

SPECIFICATION OF DOMESTIC AND FOREIGN FACTORS ON THE INVENTORY MODEL

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This paper extends the linear-quadratic inventory model by adding endogenously determined sales, foreign factors, and observed cost factors, which affect dynamic adjustments of inventory investments, and tests the model using a multicountry data set. It derives and contrasts a set of unconditional moment restrictions implied by closed and open economy specifications of the inventory model. The empirical results show that introducing an endogenous sales setting and open economy factors into the inventory model is well approximated in the cases of Canada, Japan, and the U.K., while adding the observed cost factors to the model is only supported by the U.S. data.

JEL Classification: E22, F41, C32

Keywords: Inventory Behavior, Multicountry Comparative Analysis

I. INTRODUCTION

There are two approaches to explore inventory fluctuations, similar to the extensive discussion of the sources of shocks generating the business cycle. One approach stresses demand shocks as the main source of inventory movements, while the other argues that cost or supply shocks are the dominant cause of inventory fluctuations. The inventory models of 1980s tend to focus on the demand side, where inventories play a stabilizing role as in Blinder (1982), Maccini (1984), Blanchard and Melino (1986), and West (1990).

Received for publication: Sep. 4, 2003. Revision accepted: Nov. 17, 2003.

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The paper was first written while I was at the doctoral program for economics at the Johns Hopkins University. I would like to thank Louis J. Maccini, the advisor of my doctoral program at the university, for his invaluable comments and suggestions in the earlier manuscript of this paper. I am grateful to Pedro de Lima, Carl Christ, and Laurence Ball. I am very grateful to two anonymous referees for suggestions that have improved the paper. All remaining errors are my own responsibility.

However, this approach is inconsistent with the empirical evidence of production-counter smoothing that has been observed in the postwar U.S. data. Further discussion and evidence on this point have been provided by Blinder (1986), Fare (1989), Blinder and Maccini (1991), and Kahn (1992). To account for this stylized fact, more recent inventory studies have emphasized the potential role of cost shocks as the predominant source of inventory fluctuations as in Miron and Zeldes (1988), Ramey (1991), Durlauf and Maccini (1995), and Humphrey et al. (2001).

Considering both approaches in this paper, a model specification is adopted in which inventories adjustments emerge from supply side of production costs and from demand side of sales process.

While much progress has been made in inventory research, most research has been limited to the U.S. economy despite the prominent role of inventory investment in business fluctuations in each country. Moreover, there is a paucity of cross country comparisons of inventory behavior, given their extensive use in other areas of macroeconomics such as consumption, investment, inflation, and business cycles. Some exceptions are West (1988), Wilkinson (1989), and Fukuda and Teruyama (1994).¹ To fill this gap, this paper explores the effect of inventory adjustments using multicountry quarterly data for a comparative analysis.

There are data-based and behavioral reasons why this paper focuses on the four industrialized countries - Canada, Japan, the U.K., and the U.S. The first is that these four economies have very reliable inventory data, by comparison with other G7 and OECD member economies - the data survey procedures of these countries are exactly comparable with those of the U.S.² Second, Canada and the U.K. can be considered to be small open economies in which foreign goods prices are exogenous to both economies, compared with large economies such as the U.S. and probably Japan. These countries are thus, simultaneously, comparable and distinguishable.

The liberalization of international trade has increased export and foreign sales opportunities for some manufacturing goods, and has increased competition from imports of input materials. Imported inputs play an important role in inventory behavior, particularly for small open economies. One purpose of this paper is to investigate the relationship between the dynamic behavior of finished goods inventories and foreign factors - exchange rate and foreign output, when firms

¹ West (1988) reported evidence of production counter-smoothing from G7 countries' National Accounts data and Wilkinson (1989) investigated the aggregate inventory fluctuations for four European economies. Fukuda and Teruyama (1994) studied international evidence of inventory fluctuations using annual data sets.

² Data from other G7 countries is not always comparable. The major characteristic of business surveys in other countries, for instance in Germany, is that the surveys usually ask for a respondent's judgment on the current business situation, instead of exact figures. Qualitative - not quantitative - data are provided by business surveys in most other developed countries.

have joint decision rules based upon the optimization of a rational expectations intertemporal profit maximization problem.

Another purpose of this paper is to determine whether observed cost shocks can be helpful in explaining inventory adjustment. The cost shocks derived from observable multiple sources, such as imported materials prices, are also introduced, and this is a departure from the univariate autoregressions that are the usual practice in the empirical inventory literature. Hence, both demand and supply sides are examined in this open economy extension of the inventory model.

To verify the proposed approach, a pair of Euler equations derived from the structural open economy inventory model are estimated directly using the Generalized Method of Moments (GMM) estimator. It tests whether or not the modification of the closed and open economy specifications of the inventory model is quantitatively significant in analyzing in the four sample economies, to take account of inventory movements. The empirical results, obtained from estimating the model using data for Canada, Japan, and the U.K., provide general support for the model specification with foreign factors, while the cost factors restrictions are only supported by the U.S. data.

The rest of the paper is organized as follows: Section II outlines the theoretical model of the representative firm and decisions of production and inventory investment. Section III describes the econometric specification of the model to be estimated and the estimation methodology of system used to formally test the structural model. Section IV provides estimates of the model and discuss the empirical results. Section V contains summary and some concluding remarks.

II. STRUCTURAL MODEL

1. Demand for Finished Goods

The representative producer of finished goods is faced with a traditional downward sloping domestic demand curve given by:

$$D_t = D(p_t, Y_t, u_{dt}), \quad D_{p_t} < 0, \quad D_{Y_t} > 0, \quad (1)$$

where D_t is domestic demand or sales, p_t is the domestic currency price of finished goods, and Y_t is the domestic expenditure which is the domestic shifting factor and is determined outside the system. u_{dt} is a white noise disturbance that incorporates the influence of random domestic demand shocks. In Equation (1) and throughout, trend terms that are allowed in the empirical work are suppressed for the sake of notational simplicity without loss of generality.

In this specification, finished goods are traded freely with the rest of the world at exogenously given international terms of trade. Shocks originating in other large countries or group economies can have important effects through the alteration of the relative prices as well as some direct effect. The foreign demand for home country's exports is specified as the function of the foreign currency price of exports and foreign output as follows:

$$X_t = X\left(\frac{p_t}{e_t}, Y_t^*\right), \quad X_{p_t/e_t} < 0, \quad X_{Y_t^*} > 0, \quad (2)$$

where X_t is foreign demand or exports, e_t is trade weighted index of exchange rate expressed as the home currency price of foreign exchange (home currency/foreign currency), and Y_t^* is export weighted foreign output. Therefore p_t/e_t is the foreign currency price of exported goods. The partial derivative of $X(\cdot)$ are assumed to be $X_{p_t/e_t} < 0$ which implies that falling domestic price of finished goods and/or depreciating the exchange rate increase exports, and $X_{Y_t^*} > 0$ which implies that from the viewpoint of the domestic economy, positive shocks to foreign output can be interpreted as a global improvement or a favorable effect. However, the domestic shocks are not going to affect foreign output from the small open economy assumption as in Mellander et al. (1992) and Ahmed and Park (1994).

By definition, final sales S_t is the sum of domestic demand D_t and foreign demand X_t :

$$S_t = D_t + X_t = D(p_t, Y_t, u_{dt}) + X\left(\frac{p_t}{e_t}, Y_t^*\right). \quad (3)$$

Solving the demand function Equation (3) implicitly for the inverse form of the final demand curve by assumption of imperfectly competitive demand market:

$$p_t = p(S_t, Y_t, e_t, Y_t^*, u_{dt}). \quad (4)$$

Using the implicit function theorem, the partial derivatives for this inverse function will be $p_s < 0$, $p_Y > 0$, $p_e > 0$, and $p_{Y^*} > 0$. The specification of the inverse form of endogenous demand is given by the following linearization for empirical convenience, and all variables are measured in log values in the empirical work.

$$p_t \approx -\frac{\omega_0}{2} S_t + \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^* + \omega_0 u_{dt}, \quad (5)$$

where ω_i are positive parameters and $\omega_0 u_{dt}$ is purely adopted for a matter of convenience. A decomposable environment such that the factors of demand are additively separable is to focus on the relative role of domestic and foreign factors instead of interrelationship such as the purchasing power parity.

2. Representative Producer of Finished Goods

The domestic output is assumed storable and exportable, so production that is not consumed domestically or not exported can be added to inventories. There are several motives for firms to hold inventories. Among them the major motive for holding inventories that appears in the literature is the famous production smoothing motive. If, moreover, demand is uncertain, inventories may also be used as a buffer, giving rise to the buffer stock motive as summarized in Blinder and Maccini (1991). Since this model specification especially attempts to contrast the relative importance of foreign demand shocks with domestic demand shocks, the buffering role of inventories is a primary motive for holding storable finished goods. The speculative motive for holding inventories is also considered into the model by assuming endogenously determined sales. Inventory accumulation is governed by the following identity:

$$N_t = N_{t-1} + Q_t - S_t, \quad (6)$$

where N_t is finished goods inventories at the end of period t and Q_t is domestic output of finished goods in period t . Inventories allow the firm to hold output for sale in the next period. This link suggests that in time t , the firm commits to producing output Q_t , which it allocates between inventory investments ΔN_t and sales S_t at market determined price p_t . Since three variables are related by the identity, only two of the decisions are independent. Hence, at the beginning of any period, the representative domestic producer chooses a contingency plan for its production of finished goods Q_t and inventory holdings N_t .

Let the representative firm maximize the expected discounted present value of profit over an infinite horizon.

$$\max E_t \left[\sum_{i=0}^{\infty} \beta^i R_{t+i} \right], \quad (7)$$

where

$$R_t = p(S_t, Y_t, e_t, Y_t^*, u_{dt})S_t - \Gamma(Q_t, u_{ct}) - \Psi(N_{t-1}, S_t). \quad (8)$$

The functions $\Gamma(\cdot)$ and $\Psi(\cdot)$ represent production costs and inventory holding costs respectively. $\beta = 1/(1+r)$ is the discount factor implied by a constant real rate of interest r . As usual practice, the following specification

of the production cost function is adopted:

$$I(Q_t, u_{ct}) = -\frac{c_1}{2} Q_t^2 + \frac{c_2}{2} \Delta Q_t^2 + \omega_0 u_{ct} Q_t, \quad (9)$$

where c_{1S} are parameters, u_{ct} is a cost shock that captures shifts in technology or productivity, and $\omega_0 u_{ct}$ is purely adopted for a matter of convenience.

The first term is the quadratic cost of production, which allows that marginal costs vary with the level of output and over time as factor costs change. If the parameter c_1 is positive, the marginal cost of production is an increasing function of finished goods, so that the firm has motive to smooth production. If the parameter c_1 is negative, the marginal cost of production is a decreasing function of output, so that the firm has an incentive to bunch, rather than smooth production, as noted in Ramey (1991).

The second term reflects costs of changing production which represent, for example, labor hiring and firing costs. If c_2 is positive, then there is an additional incentive to smooth production, because marginal costs of production depend on both c_1 and c_2 . Hence, the larger the convexity of marginal production costs closely related to c_1 and c_2 , the more important the production smoothing motive for carrying inventories.

Because of backlogs and stockouts, inventory holding costs are assumed to be quadratic in the difference between actual inventories and target inventories. Firms have some desired target level of inventories which is hypothesized to be a linear function of current or anticipated next period sales. Then, inventory holding cost function can be written:

$$\Psi(N_{t-1}, S_t) = \frac{b}{2} (N_{t-1} - \alpha S_t)^2, \quad (10)$$

where α and b are parameters. Especially, the parameter α is the desired inventory sales ratio in the absence of production costs. This inventory holding costs implicitly reflect the storage cost and the stockout cost which involve lost sales and backlog costs.³

³ Since there are many producers, firms risk losing sales if they cannot fill orders promptly. This suggests stocking out costs are a positive function of the sales rate. Then, the larger the slope of marginal inventory holding costs (b), or the more costly stockouts (α), the more likely firms are to abandon production cost smoothing and try to keep inventories close to target stocks. For further discussion, see Blinder and Maccini (1991).

3. Observed Multiple Cost Shocks

One of the successful empirical results of Durlauf and Maccini (1995) is to analyze observed cost shocks, instead of unobservable technology shocks to explain inventory movements, which has been considered as a most important rationale of the production counter-smoothing in the inventory literature since Maccini and Rossana (1984) added cost shocks in the form of real input price into the inventory model.

In this paper, the cost shocks derive from observable multiple sources instead of time series processes. I add explicitly cost variables to some of the regressions, in which cost shocks typically derive from multiple sources. The representative firm is assumed to produce finished goods by means of imported input materials, which is hypothesized as a nonstorable homogeneous crude or an intermediate commodity for simplicity in analysis. This assumption implies that firms purchase materials and supplies from abroad and the materials and supplies are used up within the quarter.⁴ I, therefore, hypothesize that one of the cost shocks is real input material price that represents the cost of purchasing inputs from abroad to allow for foreign factors to affect the supply side of the problem. To do this, I use a measured series on imported raw materials prices as one of the cost shocks. Production costs also can be affected by fluctuations in wages and energy prices. In order to account for the impact of these different input prices on firm production decisions, it is necessary to choose a particular functional form for the cost function. I relate the cost function to the input prices through the relation such as:

$$u_{ct} = \rho_1 w_t + \rho_2 z_t + \rho_3 q_t, \quad (11)$$

where ρ_i is the marginal cost response to a change in each input price, w_t is real wages measured by average unit earnings, z_t is real energy price measured by each country's price index for energy, and q_t is home currency price of imported input materials.

Through the effect of imported input materials, I explore the international repercussions of cost disturbances. The inventory stock adjustments associated with foreign factors are essential for the analysis in this paper because stochastic environment in foreign demand causes the buffering role of inventories and because the fluctuation of exchange rates and the price of imported input materials also cause the speculation motive of inventories.

⁴ This is a reasonable assumption in work with quarterly data in that material supplies to output ratios are only about one and one-half months, so that turnover occurs within the quarter.

4. Model Solution

To obtain the first order conditions for this problem, it is convenient to eliminate p_t from profit function (8) by substituting the inverse form of the final demand (5):

$$\begin{aligned} R_t &= p_t S_t - \frac{c_1}{2} Q_t^2 - \frac{c_2}{2} \Delta Q_t^2 - \omega_0 u_{ct} Q_t - \frac{b}{2} (N_{t-1} - \alpha S_t)^2 \\ &= \left(-\frac{\omega_0}{2} S_t + \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^* + \omega_0 u_{dt} \right) S_t \\ &\quad - \frac{c_1}{2} Q_t^2 - \frac{c_2}{2} \Delta Q_t^2 - \omega_0 u_{ct} Q_t - \frac{b}{2} (N_{t-1} - \alpha S_t)^2. \end{aligned} \quad (12)$$

By using the inventory accumulation identity $S_t = Q_t - \Delta N_t$, substitute out for S_t from profit function:

$$\begin{aligned} R_t &= -\frac{\omega_0}{2} (Q_t - \Delta N_t)^2 + (\omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^* + \omega_0 u_{dt}) (Q_t - \Delta N_t) \\ &\quad - \frac{c_1}{2} Q_t^2 - \frac{c_2}{2} \Delta Q_t^2 - \omega_0 u_{ct} Q_t - \frac{b}{2} [N_{t-1} - \alpha (Q_t - \Delta N_t)]^2. \end{aligned} \quad (13)$$

Differentiate the objective function with respect to N_t and Q_t . The first order conditions for inventories and output are arranged in the two variables N_t and Q_t :

$$\begin{aligned} E_t [&\beta (\omega_0 - b(1-\alpha)\alpha) N_{t+1} - ((1-\beta)\omega_0 + b\alpha^2 + \beta b(1-\alpha)^2) N_t \\ &+ (\omega_0 - b(1-\alpha)\alpha) N_{t-1} - \beta (\omega_0 - b(1-\alpha)\alpha) Q_{t+1} \\ &+ (\omega_0 + b\alpha^2) Q_t + \beta \omega_1 Y_{t+1} - \omega_1 Y_t + \beta \omega_2 e_{t+1} - \omega_2 e_t \\ &+ \beta \omega_3 Y_{t+1}^* - \omega_3 Y_t^* + \beta \omega_0 u_{dt+1} - \omega_0 u_{dt}] = 0 \end{aligned} \quad (14)$$

$$\begin{aligned} E_t [&(\omega_0 + b\alpha^2) N_t - (\omega_0 - b(1-\alpha)\alpha) N_{t-1} + \beta c_2 Q_{t+1} \\ &- (\omega_0 + c_1 + (1+\beta)c_2 + b\alpha^2) Q_t + c_2 Q_{t-1} \\ &+ \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^* - \omega_0 u_{ct} + \omega_0 u_{dt}] = 0. \end{aligned} \quad (15)$$

Two Euler equations, aggregate demand, and inventory identity interact to determine equilibrium N_t , Q_t , S_t , and p_t , conditional on the exogenous demand shift variables Y_t , Y_t^* , and e_t and the shocks from demand and supply. As in other macroeconomic models, one advantage of the linear quadratic framework is used to obtain explicit solutions to the model and keep the econometric estimation manageable.⁵

⁵ In order to solve the model, I conjecture reduced form solutions of the form. The value of

5. Interpretation of Euler Equations

In the simple case where $c_2=0$ (no adjustment costs), these Euler equations can be thought of as the marginal conditions that hold when firms are maximizing their profit through time. Note that using Equations (14) and (15) and setting $c_2=0$ gives:

$$\begin{aligned} & (-\omega_0 S_t + \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^*) + b\alpha(N_{t-1} - \alpha S_t) \\ & = \beta E_t[-\omega_0 S_{t+1} + \omega_1 Y_{t+1} + \omega_2 e_{t+1} + \omega_3 Y_{t+1}^* \\ & + b\alpha(N_t - \alpha S_{t+1})] - b_1(N_{t-1} - \alpha S_t) \end{aligned} \quad (16)$$

$$(-\omega_0 S_t + \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^*) + b\alpha(N_{t-1} - \alpha S_t) = c_1 Q_t. \quad (17)$$

Consider the marginal revenue of sales:

$$MR(S_t) = \frac{\partial R_t}{\partial S_t} = (-\omega_0 S_t + \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^*) + b\alpha(N_{t-1} - \alpha S_t), \quad (18)$$

which characterizes sales and also implies the shadow value of one more unit of inventories at the end of period t . This shadow value of inventories is the sum of the marginal benefit $(-\omega_0 S_t + \omega_1 Y_t + \omega_2 e_t + \omega_3 Y_t^*)$ and the value (which can be positive or negative) of marginal cost of being away from target inventories $[b\alpha(N_{t-1} - \alpha S_t)]$, which is a potential price, not a nominal price. Using the shadow value inventories, Euler equations can be reexpressed as:

$$MR(S_t) = \beta E_t[MR(S_{t+1})] - MC(N_t) \quad (19)$$

$$MR(S_t) = MC(Q_t). \quad (20)$$

Equation (19) says that the optimizing firm is indifferent between selling out a unit in this period and adding a unit to inventory in this period to be sold in the next period. The marginal revenue of this period is equal to the expected excess of discounted marginal revenue over the opportunity cost of not selling today for future sales, which generates the dynamics of the shadow price of inventories.⁶

the coefficients is found by the method of the undetermined coefficients as described, in detail, by West (1990). An alternative solution technique is the procedure developed by Anderson and Moore (1985) and is used in the inventory study by Fuhrer et al. (1995).

⁶ If I arrange Equation (19) such as $\beta E_t[MR(S_{t+1})] - MR(S_t) = MC(N_t)$, Equation (19) states that the firm puts into inventory until the expected benefit of adding a unit to ending period stocks must equal the marginal storage cost.

Equation (20) states that the firm produces until marginal production cost equals marginal revenue. At the optimum, marginal revenue must be equated with cost in each period. Therefore, the first and the second equations imply that marginal revenue, marginal cost of production, and marginal cost of selling out of inventories are all equal. More clearly, substitute (17) into (16), then:

$$c_1 Q_t = \beta E_t [c_1 Q_{t+1}] - b(N_{t-1} - \alpha S_t). \quad (21)$$

The system of Euler equations from profit maximization problem can be reexpressed as a single Euler equation derived from cost minimization problem of the benchmark inventory model:

$$MC(Q_t) = \beta E_t [MC(Q_{t+1})] - MC(N_t), \quad (22)$$

which implies that the firm equates the marginal cost from producing one unit today instead of tomorrow to the cost of holding the extra unit in inventory, which characterizes the dynamics of the costs of inventories. This condition states that the firm plans to produce each period until the marginal cost is equilibrated in every period, since marginal cost in period t is the sum of direct production costs and the cost of having too much or too little inventory. By doing this, the firm saves on future production costs but incurs a marginal inventory holding cost.⁷

III. ECONOMETRIC ANALYSIS

1. Econometric Specification

Since the structural parameters are not separately identified in Euler equations and identified only up to scale, a normalization is required to estimate the parameters. Dividing both Euler Equations (14) and (15) by ω_0 :

$$\begin{aligned} E_t [-(\beta S_{t+1} - S_t) + \frac{\omega_1}{\omega_0} (\beta Y_{t+1} - Y_t) + \frac{\omega_2}{\omega_0} (\beta e_{t+1} - e_t) \\ + \frac{\omega_3}{\omega_0} (\beta Y_{t+1}^* - Y_t^*) - \frac{b}{\omega_0} \alpha^2 (\beta S_{t+1} - S_t) \\ + \frac{b}{\omega_0} \alpha (\beta N_t - N_{t-1} + \beta S_{t+1}) - \frac{b}{\omega_0} \beta N_t + \beta u_{dt+1} - u_{dt}] = 0 \end{aligned} \quad (23)$$

⁷ If I arrange Equation (22) such as $MC(N_t) = \beta E_t [MC(Q_{t+1})] - MC(Q_t)$, the marginal cost of storage must equal the difference between the marginal cost of production in the two periods. The expected change in marginal cost could be due to expected change in factor prices, expected increases in cost due to convexity of the cost function, and changes in expected adjustment costs.

$$E_t[-S_t + \frac{\omega_1}{\omega_0} Y_t + \frac{\omega_2}{\omega_0} e_t + \frac{\omega_3}{\omega_0} Y_t^* - \frac{c_1}{\omega_0} Q_t + \frac{c_2}{\omega_0} (\beta \Delta Q_{t+1} - \Delta Q_t) + \frac{b}{\omega_0} \alpha N_{t-1} - \frac{b}{\omega_0} \alpha^2 S_t - u_{ct} + u_{dt}] = 0. \quad (24)$$

Both Euler equations were used to construct in the extent to levels versus quasi-differences (i.e., the weighted differences such that $\beta X_{t+1} - X_t$) in a manner consistent with the inventory identity constraint. For notational convenience, define the following vectors:

$$\begin{aligned} X_{1,t+1} &= [N_t, N_{t-1}, S_{t+1}, S_t, Y_{t+1}, Y_t, e_{t+1}, e_t, Y_{t+1}^*, Y_t^*] \\ X_{2,t+1} &= [N_{t-1}, Q_{t+1}, Q_t, Q_{t-1}, S_t, Y_t, e_t, Y_t^*] \\ \theta_1 &= [\frac{\omega_1}{\omega_0}, \frac{\omega_2}{\omega_0}, \frac{\omega_3}{\omega_0}, \frac{b}{\omega_0}, \alpha] \\ \theta_2 &= [\frac{\omega_1}{\omega_0}, \frac{\omega_2}{\omega_0}, \frac{\omega_3}{\omega_0}, \frac{c_1}{\omega_0}, \frac{c_2}{\omega_0}, \frac{b}{\omega_0}, \alpha]. \end{aligned}$$

Given a N -dimensional information set Ω_t which contains all information available to decision makers at time t , then

$$E_t[H_1(X_{1,t+1}, \theta_1) | \Omega_t] = 0 \quad (25)$$

$$E_t[H_2(X_{2,t+1}, \theta_2) | \Omega_t] = 0. \quad (26)$$

The parameters of the moment condition can be consistently and efficiently estimated by instrumental variables using the GMM technique developed by Hansen (1982). According to Equations (25) and (26), H_1 and H_2 are orthogonal to any variable contained in Ω_t , including endogenous variables like N_{t-j} , S_{t-j} , and Q_{t-j} , $j \geq 0$. This technique makes use of the set of unconditional moment restrictions. Let Z_t be an R -dimensional vector of instrumental variables in Ω_t , each of the R instruments assumed orthogonal to unobservable disturbance u_t , and \otimes denote the Kronecker product operator:

$$E_t[Z_t \otimes H_1(X_{1,t+1}, \theta_1) | \Omega_t] = 0 \quad (27)$$

$$E_t[Z_t \otimes H_2(X_{2,t+1}, \theta_2) | \Omega_t] = 0. \quad (28)$$

To implement GMM procedures to estimate the parameters of the system of Euler equations, it is necessary to identify a set of instruments. The common practice in the inventory literature is the use of lagged values of endogenous variables as instruments under the assumption that the factors which affect the

composite error term on the Euler equations are not correlated with measurement errors associated with the variables appearing on the Euler equations.⁸

When using lagged endogenous variables as instruments, the eligibility of variables dated time is a crucial issue. There is a trade off as to how many periods the instruments should be lagged. Many components imply more efficient instruments, but they also increase the conditioning number of the weighting matrix.⁹

I specified the instrument vector Z_t to be:

$$Z_t = [1, N_{t-1}, N_{t-2}, S_{t-1}, S_{t-2}, Y_{t-1}, Y_{t-2}, e_{t-1}, e_{t-2}, Y_{t-1}^*, Y_{t-2}^*]$$

Finally, I set β a priori equal to 0.985 following the bulk of the inventory literature, since most studies find that variations in β do not significantly affect estimates of the other parameters.¹⁰

2. Estimation Methodology of System

GMM estimation procedure is especially useful when the moment equations are overidentified in a system of optimization conditions. The results are obtained with a numerical optimization routine written in RATS. For the simultaneous estimation of both Euler equations, I have used the regression code of Nonlinear Systems Estimation (NLS) which is mainly constructed for the estimation of systems of equations by multivariate nonlinear least squares or by GMM.¹¹

The Euler equations derived from the theoretical model can be reexpressed as:

$$\begin{aligned} & -(\beta S_{t+1} - S_t) + \frac{\omega_1}{\omega_0}(\beta Y_{t+1} - Y_t) + \frac{\omega_2}{\omega_0}(\beta e_{t+1} - e_t) \\ & + \frac{\omega_3}{\omega_0}(\beta Y_{t+1}^* - Y_t^*) - \frac{b}{\omega_0} \alpha^2 (\beta S_{t+1} - S_t) \end{aligned}$$

⁸ Ramey (1991) especially, chooses current and lagged values of aggregate military expenditures and real oil prices in her empirical analysis that can be reasonably assumed to exogenous.

⁹ If the instruments are lagged only one period they are more efficient, but the GMM estimator would be inconsistent in the case of autocorrelation because some of the instruments are endogenous variables. When the endogenous instruments are lagged more than two periods, autocorrelation of the MA type does not impinge on the consistency of the GMM estimator.

¹⁰ I experimented with a variety of values of β between 0.980 and 0.990, and found that the results were almost completely insensitive to the specification of β within this range.

¹¹ NLS also automatically computes the optimal 'weighting matrix' for the orthogonality conditions to converge by iterating, which could be suitable to set up the iterated GMM estimations.

$$+ \frac{b}{\omega_0} \alpha(\beta N_t - N_{t-1} + \beta S_{t+1}) - \frac{b}{\omega_0} N_t = -\beta u_{dt+1} + u_{dt} + \xi_{1t+1} \quad (29)$$

$$- S_t + \frac{\omega_1}{\omega_0} Y_t + \frac{\omega_2}{\omega_0} e_t + \frac{\omega_3}{\omega_0} Y_t^* - \frac{c_1}{\omega_0} Q_t + \frac{c_2}{\omega_0} (\beta \Delta Q_{t+1} - \Delta Q_t) \\ + \frac{b}{\omega_0} \alpha(N_{t-1} - \alpha S_t) = u_{ct} - u_{dt} + \xi_{2t+1} \quad (30)$$

where ξ_{it+1} is an expectational error term which arises because when decisions are made at time t , the realization of some of the variables in the Euler equations may not be known to decision makers. The system of Euler equation errors, which is the right hand side of Equations (29) and (30), are denoted by $u_{i,t+1}$, for $i=1, 2$.

$$H_1(X_{1,t+1}, \theta_1) = u_{1,t+1} \quad (31)$$

$$H_2(X_{2,t+1}, \theta_2) = u_{2,t+1} \quad (32)$$

Let $H_{t+1}(H_{1,t+1}, H_{2,t+1})'$ and Z_t be the $R \times 1$ vector of observable instrument variables which do not depend upon the K dimensional vector of free parameters θ . Then, the $2R$ -dimensional vector valued function:

$$D_T(\theta) = \frac{1}{T} \sum_t Z_t \otimes H_{t+1}(\theta) \quad (33)$$

can be formed using sample information. Equations (33) represents a set of $N \times R$ orthogonality conditions which are used to estimate θ with Z_t serving as instruments for the regressors in the GMM procedure where N is the number of equations and R the number of instruments. The model is tested by measuring the orthogonality of the instruments with respect to the estimated residuals from the equations. The true value parameter vector θ^* is estimated by choosing from the admissible parameter space θ_T the one that minimizes the quadratic form criterion function:

$$J_T(\theta) = D_T(\theta)' S_T W_T D_T(\theta) \quad (34)$$

where SW is a symmetric weighting matrix. Some of the option of NLS let us set the form for the matrix SW in Equation (34). Given a set of instruments, there is a different GMM estimator for each choice of the weighting matrix SW . This is an $NR \times NR$ symmetric array. I can use the full SW array with Z_u dependence(ZUD) option which allows for dependence between the instruments and residuals.¹² NLS incorporates this information

directly into the calculations of SW , computing the minimum variance estimator in the class. The weighting matrix used in the estimation is consistent with heteroscedasticity and autocorrelation.

In addition, the GMM estimation procedure allows for tests of the model specification. Specially, when $N \times R > K$, there are $N \times R - K$ unconstrained linearly independent orthogonality conditions which are not equal to zero in the estimation procedure but should be close to zero if the model is correctly specified. $T \cdot J_T(\theta_T)$ is distributed asymptotically as chi-square (χ^2) with degrees of freedom equal to the difference between the number of equations times the number of instruments and the number of parameters to be estimated ($N \times R - K$) under the null hypothesis that the model is correctly specified.¹³ Note that if the model is just identified, $T \cdot J_T(\theta_T)$ is zero.

The use of estimated residuals from the two step two stage least squares (2SLS) regression to construct the weighting matrix may produce a poor estimate if the 2SLS estimates are biased. A proposed solution to this problem is to iterate on the weighting matrix, even if there is no guarantee that the process converges asymptotically to the true weighting matrix. In practice, it may be desirable to iterate, repeatedly updating the weighting matrix until the procedure converges. I have conducted both two stage and iterated GMM estimators.¹⁴ The two procedures have the same asymptotic properties. According to Ferson and Foerster (1994), however, the two stage GMM tests reject the null hypothesis too often in larger models such as system of equations, while an iterated GMM test statistic conforms more closely to the asymptotic distribution.

An initial guess of the parameter vector is used to construct the initial estimate of the weighting matrix. The estimate of the weighting matrix typically converged after a few iterations to give a consistent, but inefficient estimate of θ . The consistent θ is subsequently used as the initial parameter guess to construct an efficient weighting matrix for the second stage of GMM estimation. Convergence is accepted when both the relative gradient and the relative change

¹² Matrix SW which can be written in the form $\sum^{-1} \otimes W$ is just $\sum^{-1} \otimes Z'Z^{-1}$ where \sum is initial input matrix uu' and Z is the $T \times R$ matrix of instruments for the entire sample. Without ZUD option, I have to set W part and \sum part of the SW , which should compute a suboptimal estimator and get its corrected covariance matrix. It then corrects the covariance matrix for conditional heteroscedasticity or serial correlations in $u \otimes Z$.

¹³ The asymptotic power of GMM specification tests is determined by the noncentrality parameter and the degrees of freedom, since the tail probability of noncentral chi-squared distribution is increasing in the noncentrality parameter and decreasing in the degrees of freedom. Therefore, the relative magnitudes of these unconditional moments will depend on all of the structural parameters.

¹⁴ For iterated GMM estimators, Nonlinear Systems Estimation (NLS) routine in RATS recomputes the optimal weighting matrix for the orthogonality conditions and reestimates the system. It repeats this process until either the iteration limit (set equal to 50 in this work) is exceeded, or the convergence criterion is met.

in the parameter vector are less than 10^{-5} , except for some restricted versions where the criteria are changed to either the convergence of the relative gradient or the relative change in the parameter vector. The results are fairly robust to further iterations on the weighting matrix, and to different starting values for computing the weighting matrix.

IV. EMPIRICAL RESULTS

The data used in this paper are obtained from the Main Economic Indicators (MEI) from OECD. They are quarterly data measured in 1990 constant price covering 1974:1 through 1994:4. By definitions of variables in a structural model setting, the foreign factors such as foreign output (Y_t^*), exchange rate (e_t), and import price of input (q_t) were constructed as a trade weighted index of the other six of G7 countries, as in Bahmani-Oskooee (1995). Data were demeaned and detrended using a quadratic trend of time.¹⁵

Table 1 reports the analysis with endogenous sales specification in a closed economy setting ($\omega_2 = 0, \omega_3 = 0$).¹⁶ Notice that there is very little evidence against this version of the model for the sample countries Canada, Japan, and the U.K. except the U.S. While the probability value of the J -statistics varied across the countries, I can not reject, at the 5 per cent significant level, the overidentifying restrictions implied by the model in three sample countries.

Almost all the estimated parameters are indeed positive. Only one of the wrong signed coefficients are significant at the 5 per cent level in Table 1. In all the estimations, the production cost c_1 is positive and significant even at the 1 per cent level. Somewhat puzzling is the imprecision of the estimates of the target level parameter α , which is rarely significant at the 5 per cent level except the U.K. Related to this result, most of the previous inventory studies especially using GMM estimation procedures have provided poor results such that these target level parameters are estimated with the wrong sign and are invariably insignificant in the benchmark inventory model with exogenously determined sales process using the U.S. data as in Krane and Braun (1991) and Kollintzas (1995). One notable exception is Durlauf and Maccini (1995), in which they estimate more plausible values of the target level parameters even if they use a certain combination of parameters such as the stable root of the characteristic equation, which can be usually estimated more precisely than the underlying parameters. It is also noted in West and Wilcox (1994) who provide Monte Carlo evidence that the estimators of several of these target level

¹⁵ Unit root tests shows that there is little evidence of unit roots in the presence of quadratic deterministic trends. Further, experimentation with the various inventory models using first-differenced data produces qualitatively similar to those I report. See Eichenbaum (1989) for details.

¹⁶ The results of benchmark inventory model derived from cost minimization problem is well described in Durlauf and Maccini (1995).

parameters have even wider dispersions than the value predicted by asymptotic theory.¹⁷

[Table 1] Parameter Estimation in Closed Economy Setting

Parameters	Canada	Japan	UK	US
ω_1/ω_0	0.409** (0.116)	0.474** (0.077)	0.127* (0.059)	0.121 (0.094)
α	-0.773* (0.370)	-0.336 (0.374)	0.261* (0.115)	-0.169 (0.225)
b/ω_0	0.095* (0.038)	0.054* (0.027)	0.180** (0.059)	0.176 (0.102)
c_1/ω_0	0.634** (0.069)	0.721** (0.022)	0.873** (0.038)	0.932** (0.053)
c_2/ω_0	-0.207 (0.137)	0.090 (0.049)	0.053 (0.142)	0.047 (0.110)
Iteration†	11	12	10	30
$J(9)‡$	10.64	8.49	12.37	19.45#
p -value	[0.301]	[0.486]	[0.193]	[0.021]

Instruments set: $N_{t-1}, N_{t-2}, S_{t-1}, S_{t-2}, Y_{t-1}, Y_{t-2}, \text{constant}$

Asymptotic standard errors are in parentheses; asymptotic p -values are in brackets.

** refers to significance at the 1% level; * refers to significance at the 5% level.

and # denotes that the overidentify restrictions of the model are rejected at the 1%, and the 5% level of significance.

† limits the 50 iterations. I repeats the process until either the iteration limit is exceeded, or the objective function is converged.

‡ is distributed as chi-square (χ^2) with degrees of freedom equal to the difference between the number of instruments(R) times the number of equations(N) and the number of parameters(K) to be estimated($7 \times 2 - 5$).

Table 2 reports empirical results with the formulations of open economy setting. I conduct the specification tests of the model which exploit the orthogonality restrictions implicit in the first order conditions of the firm's optimal plan. The model specifications with estimating equations of open economy variables cannot be rejected at the 5 per cent significance level for Canada, Japan, and the U.K. Not surprisingly, for the U.S. manufacturing inventory data, the overidentifying restrictions associated with open economy setting in the inventory model appear to be highly implausible. This result implies that even though the open economy factors into the inventory model

¹⁷ Fuhrer et al. (1995) argue that the GMM estimation bias is always negative and a nontrivial portion of the distribution is negative. They also supply some evidence that although the GMM estimates converge toward the true values as the sample size increases, significant bias persists even in sample sizes that are extremely large relative to data availability.

may be not necessary in the analysis of the U.S. economy, it is clearly essential to model the foreign factor variations explicitly in the analysis of inventory fluctuations for other countries.

[Table 2] Parameter Estimation in Open Economy Setting

Parameters	Canada	Japan	UK	US
ω_1/ω_0	0.498** (0.065)	0.525** (0.073)	0.428** (0.059)	0.854** (0.177)
ω_2/ω_0	0.125** (0.017)	0.053** (0.015)	0.069** (0.010)	0.010 (0.011)
ω_3/ω_0	0.474** (0.095)	0.382** (0.094)	0.390** (0.066)	-0.405** (0.119)
α	-0.614 (0.389)	-0.520 (0.870)	0.573 (0.995)	0.788 (1.256)
b/ω_0	0.060** (0.022)	0.027 (0.026)	0.029 (0.035)	0.022 (0.045)
c_1/ω_0	0.412** (0.044)	0.643** (0.031)	0.617** (0.031)	0.656** (0.091)
c_2/ω_0	0.023 (0.061)	0.059 (0.056)	0.168* (0.087)	0.159** (0.042)
Iteration†	14	10	27	28
$J(15)‡$	10.67	7.53	21.25	27.63#
p -value	[0.776]	[0.941]	[0.129]	[0.024]

Instruments set: $N_{t-1}, N_{t-2}, S_{t-1}, S_{t-2}, Y_{t-1}, Y_{t-2}, e_{t-1}, e_{t-2}, Y_{t-1}^*, Y_{t-2}^*, Y^*$, constant

Asymptotic standard errors are in parentheses; asymptotic p -values are in brackets.

See [Table 1] footnote for * # † ‡ .

Still excluding the target level parameter α , other parameters, especially open economy parameters (ω_2, ω_3), are actually estimated to be positive and significant for the three sample countries, still except the U.S. The cost parameter c_1 is estimated quite accurately and indicates substantial positive serial correlation in the stochastic components of marginal costs. While imprecisely estimated, the parameter α is estimated to be positive for the U.K. and the U.S.

The estimate of the parameters associated with foreign shocks is generally positive and frequently significant despite a good deal of collinearity among the measures of foreign factors. From Table 2, the coefficients of domestic GDP (ω_1) for the U.S. and Japan are larger than those for Canada and the U.K. The coefficients of foreign output (ω_3) for Canada are clearly greater than those for Japan and the U.K. In the U.S., the estimate of ω_3 is invariably of the

wrong sign despite the statistical significance of estimate.

These results have a couple of interesting economic implications. In the two largest economies, the U.S. and Japan, the manufacturing inventory behavior could be more closely related to the domestic sales shocks than shocks from abroad. However, especially in Canada, the fluctuations of manufacturing inventories are largely due to the shocks from abroad (mostly from the U.S.). This result indicates that the assumption of taking Canada as a small open economy and the U.S. as the rest of the world, which is a common practice in the analysis of the Canadian economy, is also suitable for the analysis of inventory behavior.

[Table 3] Parameter Estimation in Open Economy Setting
with Real Cost Factors

Parameters	Canada	Japan	UK	US
ω_1/ω_0	0.570** (0.065)	0.732** (0.080)	0.474** (0.038)	0.925** (0.071)
ω_2/ω_0	0.088* (0.043)	0.130** (0.051)	0.059** (0.016)	-0.090** (0.029)
c_3/ω_0	0.261* (0.134)	0.285** (0.077)	0.487** (0.057)	-0.669** (0.076)
α	-0.799 (0.489)	-0.866 (0.845)	0.166 (0.181)	0.262 (0.404)
b/ω_0	0.044** (0.018)	0.036 (0.024)	0.083** (0.032)	0.068 (0.060)
c_1/ω_0	0.580** (0.070)	0.530** (0.038)	0.641** (0.033)	0.664** (0.025)
c_2/ω_0	0.029 (0.035)	0.141** (0.031)	0.044 (0.059)	0.128** (0.027)
ρ_1	-0.036 (0.052)	0.114** (0.023)	-0.224** (0.041)	0.235** (0.036)
ρ_2	-0.098** (0.024)	-0.045** (0.012)	0.027* (0.012)	0.207** (0.038)
ρ_3	0.026 (0.037)	0.114* (0.047)	-0.040 (0.042)	0.057* (0.025)
Iteration†	15	20	40	27
$J(24)‡$	14.92	16.31	23.08	21.53
p -value	[0.923]	[0.877]	[0.515]	[0.607]

Instruments set: $N_{t-1}, N_{t-2}, S_{t-1}, S_{t-2}, Y_{t-1}, Y_{t-2}, e_{t-1}, e_{t-2}, Y_{t-1}^*, Y_{t-2}^*, Y^*, w_{t-1}, w_{t-2}, Z_{t-1}, Z_{t-2}, q_{t-1}, q_{t-2}$, constant

Asymptotic standard errors are in parentheses; asymptotic p -values are in brackets.

See [Table 1] footnote for * # † ‡ .

Finally, the multi-component cost shocks measured by observed data is

estimated using the GMM techniques in Table 3. The model is accepted for all sample countries even including the U.S. economy. The estimates of the parameters associated with cost shocks for the U.S. data are positive and significant despite a good deal of collinearity among the measures of input prices. This result is quite consistent with the previous study of Durlauf and Maccini (1995), even though the multi-component of cost shocks is different from this paper.

However, this insertion of the multi-component cost shocks represents no improvement in the cases of Canada and the U.K., and even deterioration in Japan as result from Table 2. I also find that observed cost shocks often have the wrong sign and are invariably insignificant for these countries. In view of the poorer performance with input prices, the results for only considering open factors are clearly preferred in Canada, Japan, and the U.K. From these estimation results, however, I may conclude that in the U.S. cost shocks appear to be the predominant source of fluctuations in inventories.

V. SUMMARY AND CONCLUSION

This paper attempts to extend the benchmark approaches such that inventories and sales are jointly determined by the representative firm. A number of main results are worth mentioning. First, related to the sales specification, I find that endogenous sales specification in the inventory model is likely to be important elements of an improved model, especially in a small economy. The structural model is in fact accepted in the cases of Canada, Japan, and the U.K., in which the J -statistics are performed best for Japan and least for the U.K. For the U.S., however, there is overwhelming evidence against the overidentifying orthogonality restrictions implied by the endogenous demand inventory model such that the J -statistics strongly reject the model and are substantially higher than those of other sample countries. This highlights the support for treating sales as an endogenous variable in the inventory study using the small economy data, even if it is unnecessary for the U.S. inventory analysis.

Second, on the basis of J -statistics, the specification tests of the inventory model with the open economy variables such as a trade weighted foreign output and exchange rate provide that the model is well approximated for the realized data on inventories for Canada, Japan, and the U.K., but not the U.S. economy. I cannot reject, at the 5 per cent level, the overidentifying restrictions implied by the open economy setting for three sample countries. In the majority of cases, parameters of the open economy factors are estimated quite accurately. In the inventory analysis of the U.S. economy, the foreign factors are often ignored to simplify the analysis, and it appears to be a reasonable assumption for the U.S. In the inventory analysis of other economies, however, open economy variables are important factors in explaining inventory fluctuations of manufacturing inventories, since allowing for foreign factors in the inventory

model significantly improves the ability of the model to explain inventory movements.

I also find that although only in the U.S. economy, cost shocks play at least as important a role as demand shocks in determining the behavior of inventories, demand fluctuations play a more important role in determining the time series properties of inventories in small open economies. In explanation of inventory movements, these results provide the support for the production smoothing model which augments demand shocks are mainly deriving the inventory movements.

Formal empirical testing indicates that the model fits the data rather well, suggesting that this model specification is a good starting point for future research of open economy analysis of inventory study. The results support the view that foreign factors such as exchange rates and imported input materials prices are potentially important determinants in explaining the inventory adjustments, especially in an open economy setting.

The comparative analysis of manufacturing inventory behaviors, using multicountry data sources, provides a direction for future studies of the behavior of inventory investments. It seems plausible to argue that deeper consideration needs to be given to the forcing variables such as foreign factors and to the role of inventories as speculative purposes, in order to improve our understanding of the mechanisms underlying the dynamic characteristics of inventory decision making. These issues can be explored further in the context of the model developed in this paper.

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