not, on average, realized within one or two months following the insider trading activity. Instead, whether 6-month price changes following insider trading activity are reflected in one or two-month price changes appears to be unrelated to the strength of the association between insider trading activity and 6-month returns. In the context of the model, the interpretation of these findings is that prices take longer to reflect the information content of insider trading activity that is undertaken in response to expected long-run stock price changes.

***THE STATEMENTS IN THIS PARAGRAPH ARE SENSITIVE TO SPECIFICATION. NOT HAVING USED SQUARED CORRELATIONS MAY AFFECT THESE CONCLUSIONS. Additional observations regarding the relation between *DELTA* and *IMPORTANCE* can be made from Table IV. Our theoretical results suggest that the coefficient estimates of *IMPORTANCE* can be interpreted as the quality of information. As time passes following insider trading, the effects of unrelated factors tend to cancel out and the effects of insider trading stand out to a greater extent. Consistent with this prediction, Table IV shows that for a given horizon, the strength of the relation between *IMPORTANCE* and Δ increases as we increase the intermediate point. For the 4-month holding period, the R-square of the relation between Δ and *IMPORTANCE* increases from 15.4 percent to 15.8 percent and 26.0 percent, for 1-, 2- and 3-month early observation periods, respectively. Similar increases in R-square are observed for the 6-month holding period. ***

We have also estimated these coefficients under the requirement of a minimum of ten periods with non-zero insider trading activity. Similar results were obtained, although the number of firms meeting the data requirements decline by about 40 percent for the 6-month holding period.

While not shown here, additional tests examine the sensitivity of our results to methodological choices. Instead of using raw stock returns, we have also used market model residuals. We find similar results with market model residuals. Hence, the results are not sensitive to insiders' ability to predict firm-specific returns or total returns.

APPENDIX

Proof of Lemma 1: By definition, $\overline{\mathbf{V}}_1$ is the limit of

$$\overline{\mathbf{V}}_1(m) = \frac{1}{m}\sum_{i=1}^{m} V_o^{-1} \exp\left\{-\overline{\mu}_i - \frac{1}{2}\delta^{-1}\right\}$$
$$= V_o^{-1}\frac{1}{m}\sum_{i=1}^{m}\exp\left\{-\frac{1}{2}\delta^{-1} - (\phi_1+\phi_2 B)\theta - (\phi_1+\phi_2 G)Z - \phi_1\epsilon_i\right\}$$
$$= V_o^{-1}\exp\left\{-\frac{1}{2}\delta^{-1} - (\phi_1+\phi_2 B)\theta - (\phi_1+\phi_2 G)Z\right\}\frac{1}{m}\sum_{i=1}^{m}\exp\{-\phi_1\epsilon_i\}$$

By the law of large numbers, the almost sure limit of $\frac{1}{m}\sum_{i=1}^{m}\exp\{-\phi_1\epsilon_i\}$ as $m \to \infty$, is $\exp\left\{\frac{\phi_1^2}{2}\sigma_\epsilon^2\right\}$. Therefore,

$$\overline{\mathbf{V}}_1 = V_o^{-1}\exp\{-(\phi_1+\phi_2 B)\theta - (\phi_1+\phi_2 G)Z\}\exp\left\{-\frac{1}{2}\delta^{-1} + \frac{\phi_1^2}{2}\sigma_\epsilon^2\right\}.$$

Similar reasoning implies that

$$\overline{\mathbf{V}}_2 = V_o^{-2}\exp\{-2(\phi_1+\phi_2 B)\theta - 2(\phi_1+\phi_2 G)Z\}\exp\left\{-\delta^{-1} + \frac{4\phi_1^2}{2}\sigma_\epsilon^2\right\}$$
$$= \overline{\mathbf{V}}_1^2\exp\left\{\phi_1^2\sigma_\epsilon^2\right\}$$

as desired. ||

REFERENCES

Admati, A., 1985, "A Noisy Rational Expectations Equilibrium for Multi-Asset Securities Markets," *Econometrica*, 53, ?? - ??.

Bhattacharya, S. and P. Pfleiderer, 1985, "Delegated Portfolio Management," *Journal of Economic Theory*, ??, ?? - ??.

Danthine, J., 1978, "Information, Futures Prices, and Stablizing Speculation," *Journal of Economic Theory*, 17, ?? - ??.

Diamond, D. & Verrecchia, R., 1981, "Information Aggregation in a Noisy Rational Expectations Economy," *Journal of Financial Economics*, 9, ?? - ??.

Grossman, S., 1976, "On the Efficiency of Competitive Stock Markets When Traders Have Diverse Information," *Journal of Finance*, ??, ?? - ??.

Grossman, S., 1978, "Further Results on the Informational Efficiency of Competitive Stock Markets," *Journal of Economic Theory*, 18, ?? - ??.

Grossman, S. & Stiglitz, J., 1980, "On the Impossibility of Informationally Efficient Markets," *The American Economic Review*, ??, ?? - ??.

Hellwig, M., 1980, "On the Aggregation of Information in Competitive Markets," *Journal of Economic Theory*, 22, ?? - ??.

Huberman, G. and G. Schwert, 1985, "Information Aggregation, Inflation, and the Pricing of Indexed Bonds," *Journal of Political Economy*, 93, 92 - 114.

Kandel, S., A. Ofer and O. Sarig, 1991, "Learning From Trading," Working Paper, Tel-Aviv University.

Plott, C. and S. Sunder, 1982, "Efficiency of Experimental Security Markets with Insider Information: An Application of Rational Expectations Models," *Journal of Political Economy*, 90, 663-698.

Seyhun, H.N., 1986, "Insiders' Profits, Costs of Trading, and Market Efficiency," *Journal of Financial Economics*, 16, ?? - ??.

Sunder, S., 1990, "Market for Information: Experimental Evidence," Working Paper, Carnegie-Mellon University.

Verrecchia, R., 1982, "Information Acquisition in a Noisy Rational Expectations Economy," *Econometrica*, 50, ?? - ??.

TABLE I
Sample Characteristics of Insider Trading Activity from 1975 - 1989

Year	Number of Firms	Number of Purchases	Number of Sales	Number of Shares Purchased	Number of Shares Sold
1975	3,042	16,346	12,883	43.9	36.0
1976	3,012	15,520	14,089	54.7	48.5
1977	2,899	14,248	11,689	47.2	48.9
1978	2,884	14,313	12,249	62.2	47.4
1979	2,828	15,192	13,993	79.8	67.7
1980	2,909	17,737	21,827	176.1	166.2
1981	2,962	16,254	17,897	113.6	109.5
1982	3,010	15,424	19,896	117.7	184.4
1983	3,204	10,508	24,394	126.2	293.0
1984	3,336	15,106	15,920	222.8	332.2
1985	3,322	11,115	20,526	132.2	381.7
1986	3,218	10,898	22,219	123.8	419.1
1987	3,104	12,239	12,148	125.5	207.6
1988	3,930	15,807	14,939	212.4	278.3
1989	4,474	21,767	23,388	494.3	760.1

Insider trading activity for each firm each month is defined as the net transaction (across insiders) in each firm each month. The annual statistics are based on these monthly figures. The number of shares purchased and sold are in millions.

TABLE II
Estimation of the Importance of Information

$$R_T = a_o + a_1\ DIRECTION + a_2\ NET + a_3\ SG\ \ln(1 + |NS|)$$

T	a_o	a_1	a_2	a_3	Number of Firms	Mean R-square
2	0.037 (90.9)	-0.034 (-0.75)	0.0018 (1.29)	0.0049 (1.09)	3,772	0.046
4	0.079 (79.1)	-0.0167 (-1.27)	0.0032 (1.97)	0.0048 (2.91)	3,580	0.093
6	0.120 (70.9)	-0.0256 (-1.75)	0.0020 (1.05)	0.0075 (3.79)	2,457	0.117

The regression is estimated separately for each firm. The variable R_T is the T-month holding period return. *NET* denotes the net number of transactions by insiders and *NS* is the number of shares traded by insiders (vertical bars around *NS* denote absolute value). The variable *SG* is the sign of *NS*. *DIRECTION* takes the value of 1 if $NET > 0$, -1 if $NET < 0$, and zero otherwise. The coefficients reported in the table are cross-sectional averages of the coefficient estimates from the firm-by-firm regressions. The t-statistics in parenthases are computed using the cross-sectional distribution of coefficient estimates. The importance of insider trading information for each firm is the R-square from its regression.

TABLE III
Cross-Sectional Distribution of Estimated Values of Price Informativeness and Importance of Information for 2, 4, and 6 Month Horizons

	$DELTA_1$	$IMPORTANCE_2$	$DELTA_2$	$IMPORTANCE_4$	$DELTA_3$	$IMPORTANCE_6$
Minimum	- 0.97	0.000	- 0.90	0.000	-0.98	0.000
1%	-0.15	0.001	- 0.24	0.003	-0.12	0.005
5%	0.28	0.004	0.17	0.009	0.26	0.014
10%	0.44	0.007	0.34	0.016	0.42	0.023
25%	0.60	0.016	0.50	0.035	0.58	0.046
50%	0.72	0.033	0.66	0.069	0.71	0.091
75%	0.81	0.060	0.78	0.127	0.80	0.158
90%	0.88	0.099	0.88	0.197	0.88	0.243
95%	0.92	0.135	0.93	0.252	0.92	0.323
99%	0.98	0.225	0.98	0.389	0.96	0.450
Maximum	0.99	0.472	0.99	0.666	0.99	0.645
Mean	0.68	0.046	0.62	0.093	0.67	0.117

$IMPORTANCE_T$ denotes the R-square of the regression of T-month stock returns on a vector of insider trading variables. $DELTA_t$ denotes the correlation coefficient between t-month stock returns and T-month stock returns.

TABLE ~~IV~~ V

Cross-Sectional Regression of Price Informativeness on the Importance of Information and Firm Size

$$\text{~~DELTA~~ CORR}_t = a_o + a_1 \; IMPORTANCE_T + a_2 \; \ln(Size)$$

(t, T)	a_o	a_1	a_2	Adj. R-square
(1, 2)	0.662 (122.4)	0.323 (3.74)		0.116
(1, 2)	0.617 (25.6)	0.339 (3.96)	0.004 (1.91)	0.139

(t, T)	a_o	a_1	a_2	Adj. R-square
(1, 4)	0.413 (48.3)	0.308 (4.35)		0.154
(1, 4)	0.567 (16.9)	0.290 (4.51)	-0.014 (-4.70)	0.303
(2, 4)	0.597 (86.5)	0.252 (4.42)		0.158
(2, 4)	0.667 (22.9)	0.244 (4.38)	-0.006 (-2.48)	0.200
(3, 4)	0.792 (196.7)	0.199 (5.98)		0.260
(3, 4)	0.793 (45.2)	0.199 (5.94)	-0.000 (-0.07)	0.253

(t, T)	a_o	a_1	a_2	Adj. R-square
(1, 6)	0.489 (44.9)	-0.019 (-0.26)		-0.010
(1, 6)	0.218 (6.0)	-0.006 (-0.10)	0.023 (7.63)	0.363
(2, 6)	0.579 (63.0)	0.053 (0.87)		-0.003
(2, 6)	0.460 (12.5)	0.059 (1.01)	0.010 (3.35)	0.092
(3, 6)	0.652 (86.6)	0.118 (2.35)		0.044
(3, 6)	0.566 (18.5)	0.122 (2.52)	0.007 (2.91)	0.111
(4, 6)	0.786 (134.4)	0.092 (2.37)		0.045
(4, 6)	0.706 (30.3)	0.096 (2.61)	0.007 (3.55)	0.146
(5, 6)	0.889 (242.4)	0.075 (3.08)		0.079
(5, 6)	0.847 (56.9)	0.077 (3.27)	0.004 (2.90)	0.144

$IMPORTANCE_T$ denotes the R-square of the regression of T-month stock returns on a vector of insider trading variables. ~~DELTA~~ CORR$_t$ denotes the correlation coefficient between t-month stock returns and T-month stock returns. For each firm, $Size$ is the average year end market value of equity. t-statistics are in parentheses.