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Price Determination in a Competitive Industry with Costly Information and a Production Lag

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Price determination in a competitive industry with costly information and a production lag

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and

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We analyze the role of information for price and output adjustment when competitive firms with rational expectations cannot directly distinguish between industrywide and firm-specific cost disturbances. Firms may become informed about industrywide cost conditions by acquiring information at a cost. The sensitivity of price and output to cost disturbances decreases as more firms choose to purchase information. The equilibrium industry share of informed firms increases as the cost of information falls and total cost variability increases. The equilibrium share of informed firms is largest when there is a comparable degree of variability in both industrywide and firm-specific costs.

1. Introduction

■ In this article we examine price and output adjustment within a competitive industry in the presence of uncertainty about firm-specific and industrywide cost conditions. We formulate a model in which individual firms can directly observe their own, but not industrywide, cost conditions, and may only acquire information about industrywide conditions at a cost. An important element of our analysis concerns how the availability of this costly information influences market equilibrium.

The distinction between local and aggregate conditions is a property that characterizes so-called island models suggested originally by Phelps (1970). Such models generally assume that information about aggregate conditions is not available to individual agents at the time they maximize their objective functions. Lucas (1972, 1973, 1975) posits that agents cannot determine whether prices increase because of island-specific or economywide demand conditions. Other models (Mortensen, 1970; Grossman and Weiss, 1982; Frydman, 1982) emphasize limited information about local and aggregate cost conditions. Our model belongs to the latter category, although our analysis is easily extended to include confusion about local and aggregate demand conditions. We go beyond these articles by presuming the availability of costly information.

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There are two essential features to our model. First, firms make production decisions before determination of the market equilibrium price. Since goods production is typically a time-consuming process, this assumption of a production lag is a realistic one for many industries. Because of the lag, individual firms must form expectations about the industry market-clearing price at the time they determine output.¹ This price depends on aggregate output in the industry. In our model uncertainty about industrywide cost conditions underlies uncertainty about aggregate output. For example, wage and productivity conditions may vary among competing firms and make information about average conditions important.

The other essential feature of our analysis is that firms may choose to be informed by acquiring information about industrywide costs. The role of costly information for market adjustment has previously been addressed by Darby (1976) and Grossman and Stiglitz (1980). Using a general framework where information is costly, Darby analyzes how heterogeneous expectations may exist in an equilibrium characterized by individually rational expectations. By specifying particular distribution functions for random disturbances and a supply and demand structure, we are able to relate equilibrium price and output adjustment explicitly to the characteristics of the distribution functions. Grossman and Stiglitz (1980) introduce an information market into a financial asset-pricing model with risk-averse investors. They point to an important externality of information acquisition: the larger the share of investors that purchase information, the less is the incentive for others to do so. We obtain a similar externality result, although for different reasons.

In Section 2 we specify a model of a competitive industry of risk-neutral, expected-profit-maximizing firms. We then derive the equilibrium industry price and output levels in terms of cost and other structural parameters, while assuming that the share of informed firms in the industry is exogenous.

Section 3 describes determination of equilibrium in the information market. We derive the equilibrium share of informed firms under circumstances that rule out "free-rider" problems. We analyze how this share depends on the cost of information, industrywide relative to firm-specific cost variability, and total cost variability. We show that the share of informed firms is greatest when the variability of *both* firm-specific and industrywide cost conditions is relatively high and when information is relatively cheap.

Section 4 analyzes how the response of equilibrium price and output to cost and demand disturbances depends on parameters influencing the purchase of information. Two interesting results are that the price is relatively insensitive to a cost disturbance when either total cost variability is relatively high or the degrees of variability of firm-specific and industrywide cost conditions are comparable.

Section 5 contains conclusions and possible extensions of our research.

2. Equilibrium in the goods market

■ In this section we formulate a simple model of firms in a competitive industry. Individual firms' decisions concerning the supply of output are made at the *beginning* of a given period. The equilibrium price that then clears the goods market is determined at the *end* of the period. In this section we treat the share of firms that have chosen to purchase information as exogenous.

The supply side of the goods market consists of n firms, all producing the same homogeneous good, where n is assumed to be exogenous and a very large number. Each firm i possesses the following quadratic production cost function:

¹ We implicitly assume that output is not storable. In another paper (Glick and Wihlborg, 1984) we develop a model in which inventory adjustment and information purchase are possible.

$$C_i = C_i[y_i] = \left(\frac{1}{2z}\right)y_i^2 + k_i y_i, \quad i = 1, \dots, n, \quad (1)$$

where C_i = the cost of producing quantity of output y_i ; k_i = the realization of a random cost-condition term observed by the firm at the time production decisions are made; and z = a scale parameter assumed equal to $1/n$.²

The demand side of the goods market is given exogenously by the following aggregate demand function:

$$P = a - bY + u, \quad (2)$$

where P = the end-of-period goods market price; Y = the aggregate quantity of output supplied ($Y = \sum_{i=1}^n y_i$); u = an end-of-period realization of a random demand term; and a and b are positive parameters.

We assume that the cost-condition realization k_i observed by each individual firm is given by the sum of a component α , representing industrywide conditions affecting the costs of all firms, and a component ϵ_i , representing firm-specific cost conditions:

$$k_i = \alpha + \epsilon_i, \quad i = 1, \dots, n. \quad (3)$$

α and ϵ_i are generated by independent and normal distribution functions such that $\tilde{\alpha} \sim N(\bar{\alpha}, \sigma_\alpha^2)$ and $\tilde{\epsilon}_i \sim N(0, \sigma_\epsilon^2)$. Each firm's realization k_i thus differs from that of other firms only by the independent realizations ϵ_i . It is assumed that neither α nor ϵ_i may be directly observed by firms. The random demand term \tilde{u} is assumed distributed $N(0, \sigma_u^2)$ independently of $\tilde{\alpha}$ and $\tilde{\epsilon}_i$.

Output levels and the equilibrium price are determined in the model in the following way. At the time each firm makes its output decision, it obtains a realization of its cost condition parameter k_i . While no firm may directly distinguish between the magnitude of industrywide cost conditions (α) versus individual cost conditions (k_i), it is assumed that m firms, $0 \leq m \leq n$, have acquired information about the current value of α at a fixed cost c . The firms which have acquired this information are termed "informed." Those that have not are "uninformed." On the basis of their available information, all firms then determine how much output to supply to the goods market. At the end of the period, the equilibrium price that clears the goods market is determined. In Section 3 we determine the equilibrium number, or equivalently the industry share λ ($=m/n$), of informed firms.

Each firm's profit-maximizing output is derived by maximizing expected profits conditional on its information set, S_i , about current cost conditions. Assuming all firms regard themselves as price-takers this may be expressed as

$$E[\Pi_i|S_i] = E[P|S_i]y_i - y_i^2/(2z) - k_i y_i - c_i, \quad i = 1, \dots, n, \quad (4)$$

where $S_i = I_i$ and $c_i = c$ for $i = 1, \dots, m$, the informed firms; and $S_i = U_i$ and $c_i = 0$ for $i = m + 1, \dots, n$, the uninformed firms.

The profit-maximizing output for firm i is

$$y_i^* = z(E[P|S_i] - k_i), \quad y_i^* \geq 0 \quad i = 1, \dots, n. \quad (5)$$

² This particular specification of individual firm cost functions has the property that aggregate industry marginal costs are independent of the number of firms ($n = 1/z$). We neglect, as do most models of competitive equilibrium, determination of the equilibrium number of firms and firm size. In Section 3, however, we show that the equilibrium share of informed firms in the industry, and hence the equilibrium price, will depend on n .

Each firm's output depends positively on its expected price and negatively on its cost conditions.³

Aggregate industry output Y is given by

$$Y = \sum_{i=1}^n y_i^* = \sum_{i=1}^m y_i^* + \sum_{i=m+1}^n y_i^*, \tag{6}$$

or, after inserting (5) into (6), by

$$\begin{aligned} Y &= \sum_{i=1}^m z(E[P|I_i] - k_i) + \sum_{i=m+1}^n z(E[P|U_i] - k_i) \\ &= \lambda P_I^e + (1 - \lambda)P_U^e - \alpha, \end{aligned} \tag{7}$$

where we have assumed that n is sufficiently large that $\frac{1}{n} \sum_{i=1}^m \epsilon_i = 0$; and

$$P_I^e = \text{the average price expectation of informed firms} \left(\frac{1}{m} \sum_{i=1}^m E[P|I_i] \right),$$

$$P_U^e = \text{the average price expectation of uninformed firms} \left(\frac{1}{n - m} \sum_{i=m+1}^n E[P|U_i] \right).$$

Substituting aggregate market output Y , as described by (7), into the aggregate market demand equation (2) gives the following relation between the equilibrium market price and the average price expectations of informed and uninformed firms:

$$P = a + b\alpha - b\lambda P_I^e - b(1 - \lambda)P_U^e + u. \tag{8}$$

Equation (8) shows that the equilibrium price depends on current industrywide cost (α) and demand (u) conditions, on the average price expectations of both informed (P_I^e) and uninformed (P_U^e) firms, as well as on the share of informed firms (λ). We use the method of undetermined coefficients to solve for the equilibrium price for an exogenously given level of λ . Using this method amounts to "guessing" a solution of the form:

$$P = \bar{P} + B(\alpha - \bar{\alpha}) + u, \tag{9}$$

where \bar{P} and B depend on the structural parameters of the system in a manner described below.

For expectations to be consistent with the conjectured equilibrium, the price expectations of each firm must take the following form:

$$E[P|S_i] = \bar{P} + BE[\alpha - \bar{\alpha}|S_i], \quad i = 1, \dots, n. \tag{10}$$

Equation (10) implies that the price expectations of individual firms will differ according to their expectations of the industry-cost disturbance ($\alpha - \bar{\alpha}$). Since α is known by all informed firms, $E[\alpha - \bar{\alpha}|S_i] = \alpha - \bar{\alpha}$ for $i = 1, \dots, m$.

The uninformed, however, will form expectations of industrywide costs conditional on their individual realizations of k_i . Assuming that the joint distribution function of k_i and α is known, it follows that $E[\alpha - \bar{\alpha}|S_i] = \gamma(k_i - \bar{\alpha})$ for the uninformed firms,

³ We assume that the long-run average price component of each firm's expected price level is sufficiently high relative to the realization of its individual costs to rule out negative output levels. Although we have assumed that cost conditions are normally distributed, this constraint technically implies corresponding constraints on the cost distribution functions that we shall ignore.

$i = m + 1, \dots, n$, where $\gamma = \sigma_\alpha^2 / (\sigma_\alpha^2 + \sigma_\epsilon^2)$. The parameter γ may be interpreted as a measure of how well a firm's current observation of $k_i - \bar{\alpha}$ serves as an estimate of $\alpha - \bar{\alpha}$. For example, as γ tends to 1, the variations in observed $k_i - \bar{\alpha}$ depend increasingly on variations in industrywide cost conditions. Accordingly, $k_i - \bar{\alpha}$ serves as a better estimate of $\alpha - \bar{\alpha}$. As γ tends to 0, average industry-cost conditions, $\bar{\alpha}$, serve as a better estimate of α .⁴

The average price expectations of the informed and uninformed are given, respectively, by

$$P_I^e = \bar{P} + B(\alpha - \bar{\alpha}) \quad (11a)$$

and

$$P_U^e = \bar{P} + B\gamma(\alpha - \bar{\alpha}), \quad (11b)$$

where in the latter case it is assumed that there is a sufficiently large number of uninformed firms such that the average of their k_i observations is α .

Inserting P_I^e and P_U^e in (8), collecting terms on $\alpha - \bar{\alpha}$, comparing intercept and slope coefficients with (9), and using the method of undetermined coefficients imply

$$\bar{P} = \frac{a + b\bar{\alpha}}{1 + b} \quad (12)$$

$$B = \frac{b}{1 + b\lambda + \gamma b(1 - \lambda)}. \quad (13)$$

Substituting (13) back in (9) and (11a) and in (7) and (11b), respectively, yields the following expressions for the equilibrium industry price and output:

$$P = \bar{P} + (b/v)(\alpha - \bar{\alpha}) + u, \quad (14)$$

$$Y = \bar{P} - \bar{\alpha} - (1/v)(\alpha - \bar{\alpha}), \quad (15)$$

where $v = 1 + b\lambda + b\gamma(1 - \lambda)$. The equilibrium price depends on the long-run average price (\bar{P}), current industrywide cost disturbances ($\alpha - \bar{\alpha}$), and current demand disturbances (u). Equilibrium industry output depends on the long-run average output level ($\bar{P} - \bar{\alpha}$) and on current industry cost disturbances. It does not depend on current demand conditions, because production decisions are made before the realization of demand disturbances and the determination of the equilibrium price.

The above equilibrium presumes that each firm's information set S_i includes the structural parameters $\bar{\alpha}$, γ , a , and b as well as λ .⁵

The effects of transitory demand and industrywide cost disturbances on the equilibrium price and output are clearly discerned from (14) and (15). A positive transitory demand disturbance ($u > 0$), for example, leads to a rise in price above its average value. A transitory increase in current industry-cost conditions above their average level ($\alpha - \bar{\alpha} > 0$) will lead to a rise in price above \bar{P} and to a fall in output below $\bar{P} - \bar{\alpha}$. The magnitude of the output and price response diminishes as either the share of informed firms (λ) or the relative variance of industrywide disturbances (γ) rises. Intuitively, as more firms are informed or as individual cost conditions provide a better guide to industrywide cost conditions, the greater is the expectation that the market price will rise

⁴ The expectation formations of the uninformed firms may be interpreted as being subject to an error-in-variable measurement problem in which the variable $\alpha - \bar{\alpha}$ is measured by $k_i - \bar{\alpha}$ with error ϵ_i (Johnston, 1972, pp. 281-291).

⁵ Frydman (1982) shows that firms generally cannot learn the structural parameters, and, therefore, a rational expectations equilibrium cannot be achieved if firms do not know how others form their expectations. He has also shown that if firms know how others form expectations, then convergence to a rational expectation equilibrium like ours may occur.

in response to what is an industrywide cost increase. Since aggregate output will then contract less, the equilibrium price increase is dampened.

To illustrate the properties of the equilibrium we further analyze the characteristics of price forecast errors. Two properties of individually rational price expectations are (i) the *ex ante* forecast error is zero, and (ii) the covariance between the forecast error and the price forecast is zero.

From (10) and (14) one may derive measures of the price forecast errors of individual informed and uninformed firms. We denote these errors as δ_I^i and δ_U^i , respectively:

$$\delta_I^i \equiv P - E[P|I_i] = u, \quad i = 1, \dots, m, \quad (16a)$$

$$\delta_U^i \equiv P - E[P|U_i] = (b/v)(\alpha - \bar{\alpha} - \gamma(k_i - \bar{\alpha})) + u, \quad i = m + 1, \dots, n, \quad (16b)$$

since

$$E[P|I_i] = \bar{P} + (b/v)(\alpha - \bar{\alpha}) \quad (17a)$$

$$E[P|U_i] = \bar{P} + (b/v)\gamma(k_i - \bar{\alpha}). \quad (17b)$$

It is easily confirmed that for individual informed and uninformed firms, the above properties for rational expectations hold.

3. Equilibrium in the information market

■ The expressions for equilibrium price and output in the goods market derived in the previous section depend on the share of firms λ ($=m/n$) that have chosen to acquire information about the level of industrywide cost conditions (α). In this section we analyze the demand for industrywide cost information and determination of the equilibrium λ (denoted λ^*). We do not specify the supply side of the information market in detail, and simply assume that each firm can acquire information about the level of α at a fixed cost c from an external source.⁶

□ **Determination of the equilibrium share of informed firms (λ^*).** The equilibrium share of informed firms (λ^*) is determined when no uninformed firm can increase its expected profits by purchasing information about industrywide costs. We now specify this equilibrium condition in more detail.

Define $E[\Pi_i^*|S_i]$ as the *output-optimized* level of expected profits of firm i , where S_i is the firm's information set *after* the information purchase decision is made. Formally, the expression for $E[\Pi_i^*|S_i]$ may be obtained by inserting the expressions for the optimal output level $y_i = y_i^*$, given by (5), into the expected profit expression $E[\Pi_i^*|S_i]$, given by (4). Recalling that $z = 1/n$ and rearranging give the following quadratic formula:

$$E[\Pi_i^*|S_i] = \frac{1}{2n} (E[P|S_i] - k_i)^2 - c_i, \quad (18)$$

where $S_i = I_i$ and $c_i = c$ if a firm is informed, $i = 1, \dots, m$; $S_i = U_i$ and $c_i = 0$ if a firm is uninformed, $i = m + 1, \dots, n$.

Equilibrium in the information market requires that the m th firm purchasing information be indifferent between being informed or uninformed, given its information

⁶ The supplier of information can be interpreted as an outside advisory service. The cost of information to each firm will correspond only to the cost of transferring information among firms, unless contracts can be made to prohibit such transfer. If such contracts cannot be made, then information may not be collected at all unless there are many firms' buying information in equilibrium; i.e., unless the number of informed firms m in our model is large. The reason is that the original supplier of information must be able to spread its real resource costs in collecting and processing the useful information over many purchases. For further discussion of equilibrium in information markets, see Demsetz (1969).

set *at the time* the information purchase decision is made (cf. Grossman and Stiglitz, 1980). This information set, which we denote by T_i , includes the structural parameters of the model ($a, b, \bar{\alpha}, \sigma_\alpha^2, \gamma$). The expected profit of being informed, conditional on T_i , is $E[E[\Pi_i^*|I_i]|T_i] - c$. The expected profit of remaining uninformed evaluated at the same time is $E[E[\Pi_i^*|U_i]|T_i]$. The incentive to become informed (F_i^T) is the difference between these two expectations:

$$F_i^T \equiv E[E[\Pi_i^*|I_i]|T_i] - E[E[\Pi_i^*|U_i]|T_i] - c. \quad (19)$$

The difference between the first two terms on the right-hand side of (19) represents the expected opportunity cost of remaining uninformed. Thus, the incentive to become informed may also be interpreted as the difference between the expected opportunity cost of remaining uninformed and the cost of information.

If firms make their information purchase decision *after* obtaining knowledge about their individual cost conditions, then k_i is included in T_i as well. We show in the Appendix that a "free-rider" problem may arise in this case. The reason is that with knowledge of k_i as well as λ , the m th firm can costlessly infer $(\alpha - \bar{\alpha})^2$, and therefore the magnitude (though not the sign) of the industrywide cost disturbance.⁷ We demonstrate that this knowledge affects the m th firm's incentive to purchase information in such a way that *either* no firm *or* all firms will purchase information about current industrywide costs. No firms will purchase information when the current α is relatively small, while all firms will purchase information if the current α is relatively large. Thus, if the decision to purchase information is made at the time individual cost conditions are known, an information market will not exist in all periods. Since the supplier of information presumably must cover his fixed costs, it is likely that an information market will not exist at all in this case.

It is reasonable to assume, therefore, that information will be purchasable only *before* firms observe their individual cost conditions.⁸ The information set T_i then contains only structural parameters, and will be identical for all firms. In this case evaluation of expression (19) with the use of (17a), (17b), and (18) implies that the incentive to become informed is given by⁹

⁷ The marginal firm cannot evaluate the incentive to being informed unless it knows the number of firms that have already purchased information, and therefore λ . If the cost of information c were a monotonic function of λ , the marginal firm could learn λ by observation of c .

⁸ The information supplied could refer to the average skill and/or educational level of labor in the industry. This type of information may be available before each firm learns the productivity of its own resources. It must be assumed that factor market imperfections prevent firms from learning industrywide cost conditions by observing factor prices at the time resources are used. Alternatively, the information could relate to common weather conditions affecting firms (i.e., farms) engaged in agriculture.

⁹ To derive (19a), note first that (17a), (17b), and (18) imply

$$E[\Pi_i^*|I_i] = \frac{1}{2n} \left[(\bar{P} - k_i)^2 + \frac{b^2}{v^2} (\alpha - \bar{\alpha})^2 + 2(\bar{P} - k_i) \left(\frac{b}{v} \right) (\alpha - \bar{\alpha}) \right]$$

$$E[\Pi_i^*|U_i] = \frac{1}{2n} \left[(\bar{P} - k_i)^2 + \frac{b^2}{v^2} \gamma^2 (k_i - \bar{\alpha})^2 + 2(\bar{P} - k_i) \left(\frac{b\gamma}{v} \right) (k_i - \bar{\alpha}) \right].$$

Substitute in (19) and evaluate expectations conditional on the information set T_i which excludes k_i . We obtain (19a) by noting that

$$E \left[2(\bar{P} - k_i) \frac{b}{v} (\alpha - \bar{\alpha}) | T_i \right] = 0$$

$$E \left[2(\bar{P} - k_i) \frac{b}{v} \gamma (k_i - \bar{\alpha}) | T_i \right] = 0$$

$$F_i^T \equiv \frac{1}{2n} \left\{ \frac{b^2}{v^2} (1 - \gamma) \gamma \sigma_k^2 \right\} - c, \tag{19a}$$

where $v = 1 + b\lambda + b\gamma(1 - \lambda)$, $\sigma_k^2 = \sigma_\alpha^2 + \sigma_\epsilon^2$, and $\gamma = \sigma_\alpha^2 / (\sigma_\alpha^2 + \sigma_\epsilon^2)$. Observe that the first term on the right-hand side, the expected opportunity cost of remaining uninformed, depends on the variance of individual and relative cost disturbances, but not on the expected cost disturbance nor on demand disturbances. The reason is that only the variance of anticipated profits associated with cost uncertainty is affected by the degree of cost information, and at the time information purchase decisions are made each firm's expectation of its individual cost disturbance ($k_i - \bar{\alpha}$) is zero.¹⁰

Note also from (19a) that at the time information purchase decisions are made the incentive to become informed is the same for all firms. The incentive depends only on structural parameters (and on λ) and not on firm-specific or time-specific factors. Our analysis thus allows us to determine the industry equilibrium share (or number) of informed firms and the way in which this share depends on the structural parameters of the model, but not the individual firms that are informed.¹¹

Equilibrium in the information market occurs for $0 < \lambda^* < 1$ when $F_i^T = 0$; for $\lambda^* = 0$ when $F_i^T < 0$; and for $\lambda^* = 1$ when $F_i^T > 0$, for all i . Determination of the level of λ that solves (19a)—the equilibrium share of informed firms, λ^* —is described graphically in Figure 1. The cost of information is independent of λ , and is graphed as a horizontal line. The expected opportunity cost of remaining uninformed decreases as λ increases, however, because the greater the proportion of informed firms, the smaller is the difference between the variances of anticipated profit of being uninformed and informed, respectively. Recall from the interpretation of (14) and (15) that the price and output effects of cost disturbances decrease as more firms are informed.

Assuming λ^* lies within the lower bound of 0 and the upper bound of 1, λ^* is determined by the intersection of the two curves. The equilibrium in the information market thus determined is stable. For $\lambda < \lambda^*$, the expected opportunity cost of remaining uninformed is larger than c , and the proportion of informed firms will increase.

$$E \left[\frac{b^2}{v^2} (\alpha - \bar{\alpha})^2 | T_i \right] = \frac{b^2}{v^2} \sigma_\alpha^2 = \frac{1}{2n} \frac{b^2}{v^2} \gamma \sigma_k^2$$

$$E \left[\frac{b^2}{v^2} \gamma^2 (k_i - \bar{\alpha})^2 | T_i \right] = \frac{b^2}{v^2} \gamma^2 \sigma_k^2.$$

¹⁰ Even though firms are risk neutral, the expected profits to being informed and to remaining uninformed depend on variances, since output-optimized expected profits are quadratic in expected price and production costs. See equation (18).

¹¹ If no external suppliers of relevant information exist, it is possible to assume that firms can become informed by *investing* in one period for a fixed cost in the capability to gather and analyze the desired information for the current and all subsequent periods. It can be shown that the share of firms that do so is given by a condition that is virtually identical to (19a).

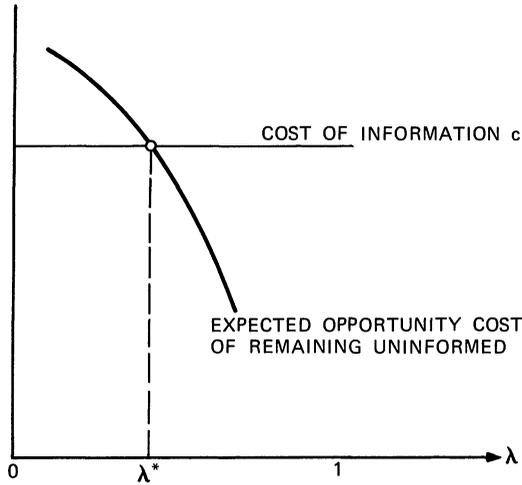
Define G_i^T as the incentive to invest in information-gathering capability for period 0 and all subsequent periods, where

$$G_i^T \equiv E_0 \left[\sum_{t=0}^{\infty} E_t [\Pi_t^* | I_t] \left(\frac{1}{1+r} \right)^t \middle| T_i \right] - E_0 \left[\sum_{t=0}^{\infty} E_t [\Pi_t^* | U_t] \left(\frac{1}{1+r} \right)^t \middle| T_i \right] - c_k$$

and E_0 is the expectation operator at time 0, T_i is the information set that includes only structural parameters, and c_k is the one-time fixed investment cost of information-gathering capability. Since $E_0[E_t[\Pi_t^*|I_t]|T_i]$ and $E_0[E_t[\Pi_t^*|U_t]|T_i]$ depend only on structural parameters and are independent of time, it is possible to obtain in a manner analogous to the derivation of (19a):

$$G_i^T \equiv \left(\frac{1}{2nr} \right) \left\{ \frac{b^2}{v^2} (1 - \gamma) \gamma \sigma_k^2 \right\} - c_k.$$

FIGURE 1
EQUILIBRIUM IN THE INFORMATION MARKET



The decrease in the expected opportunity cost of being uninformed as λ increases can be interpreted as a positive externality of information purchase: the incentive for each firm to purchase information declines as other firms buy information. In Grossman and Stiglitz (1980) another externality of information purchase exists. In their framework as λ increases, the price level becomes informationally more efficient in the sense that it conveys more information about other individuals' expectations at the time decisions are made. This externality does not exist in our framework, since the market price cannot be observed until after the decisions to purchase information and to supply output are made.

□ **Comparative statics of the equilibrium share of informed firms.** Equation (19a) may be solved explicitly for λ^* by assuming an interior solution and by setting $F_i^i = 0$. Defining $q = \sigma_\alpha/\sigma_\epsilon$ and noting that $q^2 = \gamma/(1 - \gamma)$ and that v can also be expressed as $1 + b\gamma + b\lambda(1 - \gamma)$ yield¹²

$$\lambda^* = q\sigma_k(2cn)^{-1/2} - \left(\frac{1+b}{b}\right)q^2 - \frac{1}{b}, \quad 0 < \lambda^* < 1. \quad (20)$$

The determinants of λ^* come out clearly in (20). They include industrywide relative to firm-specific cost variability (q), total cost variability of the firm (σ_k), the cost of information (c), the number of firms (n), and the price sensitivity of demand (b). The equilibrium share of informed firms thus depends only on the structural parameters contained in the information set T_i . This property of (20) allows us to separate the determination of λ^* from the determination of the goods market equilibrium.

Equation (20) shows that the equilibrium share of informed firms falls with the cost of information (c) and increases with total cost variability (σ_k). The share of informed firms will also increase with an increase in price sensitivity of demand, since

$$d\lambda^*/db = (1 + q^2)/b^2 > 0.$$

¹² From (19a), $F_i^i = 0$ gives $(b/v)^2(1 - \gamma)\gamma\sigma_k^2 = 2nc$. Since all individual terms are positive, taking the square root of both sides implies $\frac{b}{v} = \{(2nc)/(\gamma(1 - \gamma)\sigma_k^2)\}^{1/2}$. Substituting for $v = 1 + b\gamma + b\lambda(1 - \gamma)$ and for $\gamma/(1 - \gamma) = q^2$ gives (20).

Intuitively, as b increases, the equilibrium price becomes more sensitive to changes in supply brought about by variations in cost. This increases the incentive to be informed.

The effect of changes in industrywide relative to firm-specific cost variability on λ^* ,

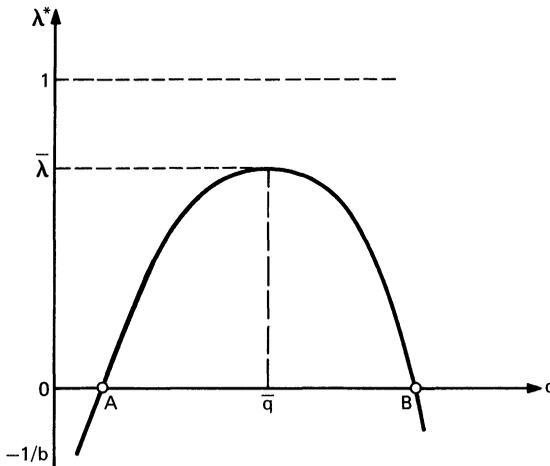
$$d\lambda^*/dq = \sigma_k(2cn)^{-1/2} - 2q(1 + b)/b,$$

is perhaps the most interesting aspect of expression (20). Figure 2 provides insight into the role of q by graphing λ^* as a function of q . Since the second derivative of λ^* with respect to q is negative, λ^* has a maximum, $\bar{\lambda}$, at \bar{q} .¹³ For $q < \bar{q}$, $d\lambda^*/dq > 0$: the number of informed firms rises as industrywide variability increases relative to firm-specific variability. The reason for this is that when there is relatively little variability in $\alpha - \bar{\alpha}$, variations in $k_i - \bar{\alpha}$ arise predominantly from firm-specific causes. Average industry cost conditions ($\bar{\alpha}$) then provide a reasonable guide to firms for current industrywide conditions. As relative industrywide variability rises, the incentive to collect costly information about the current α increases. On the other hand, for $q > \bar{q}$, $d\lambda^*/dq < 0$: the number of informed firms falls as industrywide variability increases relative to firm-specific variability. When q is relatively large, the variations in $k_i - \bar{\alpha}$ primarily reflect industrywide conditions. Therefore, $k_i - \bar{\alpha}$ is a good guide for each firm to current industrywide conditions. As q increases, this further reduces the incentive for firms to be informed about α .

The above reasoning leads to the conclusion that the incentive to collect information is high only in the middle range of values of q for which there is a comparable degree of variance in industrywide and firm-specific conditions. Then $\bar{\alpha}$ and k_i are both poor guides to industrywide conditions. In other words, the incentive to collect information is high when there is much variability in what firms want to know ($\alpha - \bar{\alpha}$) as well as much noise in what they observe ($k_i - \bar{\alpha}$).

The equilibrium share of informed firms (λ^*) is necessarily bounded by zero and one. There is a range of values of q to the left of point A and to the right of point B for which $\lambda^* = 0$ is binding and within which no firms will collect information. There may

FIGURE 2
EQUILIBRIUM SHARE OF INFORMED FIRMS AS A FUNCTION OF INDUSTRYWIDE RELATIVE TO FIRM-SPECIFIC COST VARIABILITY



¹³ It can be shown that $\bar{q} = (1/2)(\sigma_k^2/2cn)^{1/2}[b/(1 + b)]$ and that $\bar{\lambda} = (1/4)(\sigma_k^2/2cn)[b/(1 + b)] - (1/b)$.

also be a range of values of q for which the upper bound $\lambda^* = 1$ is binding and within which every firm will collect information.¹⁴

Lastly, we point out that the number of firms in the industry (n) also enters the determination of the equilibrium share of informed firms. The reason is that the total cost of information to the industry (cn) for a given share of informed firms λ ($=m/n$) increases with n . Therefore, information costs could affect the number of firms in the industry. Nevertheless, we treat n as exogenous and constant, and regard information costs as relatively insignificant for determining the number of firms in the industry.

4. Comparative statics of price and output with endogenous determination of information purchase

■ In Section 2 we discussed output and price adjustment to transitory demand and cost disturbances while assuming the industry share of informed firms is exogenous. In this section we analyze the effects on the equilibrium output and price level of changes in different structural parameters, including those that affect the equilibrium share of informed firms. In doing so we compare two industry equilibria in which firms have been able to identify the structural parameters corresponding to each equilibrium. We do not concern ourselves with the process according to which firms learn the structural parameters as the industry adjusts from one equilibrium to the other.¹⁵

To take into account the parameter shifts that cause changes in λ^* , we first rearrange (19a) to obtain

$$v \equiv 1 + b\lambda^* + b\gamma(1 - \lambda^*) = b\left(\frac{\gamma - \gamma^2}{2cn}\right)^{1/2} \sigma_k. \quad (21)$$

Substituting (21) in (14) and (15) gives the following expressions for the equilibrium industry price and output in terms of the determinants of λ^* :

$$P = \bar{P} + \left(\frac{2cn}{\gamma - \gamma^2}\right)^{1/2} \left(\frac{\alpha - \bar{\alpha}}{\sigma_k}\right) + u, \quad (22)$$

$$Y = \bar{P} - \bar{\alpha} - \left(\frac{2cn}{\gamma - \gamma^2}\right)^{1/2} \left(\frac{\alpha - \bar{\alpha}}{b\sigma_k}\right), \quad (23)$$

where $\bar{P} = (a + b\bar{\alpha})/(1 + b)$. Permanent shifts in demand are captured by changes in the intercept (a) of the demand function (2). Permanent cost changes are reflected by changes in the average level of industrywide costs ($\bar{\alpha}$). An increase in a leads to both higher levels of average industry output and price. An increase in $\bar{\alpha}$ leads to a lower level of \bar{Y} ($=\bar{P} - \bar{\alpha}$) and a higher level of \bar{P} .

From (22) and (23) the responses of price and output to changes in transitory industrywide cost disturbances (changes in α relative to a given level of $\bar{\alpha}$) are given by

$$\frac{dP}{d(\alpha - \bar{\alpha})} = \left(\frac{2cn}{\gamma - \gamma^2}\right)^{1/2} \left(\frac{1}{\sigma_k}\right) > 0 \quad (24)$$

$$\frac{dY}{d(\alpha - \bar{\alpha})}\bigg|_{\bar{\alpha}} = -\left(\frac{2cn}{\gamma - \gamma^2}\right)^{1/2} \left(\frac{1}{b\sigma_k}\right) < 0. \quad (25)$$

¹⁴ The condition for which the upper bound is binding is $\bar{\lambda} > 1$, or $[(b/(1 + b))]^2 \sigma_k^2 > 8cn$. The condition for $\bar{\lambda} > 0$ is $[b^2/(1 + b)] \sigma_k^2 > 8cn$.

¹⁵ It is assumed that the process by which firms learn the new parameters of the system is convergent (cf. Frydman, 1982).

We observe that an increase in c increases the sensitivity of P and Y to a cost increase. With higher information costs, fewer firms choose to be informed. As a result, more firms reduce output, and prices increase more in response to the cost disturbance. An increase in the *total* variability of firm cost conditions σ_k , holding *relative* variability γ constant, clearly *reduces* the sensitivity of P and Y to a cost increase by inducing more firms to buy information.

To examine the effect of an increase in *relative* cost variability γ , holding *total* cost variability σ_k constant, we obtain from (24) and (25)

$$\frac{d(dP/d(\alpha - \bar{\alpha}))}{d\gamma} = -\frac{1}{2}(\gamma - \gamma^2)^{-3/2}(1 - 2\gamma)\sigma_k^{-1}(2cn)^{1/2} \quad (26)$$

$$\frac{d(dY/d(\alpha - \bar{\alpha}))}{d\gamma} = \frac{1}{2}(\gamma - \gamma^2)^{-3/2}(1 - 2\gamma)\sigma_k^{-1}(2cn)^{1/2}b^{-1}. \quad (27)$$

The term within the first parentheses of both (26) and (27) is clearly positive since $\gamma < 1$. Thus, the term within the second parentheses of both conditions determines the sign. Specifically, if $\gamma > 1/2$, (26) is positive and (27) is negative. Hence, the sensitivity of price and output increases with higher γ . For $\gamma \leq 1/2$, sensitivity decreases with increasing γ .

This result accords with our finding that the equilibrium share of informed firms is greatest for relatively low *and* relatively high values of $q = (\gamma/(1 - \gamma))^{1/2}$ and reaches a maximum for an intermediate value. Here we find that the sensitivities of output and price are at a minimum when γ takes on the intermediate value of $\gamma = 1/2$ ($q = 1$). Note, however, that the value of γ (or q) that minimizes price sensitivity is not identical to the value of γ (or q) for which λ^* is at a maximum ($\bar{\lambda}$). The discrepancy can be explained by observing from (14) that a change in γ affects price sensitivity directly through the denominator of the price sensitivity coefficient ($v = 1 + b\lambda + b\gamma(1 - \lambda)$) as well as indirectly through its effect on λ .

Since the price effect of a cost disturbance depends on the variability of cost disturbances through γ and σ_k , it is interesting to look at how price variance (σ_P^2) depends on σ_α^2 and on σ_u^2 . Using (22), we obtain

$$\sigma_P^2 = \frac{2cn}{1 - \gamma} + \sigma_u^2, \quad \text{for } 0 < \lambda^* < 1. \quad (28)$$

Equation (28) shows that when the effect on information purchase of a change in σ_α^2 is taken into account, the price variance due to cost disturbances depends only on γ , the *relative* variance. As σ_α^2 increases relative to σ_k^2 , the price variance increases. When both σ_α^2 and σ_k^2 increase, however, the price variance remains unchanged because of the increased incentive to purchase information.

5. Conclusions and the direction of further research

■ We have analyzed the role that information plays in price and output adjustment when competitive firms with rational expectations cannot directly distinguish between industrywide and firm-specific cost disturbances. Among our results, we show that the sensitivity of price and output to *cost* disturbances decreases as more firms choose to purchase information about industrywide cost conditions. Assuming that information can only be acquired before the revelation of an individual firm's cost conditions, the equilibrium share of informed firms is determined by the cost of information, total cost variability, and the relative variability of industrywide to firm-specific cost conditions. An interesting result is that the incentive to purchase information is greatest when there is a similar degree of variability in industrywide and firm-specific cost conditions. Furthermore,

the degree of price sensitivity is then relatively small. Another result is that price variability due to cost disturbances depends only on the relative variability.

Our results provide insight into the role of information acquisition when local price changes depend on both local and aggregate *demand* disturbances (Lucas, 1972, 1973, 1975). Under such conditions firms would have an incentive to acquire information when there is variability in both local and aggregate demand.

In our framework, in contrast to Grossman and Stiglitz (1980), all firms may choose to become informed. The reason is that, even if all but one firm have acquired information, the remaining uninformed firm is still unable to infer from its local conditions whether the underlying disturbances are local or aggregate.

Our results are in one sense consistent with those of Grossman and Stiglitz (1980) since we find that under certain conditions a free-rider problem may arise, and an information market may not exist. An important topic for further research would be to analyze how the nature and timing of information availability may cause such a problem.

Another interesting extension would be to include factor and/or financial markets in the model, since prices in these markets may reveal relevant information. We have implicitly assumed that firms do not obtain any information from these markets.

Our analysis has also ruled out the possibility that firms may hold and adjust inventories. The nature of inventory decisions in response to cost and demand disturbances should be incorporated in a more complete model of firm behavior, since inventory adjustment tends to decrease price and output sensitivity to disturbances. Blinder (1982), Amihud and Mendelson (1982), and Glick and Wihlborg (1985) have developed models of price, output, and inventory adjustment for monopolistic firms. In another paper (Glick and Wihlborg, 1984) we develop a model in which the ability to adjust inventories may be viewed as potentially *substitutable* for the purchase of information in response to uncertainty about demand as well as cost conditions.

Appendix

■ **The incentive to become informed when individual cost conditions are known.** In this Appendix we show that all firms will choose to be either informed or uninformed, if their respective information sets at the time decisions are made about the purchase of information (T'_i) include their individual cost condition realizations k_i .

Evaluation of expression (1) conditional on T'_i , following the procedure described in footnote (9), implies that a firm's incentive to become informed is given by

$$F_i^{T'} \equiv \frac{1}{2n} \left\{ \left(\frac{b}{v} \right)^2 (1 - \gamma^2) \sigma_a^2 - \left(\frac{b}{v} \right)^2 \gamma^2 (k_i - \bar{\alpha})^2 \right\} - c, \quad (\text{A1})$$

where $v = 1 + b\lambda + b\gamma(1 - \lambda)$.

Expression (A1) indicates that for a given share of informed firms (λ), the incentive to become informed depends on $(k_i - \bar{\alpha})^2$. The smaller is $(k_i - \bar{\alpha})^2$, the greater is the firm's incentive to purchase information. By definition, equilibrium in the information market implies that for $i = m$, $F_m^{T'} = 0$ (assuming an interior solution). Denote by k_m the cost realization of this marginal firm.

Under the assumption that n is large, the actual cost conditions of individual firms (k_i) are distributed normally around α with a variance σ_c^2 . Then, knowledge of k_m and λ and knowledge that all firms with $(k_i - \bar{\alpha})^2 < (k_m - \bar{\alpha})^2$ are informed would enable the marginal firm to infer $(\alpha - \bar{\alpha})^2$ by solving the following equation for the share of informed firms:

$$\lambda = \int_{-(k_m - \bar{\alpha})}^{k_m - \bar{\alpha}} \frac{1}{\sqrt{2\pi}\sigma_c} e^{-[(\alpha - \bar{\alpha}) - (k_i - \bar{\alpha})]^2 / 2\sigma_c^2} dk_i. \quad (\text{A2})$$

The revelation of $(\alpha - \bar{\alpha})^2$ to the m th firm implies that its incentive to become informed must be revealed conditional on an information set T_m'' that includes $(\alpha - \bar{\alpha})^2$ as well as k_m .

Denote by $F_m^{T''}$ the incentive to become informed conditional on T_m'' . Then

$$F_m^{T''} \equiv \frac{1}{2n} \left\{ \left(\frac{b}{v} \right)^2 (\alpha - \bar{\alpha})^2 - \left(\frac{b}{v} \right)^2 \gamma^2 (k_m - \bar{\alpha})^2 \right\} - c. \quad (\text{A3})$$

The only difference between $F_m^{T^*}$ and $F_m^{T'}$ occurs in the evaluation of the expected profits of being informed.¹⁶ Recall that $F_i^{T'} = 0$ for $k_i = k_m$. Then, inserting into (A3) the value of $(k_m - \bar{\alpha})$, obtained by setting $F_i^{T'} = 0$ in (A1), implies that the incentive for the m th firm to become informed is now given by

$$F_m^{T^*} \equiv \frac{1}{2n} \{(\alpha - \bar{\alpha})^2 - (1 - \gamma^2)\sigma_\alpha^2\}. \quad (\text{A4})$$

Observe that $F_m^{T^*} < 0$ if the magnitude of the current industrywide cost disturbance does not exceed the fixed value $(1 - \gamma^2)\sigma_\alpha^2$. Then, no firm will purchase information. This result follows from the fact that $F_m^{T^*}$ is independent of $(k_m - \bar{\alpha})$. On the other hand, if $(\alpha - \bar{\alpha})^2$ is relatively large, all firms will purchase information. We assume in the text of the article that no information market can exist under these conditions because of fixed costs of information supply and costs of entering and exiting the market to the supplier.

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¹⁶ Identity (A3) is obtained by using the following conditional expectations relations:

$$E[\alpha - \bar{\alpha}|k_i, (\alpha - \bar{\alpha})^2] = E[\alpha - \bar{\alpha}|k_i], \quad E[(\alpha - \bar{\alpha})^2|(\alpha - \bar{\alpha})^2] = (\alpha - \bar{\alpha})^2$$

$$E[(\alpha - \bar{\alpha})^2|k_i] = (1 - \gamma^2)\sigma_\alpha^2.$$