

INVENTORIES AND THE BUSINESS CYCLE: TESTING A SEQUENTIAL TRADING MODEL

Benjamin Eden*

The University of Haifa

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The Uncertain and Sequential Trading (UST) model of inventories behavior with i.i.d shocks predicts that (a) the beginning of period inventories is a sufficient statistic for past variables and (b) an increase in the beginning of period inventories reduces output, employment, hours per employee and effort. I find empirical support for the second hypothesis but not for the first. The rejection of the first hypothesis is rather informative and points in the direction of adjustment costs and (or) serially correlated shocks.

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1. INTRODUCTION

Changes in inventories are volatile and small. Christiano (1988) reports that quarterly changes in inventory investment are on average 0.6% of GDP but about half the size of changes in GDP. This type of observation led Blinder (1981, page 500) to conclude that "to a great extent, business cycle are inventory fluctuations". We can therefore hope to use inventories behavior for testing competing business cycles theories. Here I focus on the implications of an Uncertain and Sequential Trading (UST) model.

UST models are based on ideas in Prescott (1975) and Butters (1977). Prescott considers an environment in which sellers set prices before they know how many buyers will eventually appear. In the UST approach taken by Eden (1990), trade is sequential and an equilibrium distribution of prices is obtained even though sellers are allowed to change their prices during trade. The UST model is used in monetary economics to study the real affects of money and other issues. See Eden (1994), Lucas and Woodford (1994), Williamson (1996) and Woodford (1996).

Bental and Eden (1993, 1996; hereafter BE) introduced storage to the UST framework. In the 1993 paper i.i.d. demand shocks arise as a result of taste shocks. In the 1996 paper they arise as a result of money supply shocks. It turns out that the predictions of the model about the behavior of real variables do not depend on the source of the demand shock. Here I focus on the 1996 monetary version.

BE (1996) use a cash-in-advance economy populated by infinitely lived households. In the typical household there are two people: a seller (producer) and a buyer. At the beginning of each period the household has money and inventories. The seller takes the inventories and goes to work. The seller produces some additional output and tries to sell some or all of the accumulated stock. The buyer takes the money and goes shopping spending the money he has plus any transfer that he may get from the government. The household consumes whatever the buyer managed to buy.

From the seller's point of view money arrives sequentially. The seller makes a contingent plan which specifies the amount that will be sold to each batch of dollars that arrives. We say that each batch of dollars opens a new market. The minimal amount of money that will arrive opens the first market. With some probability the government will inject more money and a second batch of dollars will arrive opening the second market, and so on.

We describe the seller's contingent plan as an allocation of the available supply (output + beginning of period inventories) among all potential markets. If a particular market opens the seller sells the supply allocated to that market for cash. If that market does not open, the supply is carried over to the following period as inventories. Inventories may also be held for purely speculative reasons.

2. THE "UNDESIRED INVENTORIES" HYPOTHESIS

The theory predicts a negative relationship between the beginning of period inventories and output. The intuition can be derived from Figure 1 which has the price in some market (s) on the vertical axis and total supply ($k = \text{inventories} + \text{output}$) on the horizontal axis. BE show that in equilibrium there exists standard looking demand and supply curves as in Figure 1. (Since prices in all markets are connected by arbitrage conditions all prices move together and similar figures can be drawn for any choice of s). Furthermore, an increase in the beginning of period inventories shifts the supply curve to the right without affecting the demand curve. As a result, the price in market s (and in all other markets) goes down and production goes down. Since production goes down, a unit increase in inventories is associated with less than a unit increase in k .

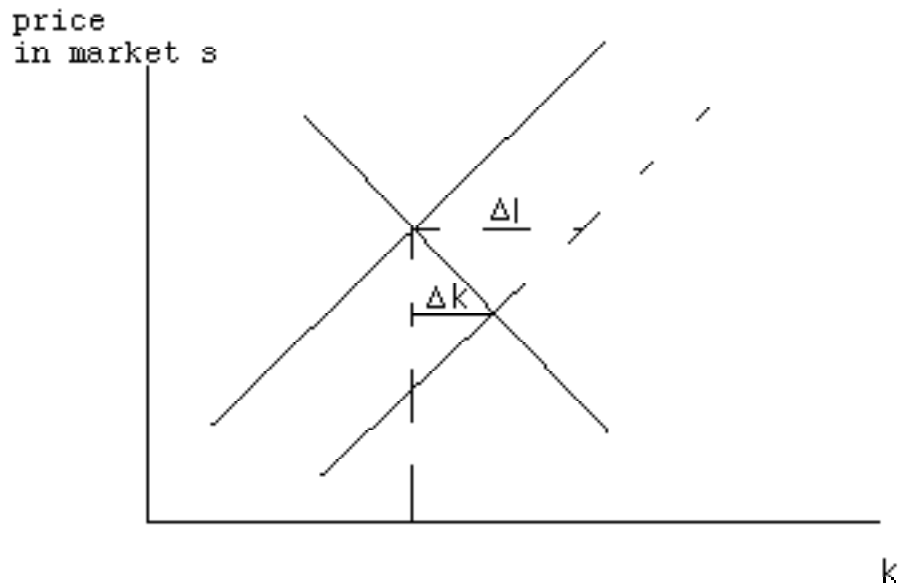


Figure 1

This prediction of a negative relationship between the beginning of period inventories and output is not shared by all models. The real business cycle models in Kydland and Prescott (1982) and Cooley and Prescott (1995) treat inventories as part of capital. If inventories are a factor of production then the correlation between the beginning of period level of inventories and output should be positive.

The production smoothing model of inventories behavior suggests that on average the beginning of period inventories will be large in a period of high demand and low in periods of low demand. Production is expected to behave in the same way leading to a positive correlation between the beginning of period inventories and output.

A negative correlation may emerge in models that assume target or desired level of inventories. Blinder and Fischer (1981) build on Lucas' confusion hypothesis and write down a modified Lucas-type supply curve where production depends not only on the price level and trend output but also on the difference between desired and actual inventories. When inventories are low the monopolistic firms increase output to get closer to the desired level of inventories. This leads to a negative correlation between the beginning of period inventories and output. Ramey and West (1997) consider a linear-quadratic model in which inventories are held to smooth production and to meet a desired ratio of inventories to sales. They use the model to explain the positive correlation between output and change in inventories but do not derive implications about the correlation between the (level of the) beginning of period inventories and output. Since Ramey and West have a desired level of inventories implicit in their formulation, I expect that for

some choice of parameters their model also predicts a negative correlation between the beginning of period inventories and output.

I now turn to an example which illustrates the working of a UST model with storage.

3. AN EXAMPLE OF A UST MODEL WITH COSTLESS STORAGE

In this example, the typical household is a worker-buyer pair. Each period the amount of money that arrives at the goods markets may take two possible realizations, depending on the amount of new money injected by the government. The low realization of the money supply arrives first, with certainty, and buys in market 1 at the price P_1 . An additional amount of money may arrive if the government injection is high. In this case, the additional amount will buy in market 2 at the price P_2 . The worker allocates his supply across the two markets. If the amount of newly printed money is low, market 2 does not open and the amount allocated to this market is carried to the next period as "undesired" inventories.

I now turn to describe the example in detail.¹ The typical household starts the period with I_{t-1}^h units of inventories and M_t^h dollars. The buyer takes the M_t^h dollars and spends it in market 1 buying M_t^h/P_{1t} units of consumption. With probability $1/2$ trading then ends. But with probability $1/2$ the government prints money and distribute it as a transfer payment to the buyers: θ dollars per dollar held at the

¹ I would like to thank Bob Lucas for a recent exam question which led to some simplification of this example.

beginning of the period. If a transfer payment occurs, market 2 opens and buyer h buys additional $\theta M_t^h / P_{2t}$ units. Expected consumption for buyer h is thus: $(M_t^h / P_{1t}) + (1/2)(\theta M_t^h / P_{2t})$.

Prior to trade the worker takes the beginning of period inventories (I_{t-1}^h) and goes to work. He produces output (y_t^h) using labor input (L_t^h) according to a Cobb-Douglas production function:

$$(1) \quad y_t^h = \varepsilon_t (L_t^h)^\alpha,$$

where ε_t is an i.i.d supply shock and α is the elasticity of output with respect to labor ($0 < \alpha < 1$). He then takes the total supply:

$$(2) \quad k_t^h = y_t^h + I_{t-1}^h,$$

and allocates it across the two markets:

$$(3) \quad k_{1t}^h + k_{2t}^h \leq k_t^h,$$

where k_{st}^h is the supply to market s .

The household is risk neutral and its single period utility function is given by:

$$(4) \quad c_t^h - v(L_t^h),$$

where $v(\cdot)$ is a standard cost function ($v' > 0$ and $v'' > 0$).

I divide all nominal magnitudes by the average per household money supply and use the money supply as a unit of account which is called a

normalized dollar. A price of one normalized dollar means that you must pay the money supply (average per household) to get a unit of consumption. A normalized dollar this period will become one normalized dollar in the next period if no transfer occurs and $1/(1 + \theta)$ normalized dollars in the next period if a transfer does occur. I use lower case letters to denote normalized prices and balances.

I drop the superscript to denote average per household magnitudes and use $x = (I_{-1}, \varepsilon)$ to denote the current aggregate state. In equilibrium all magnitudes are functions of x . I use,

$$(5) \quad k(x) = \varepsilon[L(x)]^\alpha + I_{-1},$$

to denote average supply per household and

$$(6) \quad I^s(x) = k(x) - \sum_{j=1}^s k_j(x) \geq 0,$$

to denote the average per household level of next period inventories if exactly s markets open today.

The household takes the price functions, $p_s(x)$, and the next period average inventories functions, $I^s(x)$, as given. Given these functions the following Bellman's equation describes the behavior of the typical household:

$$\begin{aligned}
(7) \quad V(m^h, I_{-1}^h; x) &= \max [m^h/p_1(x)] + (1/2)[\theta m^h/p_2(x)] - v(L^h) + \\
&\quad + (1/2)\beta EV\{p_1(x)k_1^h, k^h - k_1^h, [I^1(x), \tilde{\epsilon}]\} \\
&\quad + (1/2)\beta EV\{[p_1(x)k_1^h + p_2(x)k_2^h]/(1 + \theta), k^h - k_1^h - k_2^h, [I^2(x), \tilde{\epsilon}]\} \\
&\quad \text{s.t.} \\
&\quad k_1^h + k_2^h \leq k^h = \varepsilon(L^h)^\alpha + I_{-1}^h \text{ and non negativity constraints.}
\end{aligned}$$

Here $V(m^h, I_{-1}^h; x)$ is the maximum expected utility possible in aggregate state x , for a household that starts this period with m^h normalized dollars and I_{-1}^h units of inventories. The maximization is with respect to L^h , k_1^h and k_2^h . The first row is utility in the current period. The second row is the expected future utility given that only one market opens, where conditional expectations are taken with respect to the next period supply shock ($\tilde{\epsilon}$). The third row is the expected future utility given that both markets open. The last two rows are therefore the unconditional expected future utility.

Equilibrium is a vector of functions

$[p_1(x), p_2(x), L(x), k(x), k_1(x), k_2(x), I^1(x), I^2(x))]$ which satisfy

(5)-(6) and

(a) given the functions $[p_s(x), I^s(x)]$,

$[L^h = L(x), k_s^h = k_s(x)]$ solve the household's problem (7) for all x ;

(b) markets which open are cleared:

$$(8) \quad 1 = p_1(x)k_1(x) \ ; \ \theta = p_2(x)k_2(x).$$

Note that "undesired" inventories may be accumulated if there is no transfer payment. In this case, the second market will not open and the supply to this market (k_2) will be carried as "undesired" inventories to the next period. In addition, if $k_1 + k_2 < k$, inventories will be accumulated for purely speculative reasons even if both markets open.

In Eden (1999) I show the following Claim:

Claim: The equilibrium function $L(x)$ is decreasing in I_{-1} and increasing in ε . The equilibrium functions $k(x)$, $k_S(x)$, $I^S(x)$ are increasing in I_{-1} and in ε . The equilibrium functions $p_S(x)$ are decreasing in I_{-1} and in ε .

Some intuition can be obtained with the help of Figure 1. An increase in the beginning of period inventories shifts the supply curve to the right and leads to a reduction in prices. As a result workers cut production but not by the full amount of the increase in inventories. Total supply (inventories + output) goes up and the supply to all markets go up. The amount of inventories that will be accumulated (the supply to the markets which did not open) also goes up.

4. IMPLEMENTATION

I use various measures of labor supply: employment, hours per employee and effort. It is rather straightforward to incorporate these variables in the theoretical section. We may think of a household with many members that chooses the number of workers (N), hours per worker

(H) and effort (F). The household's cost is given by a strictly increasing function $v(N, H, F)$ and the household minimizes the cost of supplying a given amount of labor L by solving:

$$(9) \quad v(L) = \min v(N, H, F) \quad \text{s.t.} \quad (N)(H)(F) = L.$$

The maximization problem of the household is done in two stages: The household first chooses labor supply (L) by solving (7). It then chooses labor supply components (N, H, F), by solving (9). Assuming that v is symmetric implies that all labor supply components behave in the same way and are decreasing in I_{-1} and increasing in ε . For example, $v = (1/2)(N^{1/3} + H^{1/3} + F^{1/3})^6$, yields: $N = H = F = L^{1/3}$.

Following Cooley and Prescott (1995), all variables were logged and then detrended by the Hodrick-Prescott (H-P) filter, using the standard choice of $\lambda = 1600$. The same symbols are used now to denote the detrended log of the variables. I use the following model to interpret vector auto regression (VAR) of output hours and inventories.

$$(10) \quad Y_t = \alpha L_t + \varepsilon_t$$

$$(11) \quad TH_t = N_t + H_t$$

$$(12) \quad L_t = TH_t + F_t$$

$$(13) \quad TH_t = \beta_1 Y_{t-1} + \beta_2 TH_{t-1} - \beta_3 I_{t-1} + \beta_4 \varepsilon_t$$

$$(14) \quad F_t = \gamma_1 Y_{t-1} + \gamma_2 TH_{t-1} - \gamma_3 I_{t-1} + \gamma_4 \varepsilon_t$$

$$(15) \quad I_t = \delta_1 Y_{t-1} + \delta_2 TH_{t-1} + \delta_3 I_{t-1} + \delta_4 \varepsilon_t + \nu_t,$$

where $TH = (N)(H)$ denotes total hours, F denotes effort and $L = F + TH$ is labor input. To save notation the intercept term was omitted from all equations (but is present in all regressions).

Equation (10) is a Cobb-Douglas production function. (It is linear because the detrended variables are in log forms). The error term ε arises because of an i.i.d supply shock (it is equal to $\ln(\varepsilon)$ from the theory section).

Equation (11) defines total hours (TH) as the sum of employment and average hours per employee. Equation (12) defines labor supply as the sum of total hours and effort. Equations (13) - (14) specify total hours and effort as a function of lag variables and the productivity shock. Equation (15) specifies inventories as a function of lag variables the supply shock ε and the demand shock ν . Both ε and ν are i.i.d. Substituting (13) and (14) in (10) leads to:

$$(16) \quad Y_t = \alpha(\beta_1 + \gamma_1)Y_{t-1} + \alpha(\beta_2 + \gamma_2)TH_{t-1} - \alpha(\beta_3 + \gamma_3)I_{t-1} + (\alpha\gamma_4 + \alpha\beta_4 + 1)\varepsilon_t.$$

Equations (13), (15) and (16) is a VAR system. We expect:

$$(17) \quad \beta_1 = \gamma_1 = \delta_1 = \beta_2 = \gamma_2 = \delta_2 = 0,$$

because the theory says that the beginning of period inventories is a sufficient statistic for all lag variables.² We also expect:

$$(18) \quad \beta_3, \gamma_3, \delta_3 > 0,$$

because of the equilibrium relationship stated in the Claim.

Data: I use NIPA data from 1959:1 to 1997:4.³ These data have three concepts of outputs: Goods, Durable Goods and Non-Durable Goods.

(GDP = Services + Goods; Goods = Durables + Non-Durables). In 1997:4 the goods producing sector was about 40% of GDP and was equally divided between durables (20%) and non-durables (20%).

The mean of the cyclical (detrended) variables is close to zero. The standard deviation of the cyclical variables in the goods sector are 0.026 for output, 0.011 for sales, 0.014 for inventories and 0.035 for total hours. Output and the stock of inventories for the goods producing sector and their H-P trends are graphed in Figures 2 and 3.

² The NIPA reports the end of period inventories. Therefore the beginning of period inventories is equal to lag inventories in the NIPA data.

³ The output and inventories data are from the bureau of economic analysis, in the "selected NIPA tables". Inventories are in Table 5.13. Output data are in Table 1.04 (real output) and Table 7.17 (quantity indexes). The data is on the internet at:

<http://www.stat-usa.gov/> or <http://www.bea.doc.gov/>.

The data on hours is from the Bureau of labor statistics. Series ID are: EES00510040 for goods, EES31000040 for durable goods and EES32000040 for nondurable goods. All series are seasonally adjusted. The data for total hours is in: <http://stats.bls.gov/blshome.htm>

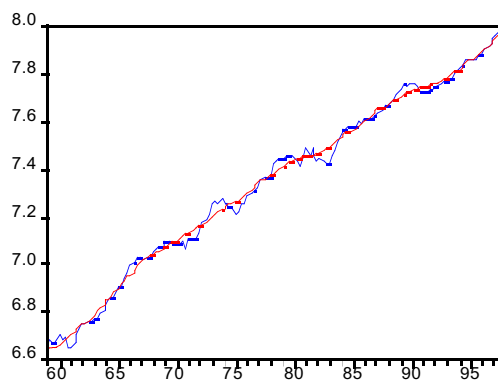


Figure 2: Output in the goods sector and its H-P trend

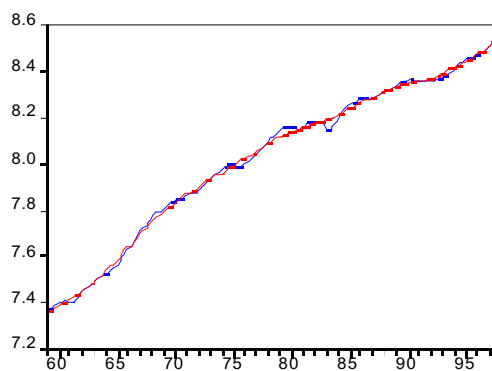


Figure 3: Inventories in the goods sector and their H-P trend

The correlation matrix for the detrended (cyclical) variables is in Table 3. The correlation between lag inventories and output (levels of detrended variables) is positive for the durable sector (0.2) and negative for the non-durable sector (-0.1). The correlation for the goods sector as a whole is positive (0.2). The correlation between hours and lag inventories are all positive and somewhat higher: 0.4 for the goods and durable sectors and 0.1 for the non-durable sector. These

correlations are not consistent with the prediction of a negative relationship between output and inventories and hours and inventories.

Table 1*: The correlation matrix for the detrended (ln) variables.

	G	I ₋₁	TH	D	I ₋₁	TH	ND	I ₋₁	TH
G	1								
I ₋₁	0.2	1							
TH	0.9	0.39	1						
D	0.94	0.19	0.89	1					
I ₋₁	0.29	0.9	0.39	0.2	1				
TH	0.91	0.39	0.98	0.92	0.4	1			
ND	0.64	0.17	0.47	0.35	0.26	0.43	1		
I ₋₁	-0.05	0.59	0.16	0	0.19	0.14	-0.1	1	
TH	0.82	0.1	0.89	0.8	0.07	0.85	0.46	0.1	1

* All variables were logged before the H-P filter was applied. We have three concepts of outputs: goods (G), durable goods (D) and non-durable goods (ND). For each output concept we have the beginning of period stock of inventories (I₋₁) and hours (TH). The correlations between output and lag inventories are in large font.

The vector auto regression regressions are in Table 2. The sign of the coefficients of lag inventories are as predicted by (18) and the hypothesis $\beta_3 = \gamma_3 = \delta_3 = 0$ can be strongly rejected (t statistics in parentheses).

Table 2* : VAR using H-P detrended log variables

	Y ₋₁	TH ₋₁	I ₋₁	Adj.R ²
<u>Goods measures</u>				
dependent var: Y	0.59 (6.0)	0.33 (4.2)	-0.69 (-6.8)	0.72
dependent var: TH	0.22 (2.2)	0.92 (11.2)	-0.70 (-6.6)	0.84
dependent var: I	0.09 (2.6)	0.09 (3.3)	0.68 (20.0)	0.90
<u>Durables measures</u>				
dependent var: Y	0.49 (4.2)	0.61 (4.2)	-0.90 (-6.8)	0.68
dependent var: TH	0.14 (1.9)	0.96 (10.5)	-0.64 (-7.7)	0.85
dependent var: I	0.05 (1.6)	0.15 (3.9)	0.65 (18.8)	0.90
<u>Non-dur. measures</u>				
dependent var: Y	0.37 (5.0)	0.21 (4.2)	-0.38 (-4.3)	0.33
dependent var: TH	0.03 (0.4)	0.84 (16.6)	-0.16 (-1.8)	0.69
dependent var: I	0.06 (1.7)	0.05 (2.0)	0.81 (18.4)	0.73

* t statistics in parentheses.

The sufficient statistic hypothesis (17) can be rejected. This suggests the possibility that something like adjustment costs is missing in the model. I elaborate on this point later.

We can examine the joint hypothesis about effort:

$\gamma_1 = \gamma_2 = 0$ and $\gamma_3 > 0$ in (14) by running Two Stage Least Squares regression of output on total hours and lag inventories, using lag variables as instruments. The results in Table 3 are consistent with the prediction of the theory. Using the regression with total hours only, we get: $-\gamma_3\alpha = -0.27$. Using the estimate $\alpha = 0.69$, this implies: $\gamma_3 = 0.39$. The introduction of lag output as an explanatory variable increases the estimated coefficient to: $\gamma_3 = 1.22$.

One possible explanation is that lag output controls for capital. Specifically, consider the following scenario. At time $t-1$ the firm experiences a large supply shock (ϵ_{t-1}). As a result it installs new machines and increases output. Not all the additional output is sold and therefore the end of period inventories tend to go up. Assume that in the next period supply conditions are back to normal and therefore the firm starts the period with above normal level of machines and inventories. Because inventories are high it wants to reduce the number of machines but because of adjustment costs it does not reduce it back to normal. This may lead to a positive correlation between output and the beginning of period inventories when we do not control for capital. It follows that when capital is not controlled for inventories tend to pick up some of the positive credit that the increase in capital should have gotten. This argument requires adjustment cost for capital.

Table 3*: The effect of beginning of period inventories on labor productivity (effort); Dependent variable = Y; 2SLS using H-P detrended log variables

	Y ₋₁	I ₋₁	TH	Adj.R ²
Goods measures		-0.27 (-4.1)	0.69 (23.3)	0.83
	0.51 (5.6)	-0.44 (-6.1)	0.36 (5.4)	0.83
Durables measures		-0.31 (-4.4)	1.04 (26.3)	0.87
	0.40 (4.1)	-0.49 (-5.6)	0.64 (5.9)	0.84
Non-dur. measures		-0.25 (-2.7)	0.38 (6.5)	0.23
	0.37 (4.9)	-0.34 (-3.9)	0.26 (4.2)	0.35

* t statistics in parentheses.

Finally, the theory says that not only total hours will go down with inventories but also employment (number of employees) and hours per employee. To test these predictions I ran employment (hours per employee) on lag employment (lag hours) lag output and lag (beginning of period) inventories. The results in Tables 4 and 5 are consistent with these predictions.

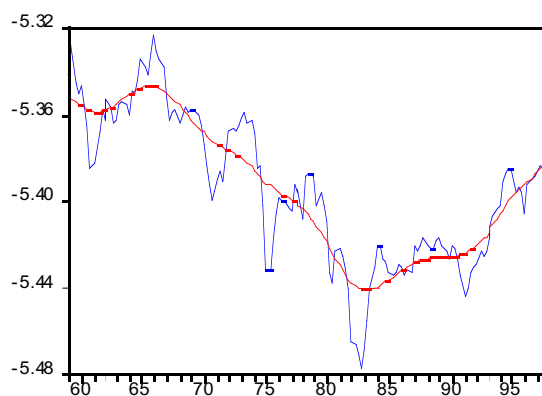


Figure 4: Hours per employee in the goods sector and their H-P trend

Table 4*: Dependent variable = number of employees (N); using H-P detrended log variables

	Y_{-1}	I_{-1}	N_{-1}	Adj.R ²
Goods measures	0.25 (4.9)	-0.43 (-5.5)	0.88 (12.7)	0.89
Durables measures	0.15 (4.6)	-0.41 (-5.9)	0.95 (12.6)	0.89
Non-dur. measures	0.09 (2.2)	-0.09 (-1.9)	0.86 (19.7)	0.78

* t statistics in parentheses.

Table 5*: Dependent variable = hours per employee (H); using H-P detrended log variables

	Y ₋₁	I ₋₁	H ₋₁	Adj.R ²
Goods measures	0.04 (0.9)	-0.26 (-5.4)	0.82 (10.4)	0.72
Durables measures	0.06 (1.6)	-0.27 (-6.8)	0.78 (8.8)	0.79
Non-dur. measures	-0.05 (-1.2)	-0.07 (-1.4)	0.79 (14.1)	0.58

* t statistics in parentheses.

5. CONCLUSIONS

The negative relationship between the beginning of period inventories and output is an important prediction of the UST model. The raw correlation between these variables is positive (and small) when using H-P detrended variables.

But when lag variables are held constant, the effect of inventories on output is negative and highly significant. In this case, inventories have a negative effect on all three components of labor supply: employment, hours per employee and effort. The following estimates were obtained for the goods sector, when controlling for lag total hours and lag output. A 1% increase in the beginning of period inventories leads to 0.7% reduction in total hours (Table 2). This reduction can be decomposed into: 0.4% reduction in the number of employees (Table 4) and 0.3% reduction in hours per employee (Table 5).

The reduction in effort which is associated with a 1% increase in inventories is 1.2% (Table 3).

Thus controlling for lag variables drastically changes the conclusion about the effects of the beginning of period inventories. One possible explanation requires adjustment costs for capital (machines). To illustrate, consider the following scenario. At $t-1$ the firm experiences a positive supply shock (large ε_{t-1}). It increases hours, capital and output. Since an increase in output leads on average to an increase in the end of period inventories, I_{t-1} is large on average. Assume that at time t supply conditions are back to normal. Because the beginning of period inventories are above normal the firm wants to reduce capital but because of adjustment costs it does not eliminate all the additional machines installed in the previous period. As a result the firm ends up with above normal capital and this increases the marginal product of labor. It therefore does not reduce labor input as much as it would if capital was adjusted back to normal. This explains why controlling for hours and capital brings out the firm desire to reduce output. Another possible explanation is that supply shocks are serially correlated.

Formally, we can think of the paper as testing two hypotheses: (a) inventories are a sufficient statistic for all lag variables and (b) an increase in inventories reduces employment, hours per employee and effort. The first hypothesis can be strongly rejected. But this rejection is constructive and suggests the incorporation of adjustment costs into the model or serially correlated supply shocks.

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