Price Reactions to Public Announcements

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Abstract: We employ a parametric rational expectations equilibrium model to study the impact of public information releases on private information acquisition and asset prices in a large economy. We demonstrate that investors treat public information as a substitute for privately acquired information. Their attempts to substitute public for private information can amplify or even reverse the effect of public information releases on price volatility. The direction of the resulting change in price volatility is dependent on the level of public information regarding asset payoffs, the variance of asset payoffs, and the extent of supply shocks, implying that firms may differ in their optimal information release policies.

JEL classification: G12, G14

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PRICE REACTIONS TO PUBLIC ANNOUNCEMENTS

1. INTRODUCTION

There is a long history of research into the effects of public announcements on security prices [see, e.g., Ball and Brown (1968), Kaplan and Roll (1972), and Mandelker (1974)]. Many earlier studies were motivated by the desire to document the impact of corporate decisions on share price and firm value. A number of subsequent studies, however, have been devoted to documenting trading behavior around public announcements [see, e.g., Patell and Wolfson (1984), Harvey and Huang (1991), Ederington and Lee (1993)]. The evidence compiled by these researchers indicates that market activity increases significantly after the release of new information [see, e.g., Mitchell and Mulherin (1994)]. However, the impact of information releases on trading activity varies across securities [see, e.g., Lee, Ready, and Seguin (1994)].

Parametric rational expectations models provide an ideal setting for examining the impact of information acquisition and public information releases on asset prices and trading activity. Consequently, a number of researchers have employed the rational expectations paradigm to examine linkages between asset and information markets. For example, Verrecchia (1982) shows that, if asset prices are not fully revealing, investors have an incentive to purchase costly private information, and the quality of the information they purchase is inversely related to their degree of risk aversion. Diamond (1984) shows that the public release of information by firms is socially desirable since it results in improved risk sharing as well as cost savings arising from the substitution by investors of free public information for costly private information. More recently, Kim and Verrecchia (1991a, 1991b) establish that, when investors can trade in *anticipation* of public information releases, price changes induced by the releases are increasing in the quality of the releases and decreasing in the quality of the information available prior to the releases.[1]

In this paper, we examine the impact of public information releases on information acquisition activity and the distribution of asset prices when investors trade only *after* the information is released, as is likely to be the case with unanticipated trading halts and information releases after the close of trade. We consider an economy that has a risky asset whose supply is noisy, and a riskless asset (numeraire) in zero net supply. Private information acquisition is costly, with the cost of private information being increasing and convex in information quality.[2] Within this framework, we establish the existence of a rational expectations equilibrium in the economy, and characterize investors' information acquisition decisions. We also provide insights into the relationship between asset prices, the quality of publicly available information, private information gathering activity, and the level of uncertainty regarding asset payoffs.

We show that improvements in the quality of public information, despite the substitution of public for private information by investors, lead to *decreased* uncertainty regarding asset payoffs. As a consequence of this decreased uncertainty, asset prices tend to increase. While the impact of changes in the precision of the public signal on private information gathering activity, uncertainty regarding asset payoffs, and price levels is unambiguous, the same cannot be said about the reaction of price volatility. As the precision of the public signal increases, asset prices become less

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[1] For other research applying the parametric rational expectations framework to asset pricing see Admati (1985), Admati and Pfleiderer (1986), Diamond and Verrecchia (1981), and Holthausen and Verrecchia (1988, 1990).

[2] By allowing for a public signal, our model generalizes that of Admati and Pfleiderer (1987), and Verrecchia (1982), who also model costly private information acquisition. By allowing for correlation between the public and private signals, heterogeneous investors, and a continuum of signals, we extend the work of Bushman (1989) and Diamond (1984). Finally, by endogenizing private information acquisition in an economy with an arbitrary covariance structure between the public and private signals, we extend the results of Lundholm (1988) and Alles and Lundholm (1990).

sensitive to supply shocks. This tends to decrease price volatility. However, the increased precision of investor information makes asset demands more sensitive to realizations of the public signal. This tends to increase price volatility. When supply noise and *ex ante* asset payoff variance are relatively high, the first effect dominates. Consequently, increases in public signal precision result in decreased price volatility. Low public information precision also results in similar price responses. However, when supply noise and asset payoff variance are relatively low, or the quality of public information is relatively high, the second effect dominates, and increases in the public signal precision result in increased price volatility.

Further insights into the role of private information acquisition on price volatility are obtained by contrasting the economy defined above with one in which investors' private signals are treated as endowments.[3] This is achieved by decomposing the impact of changes in the public signal quality on price volatility into two components. The first measures the reaction of price volatility solely to changes in the quality of the public information, while the second component measures the impact of changes in investor information acquisition decisions on price variability. The second component can either amplify or reverse the impact of the first component. It reinforces the first component for some levels of supply noise. This results in larger reductions in price volatility than would be observed if private signals were exogenously specified. For intermediate levels of asset payoff variance or intermediate levels of public information quality, the second component reverses the effect of the first component. This also results in lower price volatility, an effect opposite to that which would obtain if private signals were exogenously specified. The latter result demonstrates that the predictions derived from models where private information is treated as an endowment can differ substantially from those derived from models where information acquisition is endogenous. Therefore, policy prescriptions regarding the release of information by

[3] For a characterization of asset prices and allocations in an economy with exogenously specified private information signals, see Lundholm (1988) and Alles and Lundholm (1990).

firms, treating private information as an endowment, may result in consequences opposite to those desired.

Our results regarding the impact of public information releases on price volatility have other policy implications as well. Typically, firms acting in their shareholders' interests take actions to ensure higher share price and/or lower price volatility.[4] Our results indicate that policy prescriptions may differ for firms based on the level of publicly available information regarding them, the variance of their cash flows, and the amount of noise in the supply of their securities. Firms regarding which there is little publicly available information and firms whose shares are more susceptible to supply shocks should release more precise information to jointly achieve the objectives of higher prices and lower price volatility. There is likely to be less public information available regarding firms with a smaller analyst following and firms with diffused ownership, because incentives to acquire information regarding firms are attenuated by the diffusion of ownership. Supply shocks are likely to be large for firms whose shares are traded by investors straddling segmented markets, as market segmentation results in increased uncertainty regarding asset supplies [see, e.g., Amershi and Ramamurtie (1991)]. Our results also predict that firms with relatively stable cash flows or regarding whom there is considerable information in the public domain will be unable to jointly attain the objectives of higher security prices and lower price volatility through the release of more precise information. This would seem to be the case for firms in less cyclical industries, and firms that are actively followed by the financial press and institutional investors.

These results also have implications for empirical tests of asset prices as information transmission mechanisms [see, e.g., Simon (1989)]. As price volatility is sensitive to the level of

[4] For example, firms authorize underwriters to undertake price stabilization policies at the time of initial public offerings.

uncertainty regarding asset supply, tests that use price volatility to examine the effectiveness of information releases should incorporate some mechanism to control for the impact of supply shocks and the variability of the asset payoffs. This would be especially important for tests that attempt to measure the effect of information releases on the direction of change in price volatility.

The remainder of the paper is organized as follows: In Section 2, we describe the model and its major assumptions. In Section 3, we establish the existence of a rational expectations equilibrium. Section 4 contains comparative static results. We summarize our results in Section 5. Proofs are presented in the Appendix.

2. THE MODEL

Consider a single period model with risk averse investors who can invest in a riskless asset and a risky asset. Both assets generate payoffs at the end of the period. The economy is large and competitive, with stochastic per-capita supply of the risky asset to support costly private information acquisition [see, e.g., Hellwig (1980), and Admati (1985)]. At the beginning of the period, investors make information acquisition decisions that determine the quality of their private information. This private information is revealed simultaneously with the release of a publicly observable signal regarding the risky asset's payoff. The public signal can be released by either the issuer of the risky asset or some other agency such as a department of the government. Once investors are in receipt of both the public and the private information, they trade in both the risky and the riskless asset.

Investors are expected utility maximizers. Each investor's utility is given by a negative exponential function over end-of-period wealth, with investor k's utility given by $-e^{-\rho_k \tilde{W}_k}$, where ρ_k and $\tilde{W}_k$ represent his risk aversion coefficient and end of period wealth, respectively. Investors form a continuum characterized by their risk aversion coefficients, such that $\rho_k \in I \equiv [\underline{\rho}, \overline{\rho}] \subset (0, \infty)$ for all k. The proportion of investors with risk aversion ρ is expressed by the density function $\Pi(\rho)$.

Let N_k and B_k represent investor k's initial endowment of the risky-asset, and the initial endowment of the risk-free asset, respectively. Let the per-capita payoff and supply of the risky asset be represented by $\tilde{F}$, and $\tilde{N}$, respectively, where $\tilde{F}$ has mean $\overline{F}$ and precision V (variance V^{-1}) while $\tilde{N}$ has mean $\overline{N}$ and precision U (variance U^{-1}). The end-of-period payoff per unit of the risk-free asset is given by R. Let $\tilde{\Theta}$ represent the exogenously specified public signal for the economy, and $\tilde{Y}$ be a private signal. The public and private signals regarding the asset's payoff have the following structure:

$$\tilde{\Theta} \equiv \tilde{F} + \tilde{\varepsilon}_\theta,$$

$$\tilde{Y} \equiv \tilde{F} + \delta\,\tilde{\varepsilon}_\theta + \tilde{\varepsilon},$$

where $\tilde{\varepsilon}_\theta$ is the public signal error and $\delta\,\tilde{\varepsilon}_\theta + \tilde{\varepsilon}$ is the private signal error. Let S and S_θ represent the precisions of $\tilde{\varepsilon}$ and $\tilde{\varepsilon}_\theta$, respectively, and let each error term have 0 mean. As is standard in the parametric rational expectations models, the risky asset's payoff, its supply, the public signal, the private signals, and their error terms are joint-normally distributed. Further, error components and system parameter distributions are uncorrelated, i.e., $E\{\tilde{F} \cdot \tilde{N}\} = 0$, $E\{\tilde{F} \cdot \tilde{\varepsilon}_\theta\} = 0$, $E\{\tilde{\varepsilon}_\theta \cdot \tilde{N}\} = 0$, $E\{\tilde{\varepsilon} \cdot \tilde{F}\} = 0$, $E\{\tilde{\varepsilon} \cdot \tilde{N}\} = 0$, $E\{\tilde{\varepsilon} \cdot \tilde{\varepsilon}_\theta\} = 0$, and $E\{\tilde{\varepsilon}_i \cdot \tilde{\varepsilon}_j\} = 0$, for any two private signals i and j with independent error terms $\tilde{\varepsilon}_i$ and $\tilde{\varepsilon}_j$. It follows that the covariance between the public and private signal errors is a function of δ. Thus, δ captures the information that is "common" to both the public and private information signals.[5]

[5] Such commonalities are likely to exist because the vendors of private information about firms, such as analysts, obtain much of their information from firms that are often the source of public information about themselves.

An investor's ability to improve his asset allocation decision based on his private information is determined by the information his private signal conveys over and above the information contained in the risky asset's price and the public signal. This incremental information is a function of the private signal's independent error term, and the covariance between the error terms of the public and private signals. To capture the informativeness of a private signal, we define its "effective precision," S_e, where

$$S_e = (1 - \delta)^2 S.$$

This specification of the effectiveness of a private signal has intuitive appeal. A private signal for which $\delta = 1$ provides an investor with no incremental information because, in this case, the private signal is simply a "noisy" version of the public signal. The role of the private signal's independent error term precision is also intuitive. So long as $\delta \neq 1$, on observing the public signal and a private signal with an infinitely precise independent error term, an investor would be able to disaggregate the components of the public signal and thus determine the risky asset's payoff. As the precision of the independent error term declines, the investor's ability to disaggregate the components of the public signal and estimate the risky asset's payoff is diluted. Thus, signals with more precise independent error terms endow investors with a greater informational advantage.

We restrict our attention to a set of private signals and correlation structures with the public signal such that each investor chooses the effective precision of his signal from the closed interval $\mathcal{S}_e \equiv [0, \overline{S}_e]$, where $\overline{S}_e < \infty$. Note that an investor who chooses a private signal with zero effective precision is privately uninformed. One signal and correlation structure that results in effective

Because the extent to which a firm contributes to a vendor's information may vary, the commonalities between private and public signals may vary across signals. We capture this variation by allowing δ to vary across private signals. Variations in δ could render the correlation between the public and private signal error components to be either positive, zero, or negative, accommodating different types of private information, with a negative correlation corresponding to contrarian advice.

signal precisions forming an interval is as follows: let $S \in \boldsymbol{S}$, where $\boldsymbol{S}$ is a closed interval, and let δ be a continuous function of S. If δ is constant, then the set of effective precisions $\boldsymbol{S_e} = (1 - \delta)^2 \boldsymbol{S}$. Further, if δ is constant or decreasing in S, then a signal with a smaller independent error (higher S) will have a higher effective precision. On the other hand, if δ increases sufficiently rapidly in S, signals with larger independent errors (lower S) will have higher effective precisions.

The cost of acquiring private information is given by a twice continuously differentiable and convex function C, where, C: $\boldsymbol{S_e} \rightarrow \mathbb{R}_+$. To incorporate the notion that information is costly, we require that $C'(S_e) \geq 0$ for all $S_e \in \boldsymbol{S_e}$. Further, $C(0) = 0$, to ensure that remaining privately uninformed is costless.

Each investor's asset allocation decision is conditioned on the realizations of his private signal, the public signal, and the risky asset price. All investors have the following rational expectations equilibrium price conjecture:

$$\tilde{P} = A_0 + A_1 \tilde{F} + B \tilde{\Theta} - A_2 \tilde{N}, \tag{PC}$$

where A_2 is non-zero. In the next section, we employ this price conjecture to characterize the equilibrium asset allocation and information acquisition decisions of investors.

3. Equilibrium In Asset and Information Markets

We begin by establishing the existence of equilibrium in the asset market, given an allocation of private information signals. Each investor's objective is to maximize the expected utility of his end of period wealth, conditional on his information set Φ. An investor's information set consists of the public signal, the private signal, and the market clearing price, i.e., $\Phi \equiv \{\tilde{\Theta}, \tilde{Y}, \tilde{P}\}$. Thus, investor k's portfolio selection problem can be represented as follows:

$$\max_{n,\, n_0} E\{- e^{-\rho_k(n \tilde{F} + n_0 R)} \mid \Phi_k\}$$

$$\text{s.t.} \qquad n\,\tilde{P} + n_0 = N_k\,\tilde{P} + B_k - C(S_{ek}),$$

where S_{ek}, n_0, and n represent the effective precision of his private signal, his conditional demands for the riskfree and the risky asset, respectively.

Given the joint-normal distribution of the random variables and negative exponential utility functions, the investors' asset allocation problem can be solved using the moment generating function technique to yield the following conditional risky-asset demand for investor k [see DeGroot (1970)]:

$$D_k(\cdot \mid \Phi_k) = \frac{1}{\rho_k} \mathrm{Var}(\tilde{F} \mid \Phi_k)^{-1} \, [E\{\tilde{F} \mid \Phi_k\} - R\,\tilde{P}]. \tag{CD}$$

This expression shows that investors' equilibrium asset demands are functions of the conditional precision of the risky asset payoff, and are linear in the conditioning variables. Equilibrium in the asset market obtains when per-capita demand equals per-capita supply (almost surely) and investors' price conjectures are realized. The Law of Large Numbers ensures that the independent private signal error components are not reflected in the market clearing price obtained through the aggregation process.

The characterization of equilibrium is completed with the specification of investors' equilibrium information acquisition decisions. In equilibrium, investors' conjectures regarding the level of information acquisition activity are fulfilled. From the available set of private signals, each investor chooses one that maximizes his expected utility. This information choice is dependent only on the cost of private information, the reduction in uncertainty regarding asset payoff induced by the private information, and the investor's risk aversion coefficient. The reduction in uncertainty regarding the risky asset's payoff from being privately informed is captured by the ratio of the risky asset's payoff precision conditional on just the publicly available information, and its payoff precision conditional on both public information and a private signal, i.e.,

$$\frac{\hat{R}}{\hat{R} + S_e},$$

where $\hat{R} = V + S_\theta + Q^2 U$, represents the conditional precision of the risky asset's payoff if the investor is uninformed, $\hat{R} + S_e$ represents the conditional precision if he purchases a private signal with effective precision S_e, and Q represents the (risk tolerance weighted) average of precision of investors' private signals (see Proposition 1 below).

An investor's ability to capitalize on private information is limited by his risk aversion. As less risk averse investors have a greater propensity to bear risk, they are better able to take advantage of superior information. Thus, investors' optimal signal precisions are determined solely by their risk aversion characteristics, with private information quality and investor risk aversion displaying an inverse relationship. Further, investors who choose to be privately informed are uniformly less risk averse then those who choose to be privately uninformed.

Proposition 1: *There exists a rational expectations equilibrium in which each investor's effective signal precision is endogenously determined. In equilibrium*

$$\tilde{P} = \frac{1}{R}[Q^2 U + V + S_\theta + \hat{\rho} Q]^{-1} ([V\bar{F} + Q U \bar{N}] + Q[\hat{\rho} + Q U]\tilde{F} + S_\theta \tilde{\Theta} - [\hat{\rho} + Q U]\tilde{N})$$

and
$$S_{ek}^* = S_e^*(\rho_k, \hat{R}),$$

where
$$S_e^*(\rho, \hat{R}) = \operatorname{argmin}_{S_e}\{G(\rho, S_e, \hat{R}) \mid S_e \in \mathcal{S}_e\},$$

$$G(\rho, S_e, \hat{R}) \equiv \left[\frac{\hat{R}}{\hat{R} + S_e}\right]^{\frac{1}{2}} exp[\rho R C(S_e)],$$

$$\hat{\rho}^{-1} \equiv \int_I \frac{1}{\rho}\, \Pi(\rho)\, d\rho,$$

and

$$Q \equiv \int_I \frac{1}{\rho}\, S_e^*(\rho, \hat{R})\, \Pi(\rho)\, d\rho.$$

These results characterize the interaction between activity in asset and information markets. As is shown in the next section, insights into these interactions can be obtained by examining the impact of changes in the level of public information, supply noise, and uncertainty regarding asset payoffs on information acquisition decisions, asset prices, and asset demands.

4. Comparative Statics

This section consists of two sub-sections. The first is devoted to examining the impact changes in the level of supply noise and public information quality have on information acquisition activity. The second, to the impact public information releases have on prices.

4.1. Private Information Choices

In this sub-section, we identify the direction as well as the magnitude of the impact that improvements in the quality of public information have on private information acquisition activity. This is achieved by examining the impact of changes in the precision of the public signal on information acquisition decisions at the individual as well as the aggregate levels.

An increase in the precision of the public signal provides investors with an opportunity to substitute costless public information for costly private information. However, their incentive to do so depends on the benefit from private information. This benefit is positively related to the level of uncertainty regarding the risky asset's payoff. Thus, the substitution of public for private information can only be sustained if uncertainty regarding the risky asset's payoff is lowered by the change in public signal. In equilibrium, investors substitute public for private information, and this reduction is sustained by a decrease in uncertainty regarding asset payoffs. Uncertainty regarding the risky asset's payoff is decreased because the reduction in private information acquisition does not completely offset the effect of improved public information. The degree to which private information acquisition falls in response to improved public information is partially determined by the cost structure of private signals. If the cost of private information is strictly convex, the lower marginal cost of less informative signals discourages reductions in private information acquisition. If the cost of private signals is linear in precision, because the marginal cost of private information is constant, improvements in public information quality may lead to larger decreases in private information acquisition activity.[6]

Proposition 2: *(i) Investors' optimal private signal precisions are non-increasing in the precision of the public signal. (ii) The proportion of informed investors in the economy is non-increasing in the precision of the public signal. (iii) The conditional precisions of the risky asset payoff for informed and uninformed investors are non-decreasing in the precision of the public signal.*

While the above proposition highlights the impact of information releases on information acquisition activity and uncertainty regarding asset payoffs, the logic underlying it is more general. To establish this, we now show that reductions in the supply noise exert a similar influence on private information acquisition activity. Private information gathering activity is made viable by rendering the equilibrium price a noisy aggregator of investors' private information [see, e.g.,

[6] If the cost of private information is concave in signal precisions, characterization of investors' information acquisition decisions is complex because their objective functions, which comprise of the benefits of information acquisition (convex in the private signal precisions, see Proposition 1) and the cost of information acquisition (which is concave in the signal precision) may no longer be either concave or convex over the entire domain of their choice set. In this case, because there may not exist a continuous function mapping the level of publicly available information into investor's optimal signal precisions, there may not exist an equilibrium. Further, even if there exists an equilibrium, because of the possible discontinuities the comparative statics may be intractable.

Grossman (1976)]. Consequently, a decrease in supply noise results in the risky asset price being a better aggregator of information. This reduces the returns from information acquisition, generating results virtually identical to those induced by improvements in the quality of public information.[7]

Proposition 3: *(i) Investors' optimal private signal precisions are non-increasing in the precision of the supply noise. (ii) The proportion of informed investors in the economy is non-increasing in the precision of the supply noise. (iii) The conditional precisions of the risky asset payoff for informed and uninformed investors are non-decreasing in the precision of the supply noise.*

Together, the above results establish that the quality of public information regarding the risky asset's payoff and the asset's susceptibility to supply shocks are important determinants of information acquisition activity. This clearly has policy implications. By requiring a firm to disclose information, uncertainty regarding asset payoffs is mitigated, and repetitive costly private information gathering activity is driven down. This could lead to savings in the economy and improvements in investor welfare if the cost of releasing public information is relatively low [see, Diamond (1984)]. However, in addition to considering the impact of public information releases on the cost savings to investors, when evaluating the merits of a disclosure policy, a firm may also consider its impact on price levels and volatility.

4.2. Price Reactions

The risky asset's price reflects both supply noise and aggregate information regarding its payoff. By changing the relative importance of these two determinants of the asset's price, public information releases impact both the price level and its volatility, where the price level and price volatility are measured by the *ex ante* unconditional mean and variance of the risky asset's price,

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[7] See Admati and Pfleiderer (1987) for a similar result.

respectively. We first examine the impact of changes in the quality of public information on the price level. We then focus on the volatility changes induced by public information releases. We show that the direction of change in volatility is crucially dependent upon the levels of supply noise and the risky asset's payoff variance. The section is concluded by isolating the impact, on price volatility, of the transfer of resources between information and asset markets induced by public information releases.

Note that, from Proposition 1, it follows that the risky asset's expected price is given by

$$E\{\tilde{P}\} = R^{-1}\,[\bar{F} - \hat{\rho}\,\Delta\,\bar{N}],$$

where $\Delta \equiv [\hat{R} + \hat{\rho}\,Q]^{-1}$, represents the conditional variance of the risky asset's payoff for the "average" investor. It follows that the change in expected price resulting from an increase in the quality of public information can be represented by

$$\frac{dE\{\tilde{P}\}}{dS_\theta} = -R^{-1}\,\hat{\rho}\,\bar{N}\frac{d\Delta}{dS_\theta}.$$

From Proposition 2, it follows that uncertainty regarding asset payoffs falls as the precision of the public signal increases, i.e. $d\Delta/dS_\theta \leq 0$. Thus, an increase in the quality of publicly available information results in an increase in the price level. This is an intuitive result because the reduced uncertainty regarding the risky asset's payoff resulting from improved public information induces investors to demand a smaller risk premium for holding the asset, leading to an increase in the price level.

Proposition 4: *The ex-ante expected price of the risky asset is non-decreasing in the precision of the public signal.*

While improvements in the quality of public information can always be expected to generate higher asset prices, their impact on price volatility is more complex. When supply noise and/or the unconditional variance of the risky asset's payoff are relatively low, investors' conditional expectations of the risky asset's payoff are relatively precise, and thus supply shocks exert little influence on prices. On the other hand, when supply noise or its unconditional payoff variance is relatively high, the risky asset's price is relatively sensitive to supply shocks. Improvements in the quality of public information exert two effects on price volatility because of the increased precision of investors' conditional expectations regarding the risky asset's payoff. The first, the reduced dependence of price on supply noise acts to reduce price volatility. The second, the increased sensitivity of investor trades to realizations of the public signal, acts to increase price volatility. The following result establishes that the former effect dominates when supply noise is relatively high, risky asset's unconditional payoff variance is relatively high, or the quality of public information is relatively poor. The latter effect dominates for relatively low values of supply noise and unconditional risky asset payoff precision, or high levels of public information precision.[8]

To see this note that, from Proposition 1, price volatility is given by

$$\mathrm{Var}(\tilde{P}) = R^{-2}\,(V^{-1} + \Delta\,[\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]).$$

It follows that

$$\frac{d\mathrm{Var}(\tilde{P})}{dS_\theta} = R^{-2}\left([2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]\,\frac{d\Delta}{dS_\theta} + \hat{\rho}\,\Delta^2\,\frac{dQ}{dS_\theta}\right). \tag{PV}$$

The following proposition presents conditions under which this expression can be unambiguously signed.

[8] This result can be compared to that in Proposition 3 of Kim and Verrecchia (1991b) who show that, when investors can trade in anticipation of the receipt of public information, the change in private information acquisition activity exactly offsets the change in the public signal precision. Their result is critically dependent upon both a linear cost function for private information and the ability of investors to trade after the receipt of private information but before the realization of the public signal.

Proposition 5: *(i) If supply noise is sufficiently high, the risky asset's unconditional payoff variance is sufficiently high, or the public signal has sufficiently low precision, i.e.,*

$$\hat{\rho}^2 \geq U\,(V + S_\theta + \bar{S}_e^2\, U + \hat{\rho}\, \bar{S}_e).$$

price volatility is non-increasing in the precision of the public signal. (ii) If supply noise is sufficiently low, the unconditional variance of the risky asset's payoff is sufficiently low, or public information quality is sufficiently high, i.e.,

$$S_\theta > max\left\{ 2\ \hat{\rho}^2\ U^{-1} - V,\ \frac{1}{2\ \underline{\rho}\ R\ C'(0)} - V \right\}.$$

price volatility is non-decreasing in the precision of the public signal.

Figures 1 and 2 illustrate the results in Proposition 5. The following parameterization was employed to generate each of the plots in the figure: $\rho_k = 1$ for all k, $C(S_e) \equiv S_e^2$, and R = 1. Figure 1 focuses on the relationship between price volatility, public information quality, and supply noise. To isolate the effect of supply noise, asset payoff variance is held constant by setting V = 1. Figure 2 focuses on the relationship between price volatility, public information quality, and unconditional asset payoff variance. To isolate the effect of unconditional payoff variance, supply noise is held constant by setting U = 1.

Panel A of Figure 1 graphs the negative relationship between price volatility and public signal precision for a relatively low supply noise precision (U = 0.1). Panel B of Figure 1 graphs the positive impact improved public information has on price volatility when the precision of supply noise is relatively high (U = 3). Panel C of Figure 1 contains a three dimensional plot of price volatility as a function of both public signal precision and supply noise. It serves to illustrate the ranges of supply noise over which the negative and positive relationships between public signal precision and price volatility hold. It also illustrates that, given the cost of private signals is continuously differentiable, and consequently so is the function representing the relationship between public information quality and prices, the derivative of price volatility with respect to the precision of the public signal varies continuously from negative to positive with the level of supply noise.[9] In Figure 2, Panel A graphs the negative relationship between price volatility and public information quality for low levels of the unconditional asset payoff precision (V = 0.1), while Panel B graphs the positive relationship between these variables for high values of the unconditional asset payoff precision (V = 3). Panel C contains a three dimensional plot that illustrates how the relationship between price volatility and public information quality varies with unconditional asset payoff variance.

Even in an economy in which investors' private signals are treated as endowments, price volatility can either increase or decrease in reaction to an increase in the precision of the public signal. The direction of the change in price volatility is crucially dependent on the level of uncertainty regarding the risky asset's payoff. To see this, note that if the conditional variance of the risky asset's payoff for the "average" investor is sufficiently high, then $2\,\Delta\,[\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q] > 1$. Thus, it follows from (PV), that price volatility is decreasing in the quality of the public signal. Further, if the conditional variance of the risky asset's payoff for the "average" investor is sufficiently low, then $2\,\Delta\,[\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q] < 1$, it follows from (PV) that price volatility increases with improved public information.

From this discussion it would seem that the reaction of price volatility to changes in public signal quality does not depend on the endogeneity of private information acquisitions. However, this is not the case. To demonstrate that the transfer of resources between information and asset markets induced by changes in public information quality may have important policy implications, we now isolate the impact that endogeneity of the private information acquisition decision has on

[9] We would like to thank an anonymous referee for bringing this point to our attention.

price volatility from that arising solely from changes in the quality of the public information signal. This is done by decomposing the impact of changes in public information on price volatility into two components. The first captures the effect of public information changes, holding constant private information acquisition decisions. This price volatility effect is identical to that which would be observed in an economy in which investors are endowed with their optimal private signals. The second component expresses the impact of the changes in private information acquisition on price volatility.

As demonstrated earlier, changes in private information acquisition activity partially offset reductions in uncertainty regarding asset payoffs brought about by changes in public information quality. Thus, in general they tend to counteract the impact of public information releases on price volatility. However, for some levels of supply noise, the reaction of the private information acquisition activity may in fact reinforce the impact of the change in the precision of the public signal. On the other hand, for moderate levels of public information quality and unconditional asset payoff variance, investor reactions may in fact reverse the effect of changes in the quality of public information on price volatility. It follows that price volatility reactions in an economy with endogenous information acquisition may differ substantially from those in an economy in which investors are unable to adjust their information decisions.

Proposition 6: *The change in price volatility induced by a change in the precision of the public signal is reinforced by the changes induced by investors' private signal choices for intermediate levels of supply noise. This is the case when*

$$0 < (2\,\Delta\,[\hat{\rho}^2 U^{-1} + \hat{\rho}\,Q] - 1)\,[2\,Q\,U + \hat{\rho}] < \hat{\rho}.$$

On the other hand, the change in price volatility induced by a change in the precision of the public signal can be reversed by changes induced by investors' private signal choices for intermediate values of the public signal precision and asset payoff variance.

Figure 3 illustrates the impact investors' information acquisition decisions have on the relationship between public information quality and price volatility. The figure demonstrates how changes in price volatility in response to changes in the precision of the public signal in an economy with endogenous private information acquisition may differ from price volatility reactions in an economy in which investors cannot choose their signals. The parameterization employed to generate the figure is as follows: $\rho_k = 10$ for all k, $C(S_e) \equiv 0.001\ S_e^2$, $V = 0.001$, $U = 5$, and $R = 1$. The public signal precision, S_θ, varies between 40 and 42. Curve A captures the change in price volatility arising from a change in the public signal precision, in an economy where investors are endowed with their optimal signals. Curve B captures the corresponding change in price volatility when investors can adjust their private signals in response to changes in the public signal. For public signal precisions in the interval (40.6, 41.2) the volatility reactions in the two economies are opposite in sign, highlighting the importance of changes in investors' information acquisition. For public signal precision levels below 40.6, the price volatility change resulting from changes in investors' information acquisition decisions reinforces the volatility reaction observed in the endowment economy.

The above results illustrate that price reactions to public announcements can vary depending on the level of supply noise, the variance of the risky asset payoff, and the precision of the public signal. They also serve to highlight the role played by the transfer of resources between asset and information markets in determining the sensitivity of price to public announcements.

5. Conclusion

In this paper, we examine the interrelationships between public information releases and investors' information acquisition decisions. We demonstrate that improvements in the quality of public information reduce the overall level of uncertainty regarding asset payoffs in the economy.

This occurs despite the substitution of public information for private information by individual investors. Price reactions to changes in the quality of the public information are crucially dependent upon the quality of publicly available information, and precisions of asset payoffs and supplies. Price levels react favorably to improvements in the quality of public information. The reactions of price volatility to changes in public information are more complex. When the quality of public information is high or asset payoff variance is low, price volatility increases as the quality of the public information improves. On the other hand, when supply volatility is high, public releases of information lower price volatility. Similar variations in the price volatility reactions may result because of differences in the quality of publicly available information. These results imply that firms may differ in their information release policies. In fact, some firms may not release information even though it may reduce investor borne costs of information acquisition.

APPENDIX

Proof of Proposition 1: The proof is virtually identical to that of Lemmas 1 and 2 and the Theorem on the existence of an equilibrium in Verrecchia (1982).[10]||

Proof of Proposition 2: We prove only (iii). The proofs of (i) and (ii) are omitted as they are virtually identical. Let $S_{\theta 1}$ and $S_{\theta 2}$ be the precisions of two public signals such that $S_{\theta 1} > S_{\theta 2}$. Let Q_1 and Q_2 be the risk tolerance weighted averages of the investors' equilibrium effective signal precisions, given the public signal precisions $S_{\theta 1}$ and $S_{\theta 2}$, respectively. Next, define the terms $\hat{R}_1$ and $\hat{R}_2$, corresponding to the public signals $S_{\theta 1}$ and $S_{\theta 2}$, respectively, as follows:

$$\hat{R}_n \equiv V + S_{\theta n} + Q_n^2 U, \qquad n = 1, 2.$$

Now suppose that an increase in the precision of the public signal from $S_{\theta 2}$ to $S_{\theta 1}$ leads to a decrease in $\hat{R}$, i.e. $\hat{R}_1 \leq \hat{R}_2$. Then, it must be the case that some investors have been induced to purchase signals with lower effective precisions, i.e. for some investor with risk aversion coefficient ρ it must be the case that $S_e^*(\rho, \hat{R}_1) < S_e^*(\rho, \hat{R}_2)$, where $S_e^*(\rho, \hat{R})$ is defined in the proof of Proposition 1. For notational purposes, let $D_x f(x)$ represent the derivative of the function $f(x)$ with respect to x. Similarly, let $<< D_x f(x), x_1 - x_2 >>$ represent the differential of the function $f(x)$ with respect to x in the direction $x_1 - x_2$. Note that in the event that the public signal precision is $S_{\theta 1}$, the following condition must be satisfied by the investor's optimal signal precision, $S_e^*(\rho, \hat{R}_1)$, if it solves (PI):

$$<< D_{S_e} \ln G(\rho, S_e^*(\rho, \hat{R}_1), \hat{R}_1), S_e^*(\rho, \hat{R}_2) - S_e^*(\rho, \hat{R}_1) >> \;\; \geq 0,$$

or equivalently

10 See also Lemmas 1 and 2 in Kim (1993).

$$<< D_{S_e}\ln G(\rho, S_e^*(\rho, \hat{R}_1), \hat{R}_1), S_e^*(\rho, \hat{R}_1) - S_e^*(\rho, \hat{R}_2) >> \ \leq 0. \quad \text{(A3)}$$

Similarly, in the event that the public signal precision is $S_{\theta 2}$, the following condition must be satisfied by the investor's optimal signal precision, $S_e^*(\rho, \hat{R}_2)$:

$$<< D_{S_e}\ln G(\rho, S_e^*(\rho, \hat{R}_2), \hat{R}_2), S_e^*(\rho, \hat{R}_1) - S_e^*(\rho, \hat{R}_2) >> \ \geq 0. \quad \text{(A4)}$$

Subtracting (A4) from (A3), we obtain

$$\rho R << D_{S_e}C(S_e^*(\rho, \hat{R}_1)) - D_{S_e}C(S_e^*(\rho, \hat{R}_2)), S_e^*(\rho, \hat{R}_1) - S_e^*(\rho, \hat{R}_2) >>$$

$$- << D_{S_e}\ln(\hat{R}_1 + S_e^*(\rho, \hat{R}_1)) - D_{S_e}\ln(\hat{R}_2 + S_e^*(\rho, \hat{R}_2)), S_e^*(\rho, \hat{R}_1) - S_e^*(\rho, \hat{R}_2) >> \leq 0.$$

From the convexity of the cost function, and the concavity of $\ln(\hat{R} + S_e)$, it follows that the above expression is positive. This contradicts the hypothesis that an increase in the precision of the public signal will lead to a decrease in $\hat{R}$. Thus, an increase in the precision of the public signal cannot lead to a decrease in $\hat{R}$. Now suppose that an increase in S_θ is associated with an increase in Q. Then, it must be the case that if $S_{\theta 1} > S_{\theta 2}$, then $\hat{R}_1 > \hat{R}_2$, and for some value of the risk aversion coefficient ρ, $S_e^*(\rho, \hat{R}_1) > S_e^*(\rho, \hat{R}_2)$. By reversing the arguments used in proving the earlier result, it can be established that this is not possible.

The proof of (iii) is concluded by demonstrating that if $S_{\theta 1} > S_{\theta 2}$, then it must be that case that $\hat{R}_1 + S_e^*(\rho, \hat{R}_1) \geq \hat{R}_2 + S_e^*(\rho, \hat{R}_2)$. Suppose not, since (from the above result) $\hat{R}_1 \geq \hat{R}_2$, it must be the case that $S_e^*(\rho, \hat{R}_1) < S_e^*(\rho, \hat{R}_2)$. From arguments identical to those used above, it follows that it must be the case that

$$\rho R << D_{S_e}C(S_e^*(\rho, \hat{R}_1)) - D_{S_e}C(S_e^*(\rho, \hat{R}_2)), S_e^*(\rho, \hat{R}_1) - S_e^*(\rho, \hat{R}_2) >>$$

$$- << D_{S_e}\ln(\hat{R}_1 + S_e^*(\rho, \hat{R}_1)) - D_{S_e}\ln(\hat{R}_2 + S_e^*(\rho, \hat{R}_2)), S_e^*(\rho, \hat{R}_1) - S_e^*(\rho, \hat{R}_2) >> \leq 0.$$

From the convexity of the cost function, and the concavity of the function $\ln(\hat{R} + S_e)$ it follows that the above expression is positive. But this is a contradiction.‖

Proof of Proposition 3: This proof is identical to the proof for Proposition 2.‖

Proof of Proposition 4: Note that

$$\Delta^{-1} = \hat{R} + \hat{\rho}\, Q = \hat{\rho} \int_I \frac{1}{\rho} [\hat{R} + S_e^*(\rho, \hat{R})]\, \Pi(\rho)\, d\rho.$$

Thus, it follows from Proposition 2 that

$$\frac{d[\hat{R} + S_e^*(\rho, \hat{R})]}{dS_\theta} \geq 0,$$

and $d\Delta/dS_\theta \leq 0$. The sign of the derivative of the expected price with respect to the precision of the public signal follows directly from the sign of this derivative.‖

Proof of Proposition 5: First we prove (i). Then we prove (ii). From Proposition 2 it follows that $d\Delta/dS_\theta \leq 0$ and $dQ/dS_\theta \leq 0$. It follows that, if $2\,\Delta\,(\hat{\rho}^2\, U^{-1} + \hat{\rho}\, Q) \geq 1$, it must be the case that $dVar(\tilde{P})/dS_\theta \leq 0$. From the definition of Δ it follows that the lower bound on Δ is $[V + S_\theta + \bar{S}_e^2\, U + \hat{\rho}\, \bar{S}_e]^{-1}$. Further the lower bound on the expression $\hat{\rho}\, Q$ is 0. It follows that $2\,\Delta(\hat{\rho}^2\, U^{-1} + \hat{\rho}\, Q) \geq 1$, and $dVar(\tilde{P})/dS_\theta \leq 0$, so long as

$$U^{-1} \geq \frac{V + S_\theta + \bar{S}_e^2\, U + \hat{\rho}\, \bar{S}_e}{\hat{\rho}^2}.$$

This is the desired result.

We only show that price variance may increase with the precision of the public signal for high levels of public signal precision. The proof of the claim for the case where asset payoff variance is low is virtually identical. Let S_θ satisfy the following condition

$$S_\theta > \frac{1}{2\,\underline{\rho}\,R\,C'(0)} - V. \tag{A5}$$

This condition ensures that $D_{S_e}G(\rho, 0, V + S_\theta + Q^2 U) > 0$ for all $\rho \in I$ and $Q \geq 0$. Thus, for values of S_θ satisfying the above condition, investors will not choose to be privately informed. It follows, from Proposition 2 and the definition of Δ, that for S_θ that satisfy (A5), $dQ/dS_\theta = 0$ and

$$\frac{d\mathrm{Var}(\tilde{P})}{dS_\theta} = R^{-2}\,[2\,\Delta\,\hat{\rho}^2\,U^{-1} - 1]\,\frac{d\Delta}{dS_\theta}.$$

For $S_\theta > 2\,\hat{\rho}^2\,U^{-1} - V$, it follows that the first part of the above expression, $2\,\Delta\,\hat{\rho}^2\,U^{-1} - 1$, is negative. Because $dQ/dS_\theta = 0$ for all S_θ which satisfy (A5), it follows that $d\Delta/dS_\theta < 0$. Thus, $d\mathrm{Var}(\tilde{P})/dS_\theta > 0$ if

$$S_\theta > \max\left\{ 2\,\hat{\rho}^2\,U^{-1} - V,\ \frac{1}{2\,\underline{\rho}\,R\,C'(0)} - V \right\}. \tag{A6}$$

This is the desired result.||

Proof of Proposition 6: To see that (i) is a valid note that $d\mathrm{Var}(\tilde{P})/dS_\theta$ can also be expressed as follows:

$$- R^{-2}\,\Delta^2\,[2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]$$

$$- R^{-2}\,\Delta^2\,([2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]\,[\hat{\rho} + 2\,Q\,U] - \hat{\rho})\,\frac{dQ}{dS_\theta}. \tag{A7}$$

Note also that, from Proposition 2 and the definition of Δ, it follows that $dQ/dS_\theta \leq 0$. Thus, the two components of the price volatility change reinforce each other when

$$[2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1] > 0$$

and
$$[2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]\,[\,\hat{\rho} + 2\,Q\,U] - \hat{\rho} < 0.$$

The remainder of the proof of (i) follows by simplifying these expressions.

We provide only a sketch of the proof of (ii). We only show that a reversal will occur for intermediate levels of public signal precision. The proof of the claim for intermediate values of asset payoff variance is virtually identical. To see (ii) is valid, note that the two components of the change in price volatility counteract each other when

$$0 \geq [2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]$$

$$0 > [2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]\,[\,\hat{\rho} + 2\,Q\,U] - \hat{\rho}.$$

The desired results follow by choosing S_θ that satisfies the inequality (A6), and allowing S_θ to decrease so that $2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q)$ approaches 1. From (A7) it follows that the first component of the change in price volatility will be non-positive and approach 0 as S_θ decreases. Note also that when $2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) = 1$

$$0 > [2\,\Delta\,(\hat{\rho}^2\,U^{-1} + \hat{\rho}\,Q) - 1]\,[\,\hat{\rho} + 2\,Q\,U] - \hat{\rho}.$$

This implies that the second component of the change in price volatility will be negative so long as $dQ/dS_\theta < 0$. This will be the case so long as there exist investors whose optimal private signals lie in the interval $(0, \bar{S}_e)$ and the cost function, $C(\cdot) > 0$.||

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Figure 1. Each of the plots in the three panels are derived from the following parameterization of the economy: All investors have identical risk aversion coefficients ($\rho_k = 1$ for all k), the cost of private information is given by $C(S_e) \equiv S_e^2$, the return on the risk-free asset $R = 1$, the variance of returns on the risky asset is given by $V^{-1} = 1$. Panel A presents a plot of the relationship between price volatility and the precision of the public information when the precision of the per-capita supply noise is given by $U = 0.1$, where price volatility is given by the *ex ante* variance in the price of the risky asset. Panel B present a plot of this relationship when $U = 3$. Panel C presents a 3-D plot of the relationship between price volatility, the precision of the public information, and the precision of the supply noise.

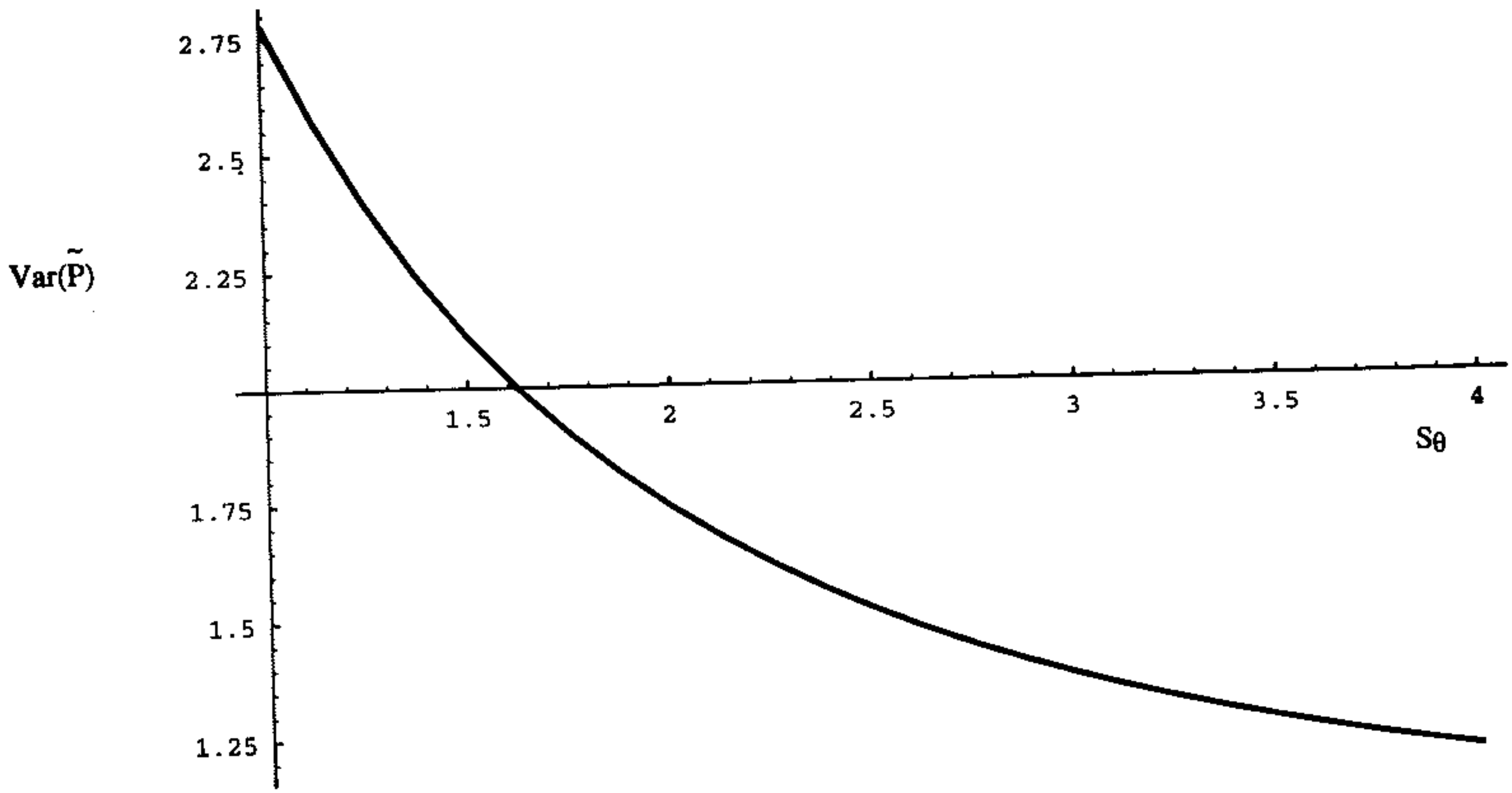


Figure 1, Panel A

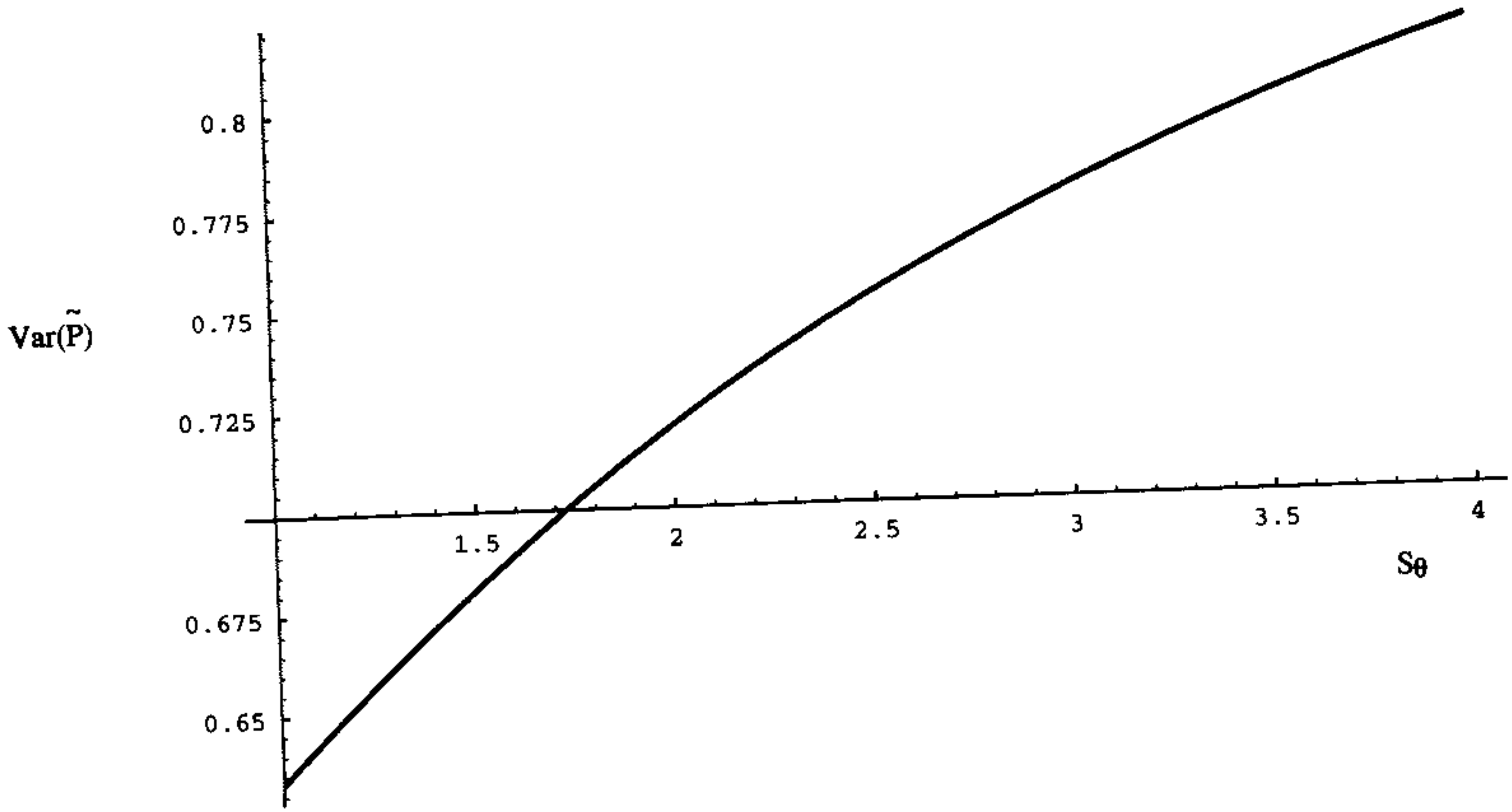


Figure 1, Panel B

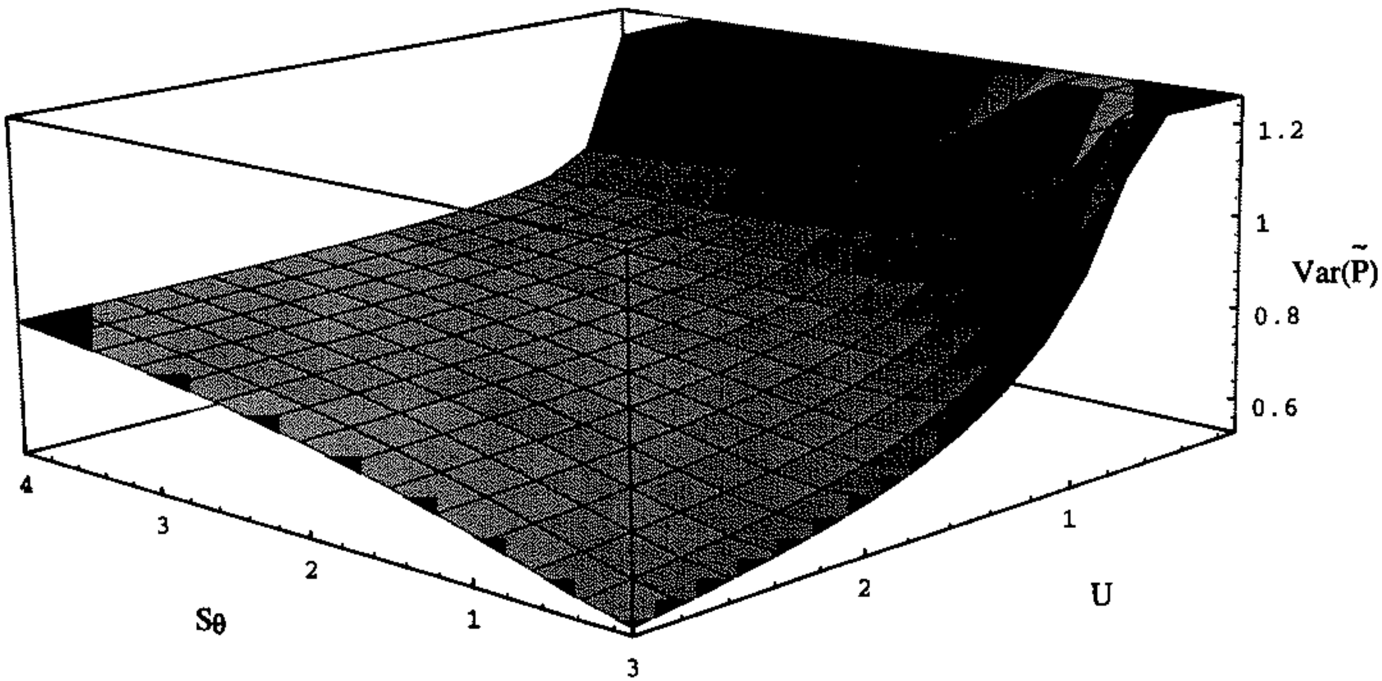


Figure 1, Panel C

Figure 2. Each of the plots in the three panels are derived from the following parameterization of the economy: All investors have identical risk aversion coefficients ($\rho_k = 1$ for all k), the cost of private information is given by $C(S_e) \equiv S_e^2$, the return on the risk-free asset R = 1, the variance of supply noise for the risky asset is given by $U^{-1} = 1$. Panel A presents a plot of the relationship between price volatility and the precision of the public information when the precision of the risky asset's payoff is given by V = 0.1, where price volatility is given by the *ex ante* variance in the price of the risky asset. Panel B present a plot of this relationship when V = 3. Panel C presents a 3-D plot of the relationship between price volatility, the precision of the public information, and the precision of the risky asset's payoff.

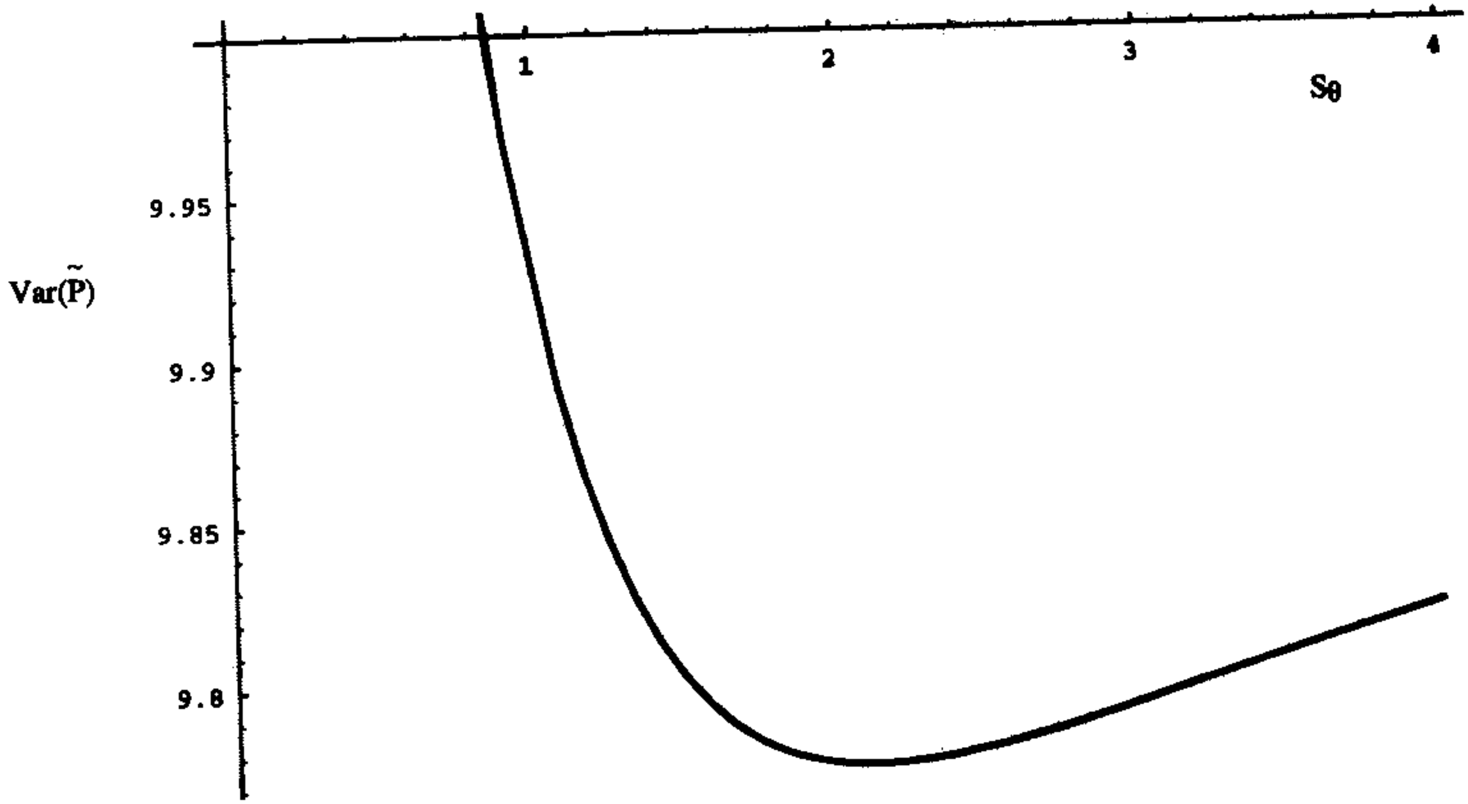


Figure 2, Panel A

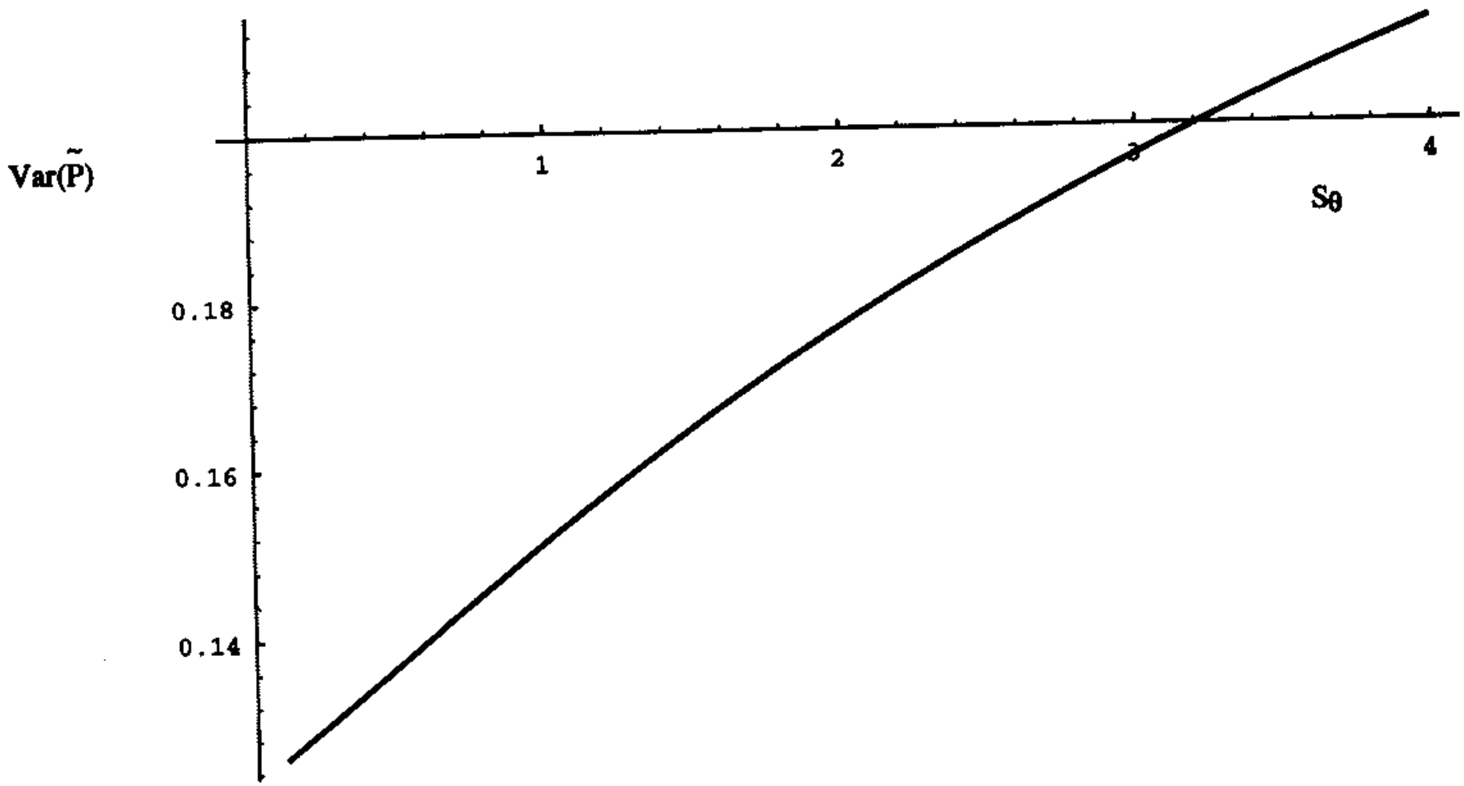
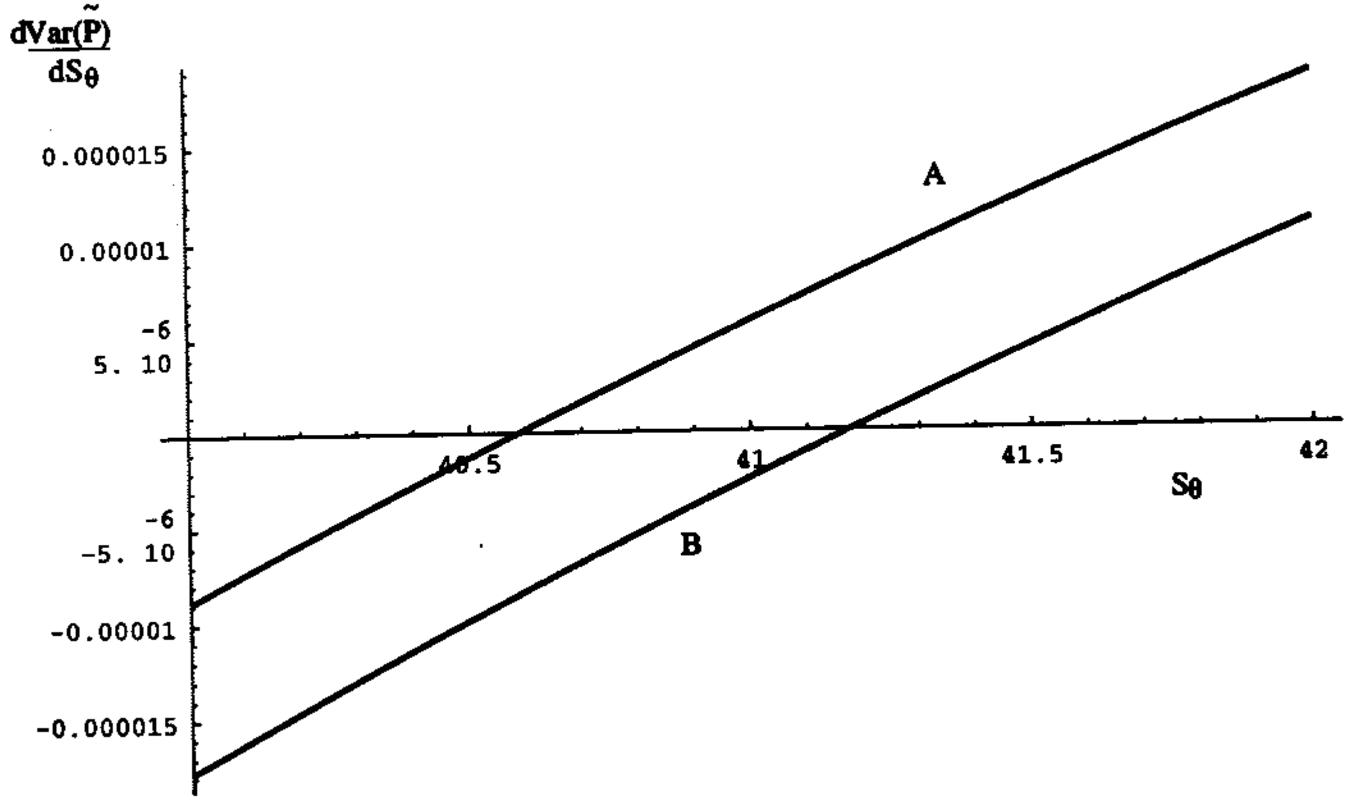


Figure 2, Panel B



$\frac{dVar(\tilde{P})}{dS_\theta}$
0.000015
0.00001
$5.\ 10^{-6}$
$-5.\ 10^{-6}$
-0.00001
-0.000015
40.5
41
41.5
42
S_θ
A
B

Figure 3