WILEY

Institute of Social and Economic Research, Osaka University

Equilibrium Adjustment with Endogenous Information and Inventories

Author(s): Reuven Glick and Clas Wihlborg

Source: *International Economic Review*, Vol. 32, No. 4 (Nov., 1991), pp. 869-890
Published by: Wiley for the Economics Department of the University of Pennsylvania and Institute of Social and Economic Research, Osaka University
Stable URL: http://www.jstor.org/stable/2527040
Accessed: 16-04-2018 23:23 UTC

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at http://about.jstor.org/terms

Wiley, Institute of Social and Economic Research, Osaka University are collaborating with JSTOR to digitize, preserve and extend access to *International Economic Review*

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

INTERNATIONAL ECONOMIC REVIEW
Vol. 32, No. 4, November 1991

EQUILIBRIUM ADJUSTMENT WITH ENDOGENOUS INFORMATION AND INVENTORIES*

By Reuven Glick and Clas Wihlborg[1]

The paper analyzes the interaction of information acquisition and inventory flexibility with industry adjustment to imperfectly perceived cost and demand disturbances. Improved information about disturbances reduces the extent to which disturbances are unperceived and dampens the use of inventories. Reduced inventory flexibility induces firms to devote more resources to acquiring information about disturbances. The analysis demonstrates how equilibrium price and output adjustment depend endogenously on the degree of inventory flexibility and other structural parameters influencing the acquisition of information.

1. INTRODUCTION

In this paper we analyze how endogenous information acquisition and inventory flexibility influence price and output adjustment in a competitive industry. We focus on the potential substitutability of information acquisition for inventory flexibility when disturbances are imperfectly perceived by individual firms. The analysis highlights the general issue of how market adjustment depends on structural parameters that influence agents' incentives to acquire information.

There are several reasons why information acquisition may play a role in market adjustment. First, the rapid development of information technology has enabled firms to gather and process data relevant to production and sales decisions from a greater number of external and internal sources. This trend has reduced the costs of forecasting and monitoring factors influencing production and demand conditions for the individual firm relative to those of its competitors, as well as for the industry as a whole. In particular, it has permitted quicker awareness of changing customer demand as well as greater control of the flow of inputs and intermediate goods during the production process. This implies that the resources devoted to information acquisition and processing have come to play an important role in firm decisions.[2]

Second, improved information about demand and cost conditions may affect the function of inventories. Inventory adjustment allows a firm's production costs to be "smoothed" in response to anticipated movements in demand and costs and to be "buffered" against unanticipated disturbances (see Ashley and Orr 1985). Thus,

* Manuscript received July 1988.

[1] The opinions expressed herein are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of San Francisco or of the Board of Governors of the Federal Reserve System. The authors are appreciative of helpful comments received from seminar participants at New York University and the University of Southern California.

[2] Examples of the implications of recent information technology advances for firm management are contained in "A Survey of Information Technology," *Economist*, June 16, 1990.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

improved information may enhance the smoothing role and diminish the buffer role of inventories by improving the extent to which disturbances can be forecast. This implies that increased inventory flexibility may lessen the incentive to acquire and process information about disturbances.

Third, several recent papers have shown how the analysis of price and output adjustment under rational expectations can be affected when information is endogenous. For example, Grossman and Stiglitz (1980) show that financial asset prices cannot reveal "available" information perfectly if agents are to have an incentive to purchase information about exogenous disturbances. Glick and Wihlborg (1986) show that, as a result of changing incentives for information acquisition, real output adjustment to monetary disturbances need not decrease and may actually increase as the relative variance of monetary disturbances rises. In a similar spirit, Hahm (1987) shows that with endogenous information acquisition the output-inflation trade-off does not necessarily vary inversely with the relative variance of monetary disturbances.

The modelling of inventory adjustment in this paper follows the production-smoothing model as developed by Amihud and Mendelson (1982) and Blinder (1982). While the production-smoothing model has generally not fared well in empirical tests, recently more disaggregate studies (e.g., Eichenbaum 1989; Fair 1989) have proven somewhat more successful.[3] The relative success of disaggregated inventory tests may perhaps be attributed to structural differences across industries that significantly influence the degree of inventory usage as an adjustment mechanism to disturbances. Topel (1982) and Haltiwanger and Maccini (1988), for example, argue that varying production through layoffs and hires may serve as a substitute for inventory adjustment and that the relative costs of employment adjustment vary across industries. Kahn (1987) shows that in industries in which stock-outs may occur the use of inventories in response to adverse demand shocks may be less than in industries in which unfilled orders can serve as negative inventories. Dudley and Lassere (1989) have argued that information and inventories may work as substitutes to varying degrees across industries. This suggests that further refinement and analysis of the production-cost smoothing model to incorporate alternative responses to disturbances may shed additional light on the role of inventories for price and output adjustment across industries.

In this paper we analyze the effect of information acquisition as well as of inventory flexibility on adjustment to cost and demand disturbances. We determine the equilibrium sales, inventories, output, and price levels within a competitive industry, as well as the share of firms in the industry devoting resources to the

[3] In contrast to the implication of the standard production-smoothing model of inventories, Feldstein and Auerbach (1976), Blanchard (1983), Eichenbaum (1984), and Christiano (1988) find that the variance of output exceeds the variance of sales and/or that inventory stock adjustment is unreasonably slow. Glick and Wihlborg (1985b) and Blinder (1986), however, show theoretically that if cost disturbances dominate demand disturbances then output variance may exceed sales variance. Eichenbaum (1989) cannot reject the existence of production cost smoothing in response to cost disturbances, and estimates faster stock adjustment. Fair (1989) finds that the variance of sales exceeds that of output in six of the seven industries he examines. It should be noted that he uses a data set for which the timing of inventory and output observations coincide more closely than that used in other studies.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

acquisition of information about factors influencing the price at which output can be sold. To better focus the analysis we assume inventories may be positive or negative; i.e., firms may accept unfilled orders. In addition, we do not consider employment adjustment.

As in other models with endogenous information, the purchase of information by some agents creates a positive externality on others. In Grossman and Stiglitz (1980) and Hahm (1987), for example, the market price becomes more revealing as an increasing number of agents acquire information about disturbances in the market. In our model this externality takes the form of a reduction in price variability that reduces the incentive of other firms to acquire information. In this respect the model is similar to that of Darby (1976) and Glick and Wihlborg (1985a). As a result of this externality it is possible that in equilibrium all firms may choose not to devote any resources to information acquisition about industry demand and cost conditions.

The plan of the paper is as follows. In Section 2 we describe the model and solve for the goods market equilibrium. Throughout this section it is assumed that an exogenous industry share of firms have acquired information about industry-wide conditions at the time production decisions are made. The equilibrium share of firms acquiring information about industry-wide conditions at the beginning of each period is determined in Section 3. In these two sections we limit the formal analysis to information about cost conditions, but it applies to information about demand conditions as well. The share of cost-informed firms is shown to depend on the cost of information, inventory flexibility, total cost variability, and the relative variability of industry-wide conditions. In Section 4 we reexamine how goods-market adjustment depends on inventory flexibility while taking account of how information acquisition about cost, as well as demand conditions, is influenced by inventory flexibility. Finally, in Section 5 we summarize our results and discuss implications of the analysis.

2. EQUILIBRIUM IN THE GOODS MARKET

In this section, we present a model of a competitive industry in which firms that produce and sell out of inventories are subject to unobservable industry-wide cost and demand disturbances. In the model several irreversible decisions are made sequentially within each period. At the beginning of each period, firms choose whether to become "informed" by acquiring information about the unobservable industry-wide cost disturbances. In addition, each firm observes individual cost and demand condition signals which only noisily reflect industry-wide conditions. The uninformed firms choose their output levels for the period based on these signals while informed firms choose output levels based on knowledge of industry-wide conditions as well. At the end of the period, each firm determines its end-of-period inventory holdings and (implicitly) how much to sell. Simultaneously, the market-clearing price level is determined.[4] We assume initially that information acquisition

[4] Our specification that output is set before price contrasts with the popular assumption of setting price before output in inventory models (see, e.g., Amihud and Mendelson 1982 and Flood and Hodrick 1985).

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

decisions have already been made, and analyze in this section equilibrium industry production, inventory, and price conditional on the given distribution of information among firms.

2.1. *Specification of Cost and Demand Functions.* The goods market consists of m firms all producing the same homogenous good, where m is assumed to be a large number. Each firm i possesses the following quadratic production cost function:

$$(1) \qquad C_t^i[y_t^i] = c_0 v_t^i y_t^i + \frac{mc_1(y_t^i)^2}{2}, \; c_0, \, c_1 > 0,$$

where $C_t^i[\cdot]$ is the cost of production at time t of the quantity of output y_t^i; v_t^i is a realization of a random production cost condition variable observed by firm i in period t; and m, the number of firms in the industry, acts as a scale parameter.[5] Note that changing realizations of cost conditions shift the firm's marginal cost of production.

The individual cost condition realization observed by firm i, v_t^i, is given by the sum of a component v_t, representing industry-wide conditions affecting the costs of all firms; and a component ε_{vt}^i, representing firm-specific cost conditions:

$$(2) \qquad v_t^i = v_t + \varepsilon_{vt}^i.$$

The variables v_t and ε_{vt}^i, are generated by independent, identical, and normal distribution (iid) functions such that $v_t \sim N(\bar{v}, \sigma_v^2)$ and $\varepsilon_{vt}^i \sim N(0, \sigma_{\varepsilon v}^2)$. Each firm's cost realization in period t, v_t^i, thus differs from that of other firms only by the independently distributed component ε_{vt}^i.

It is assumed that firms may not directly observe v_t or ε_{vt}^i separately in period t, and hence may not directly distinguish between industry-wide and firm-specific cost factors. However, for the moment, it is assumed that an exogenously given number of firms m_v, $0 \leq m_v \leq m$, or equivalently the industry share $\lambda_v = m_v/m$, have acquired knowledge of v_t at the beginning of period t. Firms which know v_t are termed "cost-informed." Those that do not are "cost-uninformed." Incomplete futures markets preclude the latter from hedging against all of the factors influencing cost conditions.

Each firm also bears inventory costs related to its inventory stock inherited from the end of the previous period, n_{t-1}^i. These costs are assumed quadratic as, for example in Blinder (1982),

The latter seems to be part of the Keynesian tradition of rigid prices. However, treating prices as less flexible than output in the market-clearing process seems incongruous with reality in many industries. Even in industries where list prices are set, substantial price adjustment often occurs through, for example, discounting.

[5] Scaling individual production costs by m implies that marginal *industry* production costs are independent of the number of firms. A similar specification is adopted for individual inventory holding costs. This enables us algebraically to express goods market equilibrium behavior independently of m as well. Since we treat m as an exogenous variable, this specification does not affect the results of the model.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

$$H_t^i[n_{t-1}^i] = h + h_0 n_{t-1}^i + \frac{mh_1(n_{t-1}^i)^2}{2}, \quad h, h_1 > 0. \tag{3}$$

$H_t^i[\cdot]$ can be interpreted as consisting of two components: storage costs that increase with inventory holdings and expected costs related, for example, to increasing price discounts when unfilled orders increase. The latter costs increase as inventory holdings fall. The "critical" level of inventories at which inventory costs are at a minimum may be positive or negative. (The parameter h_0 is restricted to values for which total inventory costs are positive.) Our main concern is with the parameter h_1 capturing the concept of inventory flexibility. It determines the slope of the marginal inventory holding-cost schedule. As h_1 falls, inventory holdings become more flexible, since a change in the inventory stock causes a smaller increase in marginal holding costs.

The volume of sales by firm i at time t, s_t^i, is related to production and inventory holdings by the following accounting identity:

$$s_t^i \equiv y_t^i - (n_t^i - n_{t-1}^i), \tag{4}$$

i.e., sales are given by current production *net* of the addition to the current inventory stock.

The demand side of the goods market is described by the following stochastic demand function:

$$P_t = d_0 + d_1 u_t - d_2 S_t, \quad d_0, d_1 > 0,$$

which by (4) is equivalent to

$$P_t = d_0 + d_1 u_t - d_2(Y_t - (N_t - N_{t-1})), \tag{5}$$

where S_t, Y_t, and N_t are the *industry* volume of sales, production, and inventories, respectively, in period t (e.g., $S_t = \Sigma_{i=1}^m s_t^i$); u_t is a realization of a random industry-wide demand condition variable; and P_t is the goods market price determined at the end of period t.

The random demand variable u_t is assumed iid and uncorrelated with any other variables such that $u_t \sim N(0, \sigma_u^2)$. While u_t is unobservable at the time production decisions are made, it is assumed that each firm obtains an individual demand condition signal u_t^i given by the sum of industry-wide demand conditions and a firm-specific error ε_{ut}^i:

$$u_t^i = u_t + \varepsilon_{ut}^i, \tag{6}$$

where $\varepsilon_{ut}^i \sim N(0, \sigma_{\varepsilon u}^2)$ and is uncorrelated with other variables.

2.2. *Decision-Making and First-Order Conditions*. Each firm determines its output for a period given an information set that includes the realization of its individual production cost conditions, v_t^i, its individual demand signal, u_t^i, its initial inventory stock, n_{t-1}^i, and, if cost-informed, v_t. Expectations formed on the basis of this information set at the time production decisions are made, are denoted E_t^i. The output level thus determined for the period is then actually produced, but

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

because of a production lag, not yet sold. Thereafter, at the end of the period each firm determines its inventory and (implicitly) sales, given observation of the market price and the previously determined level of production. Simultaneously, the market equilibrium price for the period is determined. Expectations based on the information set at the end of the period are denoted $\ddot{E}_t^i$.[6]

Formally, the output for period t is determined from the planned time paths for production ($y_{t+j}^i, j \geq 0$) and inventories ($n_{t+j}^i, j \geq 0$) that maximize the expected present value of profits:

$$\dot{E}_t^i W_t^i = \dot{E}_t^i \sum_{j=0}^{\infty} (P_{t+j} s_{t+j}^i - C_{t+j}^i[y_{t+j}^i] - H_{t+j}^i[n_{t+j-1}^i]) R^j, \tag{7}$$

where $R = 1/(1 + r)$, a discount factor; and r is a constant interest rate.

Under the specific functional cost forms above, the first-order conditions imply that

$$\dot{E}_t^i y_{t+j}^i = \frac{1}{mc_1} \dot{E}_t^i (P_{t+j} - c_0 v_{t+j}^i), \tag{8}$$

$$\dot{E}_t^i n_{t+j}^i = \frac{1}{mh_1} \dot{E}_t^i (P_{t+j+1} - P_{t+j}(1 + r) - h_0). \tag{9}$$

For $j = 0$, $\dot{E}_t^i v_t^i$ coincides with the actual cost realization v_t^i, and $\dot{E}_t^i y_t^i$ coincides with the actual production, y_t^i, for period t.[7]

At the end of the period, each firm observes the market price P_t. The end-of-period information set includes y_t^i and P_t, as well as the earlier information set. The firm chooses new expected ($\ddot{E}_t^i$) optimal time paths of inventories (n_{t+j}^i,

[6] Flood and Hodrick (1985) also employ a two-stage sequential decision process in an inventory model, but assume that firms set prices before determining their output levels. An alternative, but slightly less mathematically convenient, way of specifying the production lag is to assume that production, inventory holdings, sales, and price are determined simultaneously within each period, but that output reaches the market not at the end of the period, but in the following period. Most of our results would remain unaffected with this assumption of a full period production lag, but lagged as well as current cost conditions would then influence each period's equilibrium.

[7] In order to rule out negative production, we assume that the variances of the underlying disturbances v_t^i and u_t^i are sufficiently small relative to the relevant parameters (c_0, c_1, d_1) that negative levels of y_t^i occur with a negligible probability. To express this formally, denote $\bar{y}$ and σ_y^2 as the mean and variance of individual firm output. These distribution moments depend on the structural parameters of the cost and demand functions as well as on the moments of the underlying random cost and demand disturbances. By Tchebycheff's inequality $Pr[\bar{y} - k\sigma_y > y_t^i < \bar{y} + k\sigma_y] \leq 1 - 1/k^2$, $k > 0$. Thus for any given level of k, negative production levels can be ruled out with a probability approaching one by picking parameter values (c_0, c_1, and d_1) such that $\sigma_y/\bar{y} < k$.

The problem of how to build nonnegativity constraints in economic models with linear conditions containing additive normal variables is a common one. Assumptions similar to ours to deal with this problem are implicit or explicit in many stochastic dynamic optimization models. See, for example, Lucas and Prescott (1971), Sargent (1987, Chapter 14), and Blinder (1982). An alternative approach is to assume a nonnormal distribution (such as the log-normal) which is sufficiently truncated to rule out negative levels of y_t^i with probability one.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

$j \geq 0$) and future production (y^i_{t+j}, $j > 0$). By analogy to (9), the end-of-period condition for inventory holdings implies that for each period $t + j$, $j \geq 0$,

$$\ddot{E}^i_t n^i_{t+j} = \frac{1}{mh_1} \ddot{E}^i_t(P_{t+j+1} - P_{t+j}(1+r) - h_0). \tag{10}$$

For $j = 0$, $\ddot{E}^i_t P_t$ coincides with the actual market price P_t. Since inventories are determined at the end of the period, $\ddot{E}^i_t n^i_t$ coincides with actual inventories held at the end of period t, n^i_t.

2.3. *Industry Equilibrium.* Actual industry production for period t is given by the aggregation of individual firm output as determined by (8) for $j = 0$:

$$Y_t \equiv \sum_{i=1}^{m} y^i_t = \frac{1}{c_1} (\dot{E}^a_t P_t - c_0 v_t), \tag{11}$$

where $\dot{E}^a_t$ is defined as the *average* expectation of all firms when production decisions are made. In deriving (11), it has been assumed that the number of firms in the industry m and in the set of uninformed firms $m - m_v$ are sufficiently large so that $(1/m)(\Sigma^m_{i=1} \varepsilon^i_{vt}) = 0$ and $(1/m_v)(\Sigma^{m_v}_{i=1} \varepsilon^i_{vt}) = 0$. In similar fashion, the actual industry inventory stock held at the end of period t is obtained by the aggregation of (10) for $j = 0$:

$$N_t \equiv \sum_{i=1}^{m} n^i_t = \frac{1}{h_1} (\ddot{E}^a_t P_{t+1} - P_t(1+r) - h_0). \tag{12}$$

Substituting (11) for Y_t in the industry demand equation (5) yields the market-clearing price determined at the end of the period:

$$P_t = d_0 + d_1 u_t - \frac{d_2}{c_1} (\dot{E}^a_t P_t - c_0 v_t) + d_2(N_t - N_{t-1}). \tag{13}$$

The following reduced-form expressions are conjectured solutions for equilibrium price and industry inventory in period t:

$$P_t = \bar{P} + B_{pv}(v_t - \bar{v}) + B_{pn}(N_{t-1} - \bar{N}) + B_{pu} u_t \tag{14}$$

$$N_t = \bar{N} + B_{nv}(v_t - \bar{v}) + B_{nn}(N_{t-1} - \bar{N}) + B_{nu} u_t, \tag{15}$$

where a bar over a variable indicates its long-run average value and the B-coefficients depend on the structural parameters of the system. (Recall that the long-run average level of u_t is zero.)

It is apparent from (12) and (13) that equilibrium depends crucially on expectations at the time production decisions are made about the current period's price ($\dot{E}^a_t P_t$), and expectations at the end of the period about the subsequent period's price ($\ddot{E}^a_t P_{t+1}$). Expression (14) implies that

$$\dot{E}^i_t P_t = \bar{P} + B_{pv} \dot{E}^i_t(v_t - \bar{v}) + B_{pn} \dot{E}^i_t(N_{t-1} - \bar{N}) + B_{pu} \dot{E}^i_t u_t. \tag{16}$$

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

It is shown in the Appendix that each firm can infer the aggregate inventory stock determined at the end of any period t from observation of the market price, implying $\dot{E}_t^i N_{t-1} = N_{t-1}$.[8]

Since aggregate inventories become known at the end of each period, expression (16) implies that individual firm expectations of the equilibrium price in period t differ only according to their expectations of the current industry cost and demand disturbances. Since cost-informed firms all know v_t, $\dot{E}_t^i(v_t - \bar{v}) = v_t - \bar{v}$ for $i = 1, \dots, m_v$. For the cost-uninformed, who form expectations of industry-wide cost disturbances conditional on their individual realizations of v_t^i, $\dot{E}_t^i(v_t - \bar{v}) = \gamma_v(v_t^i - \bar{v})$, for $i = m_{v+1}, \dots, m$, where $\gamma_v = \sigma_v^2/(\sigma_v^2 + \sigma_{\varepsilon v}^2)$, $0 \le \gamma_v \le 1$. The parameter γ_v measures how accurate a perception of v_t is provided by a firm's current observation of v_t^i.

Firms are able to infer industry-wide demand only on the basis of their individual demand signals. Thus $\dot{E}_t^i u_t = \gamma_u u_t^i$, where $\gamma_u = \sigma_u^2/(\sigma_u^2 + \sigma_{\varepsilon u}^2)$, $0 \le \gamma_u \le 1$.

Average price expectations in period t at the time production decisions are made are:

$$(17) \qquad \dot{E}_t^a P_t = \bar{P} + \Omega_v B_{pv}(v_t - \bar{v}) + B_{pn}(N_{t-1} - \bar{N}) + \gamma_u B_{pu} u_t,$$

where $\Omega_v = \lambda_v + (1 - \lambda_v)\gamma_v$, $0 \le \Omega_v \le 1$; and λ_v represents the share of cost-informed firms, m_v/m. The parameter Ω_v may be interpreted as a measure of the extent to which firms on average predict current disturbances to industry-wide costs. In the following we will refer to this parameter as a measure of "clarity" about industry-wide costs. If $\Omega_v < 1$, then firms on average underpredict the magnitude of current disturbances.

In the Appendix we show how the system of equations—(13), (14), (15), and (17)—can be used to solve for the values of the B_n and B_p coefficients through the method of undetermined coefficients. The long-run equilibrium conditions $v_t = \bar{v}$, $N_{t-1} = \bar{N}$, and $u_t = 0$ permit determination of the values of $\bar{P}$ and $\bar{N}$ as well. The Appendix also shows how the coefficients in the following reduced-form expression for industry production may be subsequently derived:

$$(18) \qquad Y_t = \bar{Y} + B_{yv}(v_t - \bar{v}) + B_{yn}(N_{t-1} - \bar{N}) + B_{yu} u_t.$$

These coefficient values are all recorded in Table 1.

2.4. *Equilibrium Industry Behavior.* We now derive the implications of the model for industry equilibrium price and production. The effects of changes in inventory flexibility, which depends on h_1, can be summarized in the following proposition.

PROPOSITION 1. *As h_1 falls and inventories become more flexible, (a) a positive cost disturbance induces a smaller increase in price and a larger fall in output; (b)*

[8] As shown in the Appendix, in equilibrium all firms hold the same inventory level at the end of each period. The reason is that we have limited the analysis to temporary firm-specific disturbances and to rational expectations equilibria. When the market price is observed, expectations about future conditions are homogeneous.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

TABLE 1
REDUCED-FORM ADJUSTMENT COEFFICIENTS

$\bar{N}$	=	$-\dfrac{(d_0 + d_2 c_0 \bar{v}/c_1)r - (1 + d_2/c_1)h_0}{(1 + d_2/c_1)h_1} = -\dfrac{1}{h_1}(r\bar{P} + h_0)$	$\bar{N} < 0$
B_{nv}	=	$-\dfrac{(c_0/c_1)(1 + r)}{1 + r + A_1(1 + d_2\Omega_v/c_1)/(1 + d_2/c_1)}$	$-c_0/c_1 < B_{nv} < 0$
B_{nn}	=	$\dfrac{A_0 - \sqrt{A_0^2 - 4(1 + r)}}{2}$	$0 < B_{nn} < 1$
B_{nu}	=	$\dfrac{(d_1/d_2)(1 + r)}{1 + r + A_1(1 + d_2\gamma_u/c_1)/(1 + d_2/c_1)}$	$-d_1/d_2 < B_{nu} < 0$
$\bar{P}$	=	$\dfrac{d_0 + d_2 c_0 \bar{v}/c_1}{1 + d_2/c_1} = -\dfrac{1}{r}(h_1\bar{N} + h_0)$	$0 < \bar{P}$
B_{pv}	=	$\dfrac{d_2(B_{nv} + c_0/c_1)}{1 + \Omega_v d_2/c_1} = -\dfrac{d_2 B_{nv} A_1}{(1 + r)(1 + d_2/c_1)}$	$0 < B_{pv}$
B_{pn}	=	$\dfrac{d_2(B_{nn} - 1)}{1 + d_2/c_1}$	$B_{pn} < 0$
B_{pu}	=	$\dfrac{d_1 + d_2 B_{nu}}{1 + \gamma_u d_2/c_1} = -\dfrac{d_2 B_{nu} A_1}{(1 + r)(1 + d_2/c_1)}$	$0 < B_{pu}$
$\bar{Y}$	=	$(\bar{P} - c_0\bar{v})/c_1$	$0 < \bar{Y}$
B_{yv}	=	$(B_{pv}\Omega_v - c_0)/c_1$	$B_{yv} < 0$
B_{yn}	=	B_{pn}/c_1	$B_{yn} < 0$
B_{yu}	=	$\gamma_u B_{pu}/c_1$	$0 < B_{yu}$
where		$A_0 = 2 + r + h_1(1/d_2 + 1/c_1)$	$2 < A_0$
		$A_1 = A_0 - (1 + r + B_{nn})$	$0 < A_1$
		$\Omega_v = \lambda_v + (1 - \lambda_v)\gamma_v,$	$0 \leq \Omega_v \leq 1$

a positive demand disturbance induces a smaller increase in both price and output; for a given level of clarity.

The only somewhat nonintuitive part of this proposition is that output falls more in response to a cost disturbance as inventory flexibility increases. The reason is that with greater inventory flexibility, firms respond to any cost increase by producing less for inventories. These results are identical to those in Blinder (1982) and Glick and Wihlborg (1985b), where the level of clarity is implicitly held constant.

Next, we discuss how industry behavior is affected by changes in clarity about current disturbances to industry-wide cost conditions.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

PROPOSITION 2(a). *As Ω_v rises and cost clarity increases, a cost disturbance induces smaller changes in both equilibrium price and output.*

PROOF. From Table 1 it may be determined that

$$dB_{pv}/d\Omega_v = (B_{pv}/B_{nv})(dB_{nv}/d\Omega_v) = -B_{pv}^2/c_0 < 0$$

$$dB_{yv}/d\Omega_v = [(dB_{pv}/d\Omega_v)\Omega_v + B_{pv}]/c_1 = (B_{pv}/c_1)(1 - B_{pv}\Omega_v/c_0) > 0,$$

since $B_{pv} < c_0/\Omega_v$. Since $B_{pv} > 0$ and $B_{yv} < 0$, the coefficients B_{pv} and B_{yv} decrease in *absolute* value as Ω_v rises.

Intuitively, as the level of cost clarity improves due to either a rise in the share of cost-informed firms or in the accuracy of cost inferences by the uninformed, a given positive cost disturbance leads to a larger increase in average price expectations. Consequently, industry output contracts less, and the rise in equilibrium price is dampened.

A comparison of Propositions 1(a) and 2(a) shows that a fall in h_1 and an increase in Ω_v have identical effects on the sensitivity of price to cost. That is, an increase in the degree to which industry cost disturbances are perceived and increased inventory flexibility both reduce the degree of price adjustment to a current disturbance. Output adjustment to cost disturbances, on the other hand, is amplified by inventory flexibility, but dampened by increased clarity.

It can be shown analogously that if a given share of firms is informed about the industry-wide demand disturbance when production decisions are made, then the following proposition can be obtained.[9]

PROPOSITION 2(b). *As clarity about demand disturbances increases, demand disturbances induce a smaller change in price and a larger change in output.*

This proposition can be compared to Proposition 1(b) for increases in inventory flexibility. As with cost disturbances, increased flexibility and increased clarity both smooth price adjustment to demand disturbances, but have opposite effects on output adjustment. More specifically, increased clarity about demand disturbances reduces the underestimation of the absolute magnitude of industry demand disturbances which results from confusion, thereby inducing a greater output increase and a dampened price response. Increased inventory flexibility reduces the expected cost of adjusting sales out of inventories to meet greater demand. This dampens output as well as price rises.

The analysis above implies that increased clarity enables firms to better utilize inventories to minimize production costs over time by reducing the extent to which disturbances are unperceived. In this sense clarity can be interpreted as a complement to inventory flexibility. At the same time increased clarity reduces the need for inventories as a buffer against unanticipated disturbances. Thus clarity also may be viewed as a substitute for inventory flexibility. In order to analyze these issues further we turn next to the analysis of information acquisition.

[9] A copy of a working paper deriving this proposition can be obtained from the authors upon request.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

3. EQUILIBRIUM INFORMATION ACQUISITION

In this section we determine the equilibrium share of cost-informed firms, λ_v^*, and derive comparative statics results about its determinants. This analysis is applicable to the determination of the equilibrium share of demand-informed firms as well, assuming that firms could acquire information about industry-demand conditions at the beginning of the period.

It is assumed that information about industry-wide cost conditions v_t can be acquired at a cost x in each period. This information can be interpreted as referring to knowledge about cost conditions of competitors that enables each firm to better distinguish industry-wide supply conditions from firm-specific conditions. Similarly, on the demand side, information about industry-wide conditions could refer to knowledge about the demand facing close competitors that enables each firm to better evaluate the usefulness of its own demand signal for anticipating the price that can be charged when current production reaches the market. In general, any information that enables the firm to better forecast the sales price, as well as information that reduces the variance of firm-specific shocks, is relevant. The fixed cost of acquiring information could refer to a market price for information from external forecast services as well as the opportunity cost of employee time used in gathering and analyzing information.[10]

To determine equilibrium information acquisition we follow the approach of Glick and Wihlborg (1985a) and extend their analysis by incorporating the possibility of inventory adjustment. We begin by deriving the equilibrium information acquisition for a given period t. Expectations based on the information set at the time information purchase decisions are made are denoted E_t^i. The information set at the time information decisions are made does not include firm-specific cost conditions in period t. This implies that the commitment to employ resources in information-related activities is made *before* production decisions.[11]

Recall the definition of $\dot{E}_t^i W_t^i$ as firm i's expected present value of profits when production decisions are made, and define $\dot{E}_t^{iI} W_t^i$ as the present value of profits conditional on firm i being *informed* by acquiring information at the beginning of period t about v_t and choosing *optimal* production and inventory paths. $\dot{E}_t^{iU} W_t^i$ is the analogous expression when firm i chooses to be *uninformed* by *not* acquiring information. The expected present value at the time the information acquisition decision is made (E_t^i) for a firm choosing to be informed is thus given by $E_t^i[\dot{E}_t^{iI} W_t^i]$. Correspondingly, the expected present value for the firm if it remains uninformed is $E_t^i[\dot{E}_t^{iU} W_t^i]$.

The firm's incentive to acquire information (F_t^i) can be expressed as the

[10] Glick and Wihlborg (1985a, fn. 11) show that if the cost of information is interpreted as a multiperiod investment in capability to gather and analyze information, then the share of firms choosing to make such an investment is determined by exactly the same factors as in the analysis here.

[11] In Glick and Wihlborg (1985a) it is shown that equilibrium information market conditions can reveal to other firms information about industry cost conditions if information becomes available after individual cost conditions become known. In this case either all firms or no firms will acquire information, depending on the absolute size of the industry-wide disturbance. This free-rider problem arises because equilibrium in the information market reveals the absolute size of the disturbance in the period.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

difference between the expected present value of being informed and uninformed, net of the cost of information:

(19) $$F_t^i = E_t^i[\dot{E}_t^{iI} W_t^i - \dot{E}_t^{iU} W_t^i] - x.$$

In the Appendix we show how (19) reduces to:

(20) $$F_t^i = \left(\frac{1}{2mc_1}\right)[B_{pv}^2(1 - \gamma_v)\gamma_v \sigma^2] - x,$$

where $\sigma^2 = \sigma_v^2 + \sigma_{\varepsilon v}^2$, $\gamma_v = \sigma_v^2/(\sigma_v^2 + \sigma_{\varepsilon v}^2)$, and B_{pv} depends on λ_v, γ_v, and h_1 (see Table 1).[12]

Observe that the gain from acquiring cost information depends essentially on its contribution to forming price expectations at the time production decisions are made. Note also that there is an externality in the information market, since each firm that purchases information contributes to the lowering of B_{pv} in (20). Thereby the incentive for others to become informed is diminished.[13] The existence of this externality implies that the existence of an information market equilibrium requires that each potential buyer of information knows the share of firms that already have acquired information. However, since we are assuming that all firms face identical information costs and the incentive to acquire information represented by (20) is independent of firm-specific variables, which individual firms acquire information is, in principle, indeterminate.[14]

Information market equilibrium occurs for $0 < \lambda_v^* < 1$ when $F_t^i = 0$; for $\lambda_v^* = 0$ when $F_t^i < 0$; and for $\lambda_v^* = 1$ when $F_t^i > 0$, for all firms. Substituting the expression for B_{pv} in Table 1 into (20) and assuming an interior solution ($0 < \lambda_v^* < 1$) allows derivation of the following expression for the equilibrium share of informed firms:

(21) $$\lambda_v^* = \sigma c_0 \left[\frac{\gamma_v/(1 - \gamma_v)}{2c_1 mx}\right]^{1/2} - \left[\frac{(1 + r)(1 + d_2/c_1)}{A_1} + 1\right] \frac{1}{(1 - \gamma_v) d_2/c_1} - \frac{\gamma_v}{1 - \gamma_v},$$

where $A_1 = A_0 - (1 + r + B_{nn}) > 0$.

[12] The incentive to become informed depends on variances even though firms are assumed risk-neutral since expected profits evaluated at the optimal planning path are quadratic in expected price and costs. In Hahm (1987) the incentive to become informed is based on risk-aversion in households' labor-supply and consumption decisions. It is controversial whether firms are risk-neutral or risk-averse, and, in the latter case, whether they are averse to fluctuation in profits or output. Finance theory suggests that firms are risk-neutral if financial markets are efficient.

[13] In Haltiwanger and Waldman (1985) information is said to have "synergistic" effects if the information acquisition of others increases the value of information to each firm, while it is said to have "congestion" effects if others' acquisition reduces the value of information. The externality here appears to be one of "congestion." A change in the share of informed firms has a disproportionately large effect on equilibrium goods market behavior.

[14] Determination of which individual firms choose to acquire information requires that, firms differ, if only slightly, in terms of either the timing of information decisions or the costs of information acquisition.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

Equation (21) implies that the equilibrium share of informed firms, λ_v^*, depends on structural parameters (c_0, c_1, d_2, γ_v, and σ), the cost of information (x), the number of firms in the industry (m), inventory flexibility (h_1, through B_{nn}), and the interest rate (r).[15] The incentive to acquire information must exceed a threshold before any firm actually seeks to acquire information in order to cover the fixed cost of information x. When this is not the case, the constraint $\lambda_v^* = 0$ is binding on (21). Analogously, when the incentive to acquire information is very strong, the constraint $\lambda_v^* = 1$ may be binding.

As in Glick and Wihlborg (1985a), it can be shown that the equilibrium share of informed firms increases as the cost of information (x) falls, and as the total variability of costs (σ^2) increases. The effect on λ_v^* of changes in γ_v—industry-wide cost variability relative to total firm cost variability—is described by a concave function with a maximum when there is comparable variability in firm-specific and industry-wide cost disturbances, and hence, the information content of individual firm conditions is low. Intuitively, when there is relatively little variability in either ε_{vt}^i or v_t, there is little incentive to acquire information since observation of individual firm costs (v_t^i) or average industry costs ($\bar{v}$) then provides relatively good information about industry-wide conditions. In the Appendix we present representative calculations for the range of industry information costs over which $0 < \lambda_v^* < 1$. It is within this range that it is most meaningful to conduct comparative statics analysis of λ.

We are primarily interested here in the relationship between λ_v^* and inventory flexibility (h_1) and derive the following proposition.

PROPOSITION 3. *An increase in inventory flexibility* (*lower* h_1) *reduces the incentive to acquire information as well as the equilibrium share of cost-informed firms, for* $0 < \lambda_v^* < 1$.

PROOF.

$$\frac{d\lambda_v^*}{dh_1} = \frac{(1+r)(1+d_2/c_1)}{(1-\gamma_v)(d_2/c_1)A_1^2}\cdot\frac{dA_1}{dh_1} > 0, \quad \text{since} \quad dA_1/dh_1 > 0.^{16}$$

Intuitively, higher inventory flexibility reduces the degree to which price responds to cost disturbances (see Proposition 1(a)). Therefore, the cost to being uninformed and hence the incentive to acquire information falls. Similarly, reduced inventory flexibility induces firms to substitute for the higher cost of adjusting inventories by purchasing information. This proposition is similar to one in Dudley and Lassere (1989) who show that higher inventory adjustment costs cause an increase in the accuracy of information.

An expression like (21) can be derived as well for the equilibrium share of firms

[15] Note that an increase in the number of firms m decreases the incentive to acquire information. The reason is that marginal *industry* production and inventory costs are independent of m, while marginal industry costs to purchasing information (xm_v) rise with an increase in m for a given level of λ_v.

[16] From the definition of A_1, $dA_1/dh_1 = (1/d_2 + 1/c_1) - dB_{nn}/dh_1$. It is easily established that $dB_{nn}/dh_1 = (dB_{nn}/dA_1)(dA_0/dh_1) < 0$. Hence, $dA_1/dh_1 > 0$.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

becoming informed about industry-demand disturbances when firms obtain a firm-specific demand signal in the beginning of the period, and industry-demand information can be acquired at a cost. The γ and σ parameters in this expression refer to relative and total variances of industry-wide and firm-specific demand conditions, respectively.[17]

4. IMPLICATIONS OF EQUILIBRIUM INFORMATION ACQUISITION FOR THE GOODS MARKET

When information is endogenous, comparative statics analysis must take into account the effects of structural changes on the information sets of agents. Changes which affect the degree of clarity about disturbances, by influencing either the relative variability of industry-wide and firm-specific conditions or the incentive to acquire information about industry-wide conditions, will affect the overall equilibrium market adjustment to disturbances. In other words, the overall effects of structural changes on market adjustment depend on the direct impact of such changes as well as on the induced effects on information acquisition.

We now consider this issue within the framework of the model formulated within this paper. Specifically, we address how goods market adjustment to aggregate disturbances depends on inventory flexibility (h_1) taking into account how the incentive to acquire information and cost clarity are endogenously influenced by inventory flexibility. When information is endogenous, the total effect on any adjustment coefficient B of a change in any structural parameter z can be expressed as

$$dB/dz = \partial B/\partial z + (\partial B/\partial \lambda)(d\lambda/dz), \tag{22}$$

where B can refer to any B_p, B_n or B_y coefficient; z may refer to inventory flexibility (h_1), total cost variance (σ), relative industry-wide cost variance (γ_v), etc.; and λ refers to the fraction of cost-informed firms (λ_v) or demand-informed firms. In this section, we emphasize changes in h_1 and the implications for information acquisition about cost disturbances, i.e., $z = h_1$ and $\lambda = \lambda_v$. The effects of changes in variances have been analyzed in Glick and Wihlborg (1985a).

Proposition 1(a) refers to the direct effects of inventory flexibility on market adjustment to cost disturbances, assuming that clarity (and λ_v) is held constant. These results may be associated with the first term on the right-hand side of (22). Proposition 3 implies that the sign of $d\lambda/dz$ in (22) is positive for the case in which

[17] The relative variance of money shocks plays an important role in so-called "island" models of output adjustment to monetary shocks (e.g. Lucas 1973). Our analysis of the incentive to acquire information is easily extended to the case of confusion between real industry disturbances and economy-wide monetary disturbances. Specifically, in the case of monetary disturbances, ε_{ut}^i in (6) may be reinterpreted as the part of the observable demand signal, u_t^i, which is caused by an increase in economy-wide demand, while u_t, as before, is the part that depends on industry-wide demand. An increase in economy-wide demand caused by a monetary disturbance will be partially misperceived as an increase in industry demand, and all firms will change their plans for output and inventory adjustment. As in the model, higher inventory flexibility will reduce relative price variability due to monetary shocks, and accordingly, the incentive to acquire information declines.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

TABLE 2
ADJUSTMENT COEFFICIENTS WITH OPTIMAL INFORMATION ACQUISITION

B_{pv}	=	$\frac{1}{\sigma} \cdot \left(\frac{2c_1 mx}{\gamma_v(1-\gamma_v)}\right)^{1/2}$	$0 < B_{pv}$
B_{nv}	=	$-(B_{pv}/d_2)\frac{(1+r)(1+d_2/c_1)}{A_1}$	$-c_0/c_1 < B_{nv} < 0$
B_{yv}	=	$-(B_{pv}/d_2)\left[1+\frac{(1+r)(1+d_2/c_1)}{A_1}\right]$	$B_{yv} < 0$

Note that the restriction $0 < \lambda_v^* < 1$ implies corresponding restrictions on the domain of the parameters entering into equation (21).

$\lambda = \lambda_v$ and $z = h_1$. Proposition 2(a) may interpreted as referring to the term $\partial B/\partial\lambda$ for changes in clarity (Ω_v) arising from information acquisition.

Table 2 presents the coefficients of adjustment of price (B_{pv}), inventory (B_{nv}), and output (B_{yv}) in response to cost disturbances in period t, derived by utilizing the definition of clarity, $\Omega_v = \lambda_v + (1 - \lambda_v)\gamma_v$, and equation (21) for λ_v^*, and then substituting for Ω_v in the corresponding coefficients in Table 1. The resulting coefficients enable determination of the overall effect (dB/dz in (22)) of inventory flexibility ($z = h_1$) on price, inventory and output adjustment to cost disturbances, as summarized in the following proposition.

PROPOSITION 4(a). *As h_1 falls and inventory holdings become more flexible, output sensitivity to cost disturbances increases, while price sensitivity remains unchanged, for* $0 < \lambda_v^* < 1$.

Proposition 4(a) should be compared to Proposition 1(a) in Section 2. There we showed that as inventory flexibility increases, output adjustment increases in response to cost disturbances *for a given level of* λ_v. Proposition 3 states that as inventory flexibility increases, equilibrium $\lambda_v(\lambda_v^*)$ decreases. By Proposition 2(a), the decreased clarity about industry-wide costs amplifies further the output response to the cost disturbance. These propositions also imply that the effects of increased inventory flexibility and decreased clarity work in opposing directions for price adjustment to cost disturbances. Proposition 4(a) states that when information acquisition is endogenous these effects fully offset each other.

When the analysis is generalized to include confusion about demand disturbances, the following proposition can be derived.[18]

PROPOSITION 4(b). *As h_1 falls and inventory flexibility increases, output and price sensitivity to demand disturbances decreases, for interior solutions for the share of demand-informed firms.*

[18] The proof can be obtained from the authors upon request.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

Propositions 4(a) and 4(b), in more general terms, state that the effect of inventory flexibility on price adjustment is partially or fully offset by induced information acquisition, while the effect on output adjustment is amplified. We suggested above that information acquisition and inventory flexibility can be seen both as substitutes and complements. Here it has been shown that when the degree of information acquisition is endogenous they are complements with respect to output adjustment, but substitutes with respect to price adjustment.

Our analysis also implies that the effect of varying the level of information is as important for price and output adjustment as varying inventory flexibility. In the Appendix we illustrate this point further by investigating the sensitivity of the price and output coefficients to varying levels of industry informativeness for representative parameter values. There we show that the adjustment of price, output, and inventory in response to cost shocks declines significantly in magnitude as the share of informed firms increases. Analogously, it can be shown that the output response to demand disturbances would increase.

5. CONCLUSIONS AND IMPLICATIONS

We have developed an inventory adjustment model that takes into account how agents' incentive to acquire information depends endogenously on structural parameters. It was suggested how increased inventory flexibility and information acquisition may be substitutable as well as complementary responses to limited information about industry cost and demand conditions. The sense in which these activities are substitutable arises from the property that a decrease in inventory flexibility increases the degree of information acquisition, which in turn offsets the dampening effects of inventory flexibility on price adjustment to disturbances. However, endogenous information acquisition also strengthens the effects on output adjustment of inventory flexibility. From this point of view, information acquisition and inventory flexibility seem complementary.

Our results provide support for the view that the rapid development of information technology has reduced the vulnerability of firms to unanticipated fluctuations. Reductions in the costs of forecasting and monitoring factors influencing production and demand conditions can be viewed as a decline in the cost of information. In our model the resulting increase in information acquisition leads to less adjustment of changes in inventories, price, and output to cost disturbances and more adjustment of output to demand disturbances.

For empirical work, our analysis implies that differences across industries, such as in the extent of information acquisition as well as in inventory flexibility, may significantly influence the degree of inventory usage as an adjustment mechanism to disturbances. For example, our analysis suggests that the resources devoted to information-gathering activities should be relatively low in industries with high inventory flexibility. Ideally, any empirical analysis should also take into account relative output flexibility and employment flexibility, measured in terms of the costs

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

of new hires and layoffs, as well as of inventory flexibility and information acquisition.[19]

The relative costs associated with these alternative responses to disturbances, particularly with respect to information acquisition, are, of course, difficult to gauge. However, there are several instances in which costs related to specific types of information acquisition might be measurable. In particular, costs associated with monitoring flows of inputs and intermediate goods in the production process can be measured. Improved information technology has lowered the costs of such monitoring and enabled firms to decrease their inventories of inputs and intermediate goods. Although our model explicitly incorporates only output inventories, we consider it applicable to inputs and intermediate goods as well, since inventories at different stages of the production process can be seen as substitutes. Thus, for example, adjustment of input inventories as well as final goods may serve to buffer against demand shocks. Within our model a decrease in information costs reduces the inventory adjustment associated with a particular shock and one would expect this to lead in the longer run to reduced investments in inventory flexibility.

Another type of information for which costs could be measured is that associated with forecasting exchange rate changes. For a firm selling in a foreign market in competition with foreign firms, real exchange rate changes can be viewed as a firm-specific cost shock. For a firm selling in the domestic market in competition with imported goods, such changes can be seen as demand shocks. In this context, to the extent that foreign exchange futures markets are incomplete relative to the time horizon of firms, they have an incentive to acquire information from foreign exchange advisory services or through internal analysis.

From a policy viewpoint, our analysis implies that governments' dissemination of information about aggregate disturbances and industry associations' dissemination of industry information could lead to cost-savings of two kinds. First, such policies would reduce the incentive for individual firms to incur costs of gathering similar information. Second, they would reduce the incentive to invest in greater inventory flexibility.

Federal Reserve Bank of San Francisco, U.S.A.
University of Gothenburg, Sweden

APPENDIX

1. *Equilibrium Industry and Individual Inventory Stocks.* We show here that in rational expectations equilibrium firms can infer the aggregate inventory stock at the end of the period by observing the price P_t, and that all firms hold the same level of inventories.

Expression (12) describes how the aggregate inventory stock depends on expected and current prices:

[19] Topel (1982) and Haltiwanger and Maccini (1988) analyze the interaction of employment and inventory adjustment. Belsley (1969) suggests that inventory flexibility may be related to costs of adjusting production.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

(12) $$N_t = \frac{1}{h_1}(\ddot{E}_t^a P_{t+1} - P_t(1+r) - h_0).$$

Expression (14) implies

(A.1) $$\ddot{E}_t^a P_{t+1} = \bar{P} + B_{pn}\ddot{E}_t^a(N_t - \bar{N}),$$

since expected cost and demand conditions for $t + 1$ are $\bar{v}$ and $\bar{u}(= 0)$, respectively. Inserting (A.1) into (12) gives

$$N_t = \frac{1}{h_1}(\bar{P} + B_{pv}\ddot{E}_t^a(N_t - \bar{N}) - P_t(1+r) - h_0).$$

Assume that in rational expectations equilibrium, $\ddot{E}_t^a N_t = N_t$. Then,

(A.2) $$N_t(h_1 - B_{pn}) = (\bar{P} - B_{pn}\bar{N} - P_t(1+r) - h_0).$$

Since all firms can observe P_t at the end of the period, (A.2) implies that in this equilibrium each firm may infer N_t at the same time.

(10) implies that the inventory levels of individual firms will differ if their future price expectations vary. However, (14) implies that $\ddot{E}_t^i P_{t+1} = \bar{P} + B_{pn}(N_t - \bar{N})$. Thus, each firm holds the same level of inventory. The intuitive reason is that inventories depend on expectations of the future price relative to the current price and that each firm has the same current price observation and expectation about future cost and demand disturbances.

2. *Derivation of Reduced-form Adjustment Coefficients in Table 1.* Substitute in (13) for N_t with (15) and for $\dot{E}_t^a P_t$ with (17). Rearranging terms yields

(A.3) $$P_t = d_0 - \frac{d_2\bar{P}}{c_1} + \frac{d_2 c_0 \bar{v}}{c_1} + \frac{d_2 c_0}{c_1} + d_2 B_{nv} - \frac{d_2 \Omega_v B_{pv}}{c_1}(v_t - \bar{v})$$
$$+ \left(d_2 B_{nn} - \frac{B_{pn} d_2}{c_1} - d_2\right)(N_{t-1} - \bar{N}) + \left(d_1 + d_2 B_{nu} - \frac{d_2 \gamma_u B_{pu}}{c_1}\right)u_t.$$

Comparison with (14) enables the determination of the B_p coefficients in terms of the B_n coefficients. The long-run equilibrium conditions $v_t = \bar{v}$, $N_{t-1} = \bar{N}$, and $u_t = 0$ then yield $\bar{P}$.

Next, substitute in (12) for P_t with (14) and for $\ddot{E}_t^a P_{t+1}$ with (A.1) and recall that $\ddot{E}_t^a N_t = N_t$. After rearranging, we obtain:

(A.4) $$N_t(h_1 - B_{pn}) = -r\bar{P} - h_0 - B_{pn}\bar{N} - (1+r)B_{pv}(v_t - \bar{v})$$
$$- (1+r)B_{pn}(N_{t-1} - \bar{N}) - (1+r)B_{pu}u_t.$$

Divide the right-hand side by the coefficient term $h_1 - B_{pn}$. Substitute in for B_{pv}, B_{pn}, and B_{pu} in terms of the B_n-coefficients. Comparison with (15) yields the B_n coefficients. The value of $\bar{N}$ follows immediately.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

It should be noted that the value of B_{nn} is obtained from the solution to the characteristic equation

$$B_{nn}^2 - B_{nn}\left[2 + r + h_1\left(\frac{1}{d_2} + \frac{1}{c_1}\right)\right] + (1 + r) = 0.$$

There are two possible values for B_{nn}—one less than 1, and the other greater than $1 + r$. We choose the former since otherwise industry inventories will follow an explosive path. Moreover, the transversality condition of each firm's decision problem prohibits inventories from growing faster than the rate $1 + r$.

In order to determine the B_y coefficients, substitute (17) in (11) to obtain

$$\text{(A.5)} \qquad Y_t = \frac{\bar{P} - c_0\bar{v}}{c_1} + \frac{B_{pv}\Omega_v - c_0}{c_1}(v_t - \bar{v}) + \frac{B_{pn}}{c_1}(N_{t-1} - \bar{N}) + \frac{B_{pu}}{c_1}u_t.$$

Equating coefficients with (18) gives the $B_y s$ in terms of the B_p-coefficients.

3. *Derivation of the Incentive for Information Acquisition (20).* Recall expression (19) for the incentive of firm i to purchase industry-wide cost information at the beginning of period t: $F_t^i = E_t^i[\dot{E}_t^{iI}W_t^i - \dot{E}_t^{iU}W_t^i] - x$, where E_t^i is the expectations operator for firm i before individual cost conditions are known and production decisions are made in period t. Neither v_t nor v_t^i is included in the firm's information set at the time the information purchase decision is made. $\dot{E}_t^{iI}W_t^i$ and $\dot{E}_t^{iU}W_t^i$ refer to the expected present value of profits when the firm is informed and uninformed, respectively, about v_t in period t. The incentive to purchase information about v_t in period t thus depends on the expected profit increase *net* of the cost of information from knowing v_t when y_{t+j}^i and n_{t+j}^i are determined for all $j \geq 0$.

From equation (10), and the discussion in Section 2, it can be inferred that in goods market equilibrium at the end of each period, the individual firm's inventory decision is independent of direct knowledge of v_t and depends only on observation of P_t. Therefore, at the time the information purchase decision is made, knowledge of v_t has no effect on the planned sequence of *current and future* inventory decisions, n_{t+j}^i, $j \geq 0$. Similarly, knowledge of v_t is irrelevant for output decisions in all *future* periods, y_{t+j}^i, $j > 0$, since the expected price at the beginning of any future period $t + j$, $j > 0$, depends only on expectations about cost disturbances in period $t + j$ which are independent of v_t (see equations (8) and (16)). The only firm decision that is differentially affected by knowledge of v_t is thus the output decision for period t.

The incentive to purchase information in period t thus simplifies to the following expression:

$$\text{(A.6)} \qquad F_t^i = E_t^i\{\dot{E}_t^{iI}[P_t y_t^i - C_t[y_t^i]] - \dot{E}_t^{iU}[P_t y_t^i - C_t[y_t^i]]\} - x,$$

where $C_t[y_t^i]$ is given by (1). To derive expression (20) in the text, first develop (A.6) by inserting expression (8) for the optimal output level:

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

$$F_t^i = E_t^i\left[P_t \cdot \frac{1}{mc_1}(\dot{E}_t^{iI}P_t - c_0 v_t^i) - c_0 v_t^i \frac{1}{mc_1}(\dot{E}_t^{iI}P_t - c_0 v_t^i)\right.$$

$$\left. - mc_1 \cdot \frac{1}{2m^2c_1^2}(\dot{E}_t^{iI}P_t - c_0 v_t^i)^2\right] - E_t^i\left[P_t \cdot \frac{1}{mc_1}(\dot{E}_t^{iU}P_t - c_0 v_t^i)\right.$$

$$\left. - c_0 v_t^i \frac{1}{mc_1}(\dot{E}_t^{iU}P_t - c_0 v_t^i) - mc_1 \frac{1}{2m^2c_1^2}(\dot{E}_t^{iU}P_t - c_0 v_t^i)^2\right] - x.$$

This can be simplified to

$$\text{(A.7)} \quad F_t^i = \frac{1}{2mc_1} E_t^i[(\dot{E}_t^{iI}P_t - c_0 v_t^i)(P_t - \dot{E}_t^{iI}P_t) + (\dot{E}_t^{iI}P_t - c_0 v_t^i)(P_t - c_0 v_t^i)]$$

$$- \frac{1}{2mc_1} E_t^i[(\dot{E}_t^{iU}P_t - c_0 v_t^i)(P_t - \dot{E}_t^{iU}P_t) + (\dot{E}_t^{iU}P_t - c_0 v_t^i)(P_t - c_0 v_t^i)] - x.$$

The first product within each bracket represents the covariance between the firm's price forecast error and its optimal output when informed and uninformed, respectively. In rational expectations equilibrium, this covariance is zero.

Using (16) for $\dot{E}_t^{iI}P_t$ and $\dot{E}_t^{iU}P_t$ in the second product within the brackets, note that the covariances of v_t and v_t^i with other exogenous variables are zero. Thus, (A.7) reduces to

$$F_t^i = \frac{1}{2mc_1} E_t^i[(B_{pv}(v_t - \bar{v}) - c_0(v_t^i - \bar{v}))(B_{pv}(v_t - \bar{v}) - c_0(v_t^i - \bar{v}))$$

$$- (B_{pv}\gamma_v(v_t^i - \bar{v}) - c_0(v_t^i - \bar{v}))(B_{pv}(v_t - \bar{v}) - c_0(v_t^i - \bar{v}))] - x$$

from which (20) follows readily by observing that $\gamma_v = \sigma_v^2/\sigma^2$.

4. *Representative Calculations of Effect of Information Costs on λ_v and Implications for Market Adjustment*. To calculate plausible ranges of x for which λ_v takes on an interior solution it is necessary to make assumptions about the parameter values of the model. We assume $m = 10$, $\bar{P} = 1$, $\bar{S} = \bar{Y} = 100$, and $r = .1$. Assuming in the cost function (1) that $c_0 = 1$ and $c_1 = .008$, it follows from (11) that in the steady state $\bar{v} = .2$. In the demand function (5), assume $d_2 = .08$, implying $d_0 = .9$. In the inventory cost function (3), let $h = 2$, $h_0 = .3$, and $h_1 = .04$, implying that in the steady state each firm holds inventories of -1. It follows that $A_0 = 7.6$, $B_{nn} = .15$, and $A_1 = 6.35$. Under these assumptions, individual firm revenues, production costs, and inventory holding costs in the steady state are 10, 6, and 1.9, respectively.

We next employ (21) to calculate the information cost levels for which $\lambda_v^* = 1$ and $\lambda_v^* = 0$, given the standard deviation of total firm production costs (σ) and the proportion of the variance of total firm production costs attributable to industry-

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

wide cost variance (γ_v). The table below expresses these values of x for varying levels of σ, γ_v, and h_1.

			x	
σ	γ_v	h_1	$\lambda_v^* = 1$	$\lambda_v^* = 0$
.6	.5	.04	.34	.90
.6	.3	.04	.28	1.36
.6	.7	.04	.44	.87
.5	.5	.04	.23	.62
.7	.5	.04	.46	1.22
.6	.5	.08	.40	1.14

For example, when $\sigma = .6$, $\gamma_v = .5$, and $h_1 = .04$, all firms will be fully informed ($\lambda_v^* = 1$) when x is as low as .34 (i.e., 3.4 percent of an individual firm's sales revenue), while no firms will be informed when x is as high as .90. Observe that the range of information costs for which λ_v takes on an interior solution is higher when γ_v is lower and firm-specific disturbances dominate industry-wide cost shocks. In addition, both an increase in σ and in h_1 increase the information cost up to which all firms choose to be informed.

Lastly, we investigate the effects of varying levels of information acquisition on inventory, price, and output adjustment to cost shocks. For this exercise we set $\sigma = .6$, $\gamma_v = .5$, and $h_1 = .04$ and continue to maintain the other parameter value assumptions made above. With these assumptions we calculate below the values of

	$\lambda_v^* = 0$	$\lambda_v^* = .32$	$\lambda_v^* = 1$
B_{nv}	−30.13	−25.01	−18.46
B_{pv}	1.26	1.05	.78
B_{yv}	−46.25	−38.13	−28.12

B_{nv}, B_{pv}, and B_{yv}, for $\lambda_v^* = 0$ and $\lambda_v^* = 1$ using the formulas in Table 1, and, when $x = .62$ (the midpoint of the cost range within which there is an interior solution for λ_v), for $\lambda_v^* = .32$ using the formulas in Table 2.

Observe that increased information acquisition within the industry decreases the sensitivity of inventory, price, and output adjustment to cost shocks.

REFERENCES

AMIHUD, Y. AND M. MENDELSON, "The Output-Inflation Relationship: An Inventory Adjustment Approach," *Journal of Monetary Economics* 9 (1982), 163–184.

ASHLEY, R. A. AND D. ORR, "Further Results on Inventories and Price Stickiness," *American Economic Review* 75 (1985), 964–975.

BELSLEY, D. A., *Industry Production Behavior: The Order Stock Decision* (Amsterdam: North-Holland, 1969).

BLINDER, A., "Inventories and Sticky Prices: More on the Microfoundations of Macroeconomics," *American Economic Review* 72 (1982), 334–348.

———, "Can the Production Smoothing Model of Inventory Behavior be Saved?" *Quarterly Journal of Economics* 101 (1986), 431–454.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms

Christiano, L. J., "Why Does Inventory Investment Fluctuate So Much?" *Journal of Monetary Economics* 21 (1988), 247–280.

Darby, M., "Rational Expectations Under Conditions of Costly Information," *Journal of Finance* 31 (1976), 889–895.

Dudley, L. and P. Lassere, "Information as a Substitute for Inventories," *European Economic Review* 33 (1989), 67–88.

Eichenbaum, M. S., "Rational Expectations and the Smoothing Properties of Inventories of Finished Goods," *Journal of Monetary Economics* 14 (1984), 71–96.

———, "Some Empirical Evidence on the Production Level and Production Cost Smoothing Models of Inventory Investment," *American Economic Review* 79 (1989), 853–864.

Fair, R. C., "The Production Smoothing Model is Alive and Well," *Journal of Monetary Economics* 24 (1989), 353–370.

Feldstein, M. S. and A. Auerbach, "Inventory Behavior in Durable Goods Manufacturing: The Target-Adjustment Model," *Brookings Papers on Economic Activity* No. 2 (1976), 351–396.

Flood, R. and R. Hodrick, "Optimal Price and Inventory Adjustment in an Open-Economy Model of the Business Cycle," *Quarterly Journal of Economics* 100 (1985), 887–914.

Glick, R. and C. Wihlborg, "Price Determination in a Competitive Industry with Costly Information and a Production Lag," *Rand Journal of Economics* 16 (1985a), 127–140.

——— and ———, "Price and Output Adjustment, Inventory Flexibility, and Cost and Demand Disturbances," *Canadian Journal of Economics* 8 (1985b), 566–573.

——— and ———, "The Role of Information Acquisition and Financial Markets in International Macroeconomic Adjustment," *Journal of International Money and Finance* 5 (1986), 1–20.

Grossman, S. and J. Stiglitz, "The Impossibility of Informationally Efficient Markets," *American Economic Review* 70 (1980), 393–408.

Hahm, S., "Information Acquisition in an Incomplete Information Model of the Business Cycle," *Journal of Monetary Economics* 20 (1987), 123–140.

Haltiwanger, J. and L. Maccini, "A Model of Inventory and Layoff Behavior under Uncertainty," *Economic Journal* 93 (1988), 731–745.

——— and M. Waldman, "Rational Expectations and the Limits of Rationality," *American Economic Review* 75 (1985), 326–330.

Kahn, J., "Inventories and the Volatility of Production," *American Economic Review* 77 (1987), 667–679.

Lucas, R. E., "Some International Evidence on Output-Inflation Tradeoffs," *American Economic Review* 63 (1973), 326–334.

——— and E. C. Prescott, "Investment Under Uncertainty," *Econometrica* 39 (1971), 659–681.

Sargent, T. J., *Macroeconomic Theory* (New York: Academic Press, 1987).

Topel, R. H., "Inventories, Layoffs, and the Short Run Demand for Labor," *American Economic Review* 72 (1982), 769–787.

This content downloaded from 199.169.204.182 on Mon, 16 Apr 2018 23:23:19 UTC
All use subject to http://about.jstor.org/terms