Durable Goods, Inventories, and the Great Moderation

James A. Kahn

October 2007
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  - Financial innovation (Dynan et al): No direct micro evidence?
  - Technology/Inventory Control (Kahn et al): Original model had some counterfactual implications. Evidence mainly anecdotal, indirect.
Motivation

- From Campbell, Lettau et al (2001): No postwar reduction in financial volatility

Figure 1. Standard deviation of value-weighted stock index. The standard deviation of monthly returns within each year is shown for the period from 1926 to 1997.
From NY Times, 3/1/84

The Age of Leaner Inventory

Impact Seen On Economy

By WINSTON WILLIAMS

Special to The New York Times

CHICAGO, Feb. 29 — If the customary rhythms of the business cycle held sway today, manufacturers and retailers would be ordering more materials than they need just yet and turning out more widgets than they can sell right away. Inventory building, a stage of economic recovery that usually follows closely behind revived consumer spending, would be rolling into high gear.

But buyers, production managers and accountants are apparently out of sync with historical patterns. After more than a year of economic recovery, no substantial inventory building has occurred, although consumer spending is still buoyant and factory production is rising robustly.

Many companies are doggedly adhering to a new self-discipline on inventories made possible by computers and forced on them by recession. The possibility of missing some sales because of inadequate supplies hardly diminishes the determination.

Could Affect Economy

That means the economy may not get as much of a kick as it usually does from inventory rebuilding. Economists regard the level of inventories as a key economic indicator, often referring to business’s stockpiles as “the tail that wags the dog.” The shifting attitude on inventories, they note, has contributed to the marked slowdown in the economy.

Drop in sales, would have fewer “excess inventories” to work off. Sparse inventories could also reduce pressure on interest rates by cutting the borrowing needs of business.

Whatever the benefits or costs to the economy, companies have decided that leaner inventories mean fatter profits, and programs to trim stockpiles are proliferating across the country.

Inventory adjustments as sales are run up, have thrust retailers into another era. So has the high cost of stocking shelves. Manufacturers, concerned with cutting costs to compete with foreign producers, are concentrating on inventory management as much as anything else.

“Inventory may rise slightly because production is rising,” said Harry Geller, manager of production

[Graph showing inventory levels and sales ratio]
Motivation

GDP Growth, 1947-2007

Quarterly, Annual Rate. Source: NIPA
Motivation

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  - Fama, French (financial)
Comparison of Share-Weighted Sectoral Growth Rates

GDP

Durables

Nondurables

Services

Quarterly, Annual Rate. Source: NIPA
Motivation

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Standard deviations of growth rates
The decline in volatility was not uniform or simultaneous across sectors or expenditure categories.

### Standard deviations of growth rates

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Durable Goods Sector Volatility
(5-Year Centered Rolling Standard Deviations)

Annualized Quarterly Growth Rates

- Final Sales Volatility
- Production Volatility
An Inventory Model for Durable Goods

Durables Volatility and Lead Time for Orders

Pre-84 average = 65.8
Post-83 average = 48.0

Production Materials: Avg. Lead Time for Orders*
Output Volatility (Durables)**

* Source: ISM survey
**5-year centered rolling variance
**Motivation**

Durable Goods Inventory-Sales Ratio*

*The series is discontinuous (and overlapping for one year) due to the change from SIC to NAICS industry definitions.*
An Inventory Model for Durable Goods

Production to Order

Note: For simplicity, no materials stocks.
Continuum of symmetric firms
Details

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- Technology
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    $Y_{Mt} = \min\{D_t / b_M, N_M\}$, $Y_{Ft} = \min\{X_t / b_F, N_F\}$
  - Resource constraints:
    
    $M_t = M_{t-1} + Y_{Mt} - X_t$
    $U_t = U_{t-1} + O_t - Y_{Ft-1}$
    $M_t \geq 0$
    $U_t \geq Y_{Ft}$
Continuum of symmetric firms

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Stochastic orders for firm $i$: $O_{it} = \rho O_{t-1} + \eta_t + v_{it}.$ where $\int v_{it} \, di = 0.$
Firm’s problem

\[
\max E_0 \left\{ \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[ p Y_{F\tau} - q D_{\tau} - w (N_{M\tau} + N_{F\tau}) \right] \right\}
\]

subject to technology, uncertainty.

- For simplicity, take \( p, q, w \) as exogenous, fixed.
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- For simplicity, take \( p, q, w \) as exogenous, fixed.
- For \( p \) sufficiently large, firm always wants to sell as much as possible, i.e.

\[
\begin{align*}
Y_{Ft} & = \min \left\{ U_t, b_F^{-1} \left[ M_{t-1} + b_M^{-1} D_t \right] \right\} \\
X_t & = \min \left\{ M_{t-1} + b_M^{-1} D_t, b_F U_t \right\}
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- Then firm just optimizes over \( Z_t \), trade off carrying costs of \( M \) versus delayed sales due to unfilled orders.
Firm’s problem (cont.)

Suppose $\tau = 1$. (Note: $\tau = 0$ implies $M_t = 0$, $Y_{Ft} = O_t$.)
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- Solution will take the form

$$D_t = Z_{t-1} = b_M \left[ b_F (E_{t-1} \{ U_t \} + \kappa) - M_{t-1} \right]$$

where $\kappa$ depends on distribution of $\eta_t + v_{it}$, the markup, and the discount rate.
Firm’s problem (cont.)

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where $\kappa$ depends on distribution of $\eta_t + \nu_{it}$, the markup, and the discount rate.

- This implies “sales” (total expenditures on final goods) and “production” (sales plus the change in inventory) satisfy

$$Y_{Ft} = b_F^{-1} X_t = E_{t-1} \{O_t\} + \eta_{t-1} + \min \{\kappa, \eta_t\} - \min \{\kappa, \eta_{t-1}\}$$

$$Y_{Ft} + \Delta M_t = E_{t-1} \{O_t\} + \eta_{t-1} + (1 - b_F) \left[ \min \{\kappa, \eta_t\} - \min \{\kappa, \eta_{t-1}\} \right]$$
Here is a slightly simplified (abstracting from labor costs and idiosyncratic risk) derivation. The first-order condition for incrementally adding to orders $Z_t$ is

$$-c + p \frac{dY_{F_{t+1}}}{dZ_t} + \beta c \left( 1 - \frac{dY_{F_{t+1}}}{dZ_t} \right) = 0$$

where $c = q b_M b_F$. Turns out

$$\frac{dY_{F_{t+1}}}{dZ_t} = \Pr \left( b_F U_{t+1} > M_t + D_{t+1} / b_M \right)$$

The probability is of a materials stockout at data $t + 1$. 
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The probability is of a materials stockout at data $t + 1$. So

$$p \Pr \left(b_F U_{t+1} > M_t + D_{t+1} / b_M\right) = -c + \beta c \left[1 - \Pr \left(b_F U_{t+1} > M_t + D_{t+1} / b_M\right)\right]$$

Suppose $\eta_t$ has a c.d.f. of $G$. We then get

$$\kappa = b_F G^{-1} \left(\frac{p - c}{p - \beta c}\right).$$
Firm’s problem (cont.)

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- Solution again will take the form

$$D_t = Z_{t-2} = b_M \left[ b_F \left( E_{t-2} \{ U_t \} + \kappa' \right) - E_{t-2} \{ M_{t-1} \} \right]$$

where $\kappa'$ depends on distribution of $\eta_{t-1} + \nu_{it-1}$ and $\eta_t + \nu_{it}$, the markup, and the discount rate.
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- This implies “sales” (total expenditures on final goods) and “production” (sales plus the change in inventory) satisfy

$$Y_{Ft} = E_{t-2} \{ O_t \} + (1 + \rho) \eta_{t-2} + \Delta \min \{ \kappa', \eta_t + (1 + \rho) \eta_{t-1} \}$$

$$Y_{Ft} + \Delta M_t = E_{t-2} \{ O_t \} + (1 + \rho) \eta_{t-2} + (1 - b_F) \times \Delta \min \{ \kappa', \eta_t + (1 + \rho) \eta_{t-1} \}$$
Suppose $\tau = 1$. Let

$$\zeta_t \equiv \int_{-\infty}^{\infty} \min \{\kappa, \eta_t + \sigma_v v\} \phi(v) \, dv$$

$$= \int_{-\infty}^{\frac{\kappa - \eta_t}{\sigma}} (\eta_t + \sigma_v v) \phi(v) \, dv + \kappa \left[ 1 - \Phi \left( \frac{\kappa - \eta_t}{\sigma_v} \right) \right]$$
Aggregation

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Aggregate $M_t$ is then

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$$

Aggregate $M_t$ is then

$$
M_t = b_F (\kappa - \zeta_t)
$$

Similarly,

$$
Y_{Ft} = \eta_{t-1} + \rho O_{t-1} + \zeta_t - \zeta_{t-1}
$$

$$
Y_{Ft} + \Delta M_t = \eta_{t-1} + \rho O_{t-1} + (1 - b_F) (\zeta_t - \zeta_{t-1})
$$
We can linearize $\xi$ around $\eta_t = 0$:

$$\xi_t \approx \kappa \left[ 1 - \Phi \left( \frac{\kappa}{\sigma_v} \right) \right] + \Phi \left( \frac{\kappa}{\sigma_v} \right) \eta_t = \theta \eta_t$$

where

$$\theta \equiv \Phi \left( \frac{\kappa}{\sigma_v} \right)$$

Note that for finite $\kappa$, $\theta \in (0, 1)$. 

So we have

\[ Y_{Ft} \approx (1 + \rho - \theta) \eta_{t-1} + \rho^2 O_{t-2} + \theta \eta_t \]
\[ Y_{Ft} + \Delta M_t \approx (1 + \rho - \theta (1 - b_F)) \eta_{t-1} + \rho^2 O_{t-2} + \theta (1 - b_F) \eta_t \]

\[ \text{Var} \left( Y_{Ft} \right) \approx (1 + \rho - \theta)^2 \sigma^2_{\eta} + \rho^4 \sigma^2_{\eta} / (1 - \rho^2) + \theta^2 \sigma^2_{\eta} \]
\[ \text{Var} \left( Y_t \right) \approx (1 + \rho - \theta (1 - b_F))^2 \sigma^2_{\eta} + \rho^4 \sigma^2_{\eta} / (1 - \rho^2) + \theta^2 (1 - b_F)^2 \sigma^2_{\eta} \]
So

\[
\frac{\text{Var}(Y_t) - \text{Var}(Y_{Ft})}{\sigma^2} = (1 + \rho - \theta (1 - b_F))^2 - (1 + \rho - \theta)^2 + \theta^2 (1 - b_F)^2 - \theta^2 \\
= 2\theta b_F (\rho - 2\theta + \theta b_F + 1) > 0 \text{ if } 1 + \rho > (2 - b_F) \theta
\]
Aggregation (cont.)

So

\[
\frac{\text{Var} (Y_t) - \text{Var} (Y_{Ft})}{\sigma^2_{\eta}} = \frac{(1 + \rho - \theta (1 - b_F))^2}{(1 + \rho - \theta)^2 + \theta^2 (1 - b_F)^2 - \theta^2}
\]

\[
= 2\theta b_F (\rho - 2\theta + \theta b_F + 1)
\]

\[
> 0 \text{ if } 1 + \rho > (2 - b_F) \theta
\]

For sufficiently large \( \rho \), production is more volatile than sales. Note that \( \rho \) need not even be positive for this to be true.
Now let $\tau = 2$. Define

$$\zeta_t \equiv \int_{-\infty}^{\infty} \min \left\{ \kappa, \eta_t + (1 + \rho) \eta_{t-1} + \sigma_v v \right\} \phi(v) dv$$

$$\approx \Phi \left( \frac{\kappa'}{\sigma_v} \right) \left[ \eta_t + (1 + \rho) \eta_{t-1} \right]$$

$$= \theta' \left[ \eta_t + (1 + \rho) \eta_{t-1} \right]$$

$$Y_{Ft} = \rho^3 O_{t-3} + (1 + \rho + \rho^2 - \theta' (1 + \rho)) \eta_{t-2} + \theta_2 \left( \eta_t + \rho \eta_{t-1} \right)$$

$$Y_t = \rho^3 O_{t-3} + (1 + \rho + \rho^2 - (1 - b_F) \theta' (1 + \rho)) \eta_{t-2} + (1 - b_F) \theta' \left[ \eta_t + \rho \eta_{t-1} \right]$$
So

\[
\frac{\text{Var}(Y_F)}{\sigma_{\eta}^2} = \frac{\rho^6}{(1 - \rho^2)} + (1 + \rho + \rho^2 - \theta' (1 + \rho))^2
\]

\[
+ \theta'^2 + (\theta' \rho)^2
\]

\[
\frac{\text{Var}(Y)}{\sigma_{\eta}^2} = \frac{\rho^6}{(1 - \rho^2)} +
\]

\[
(1 + \rho + \rho^2 - (1 - b_F) \theta' (1 + \rho))^2
\]

\[
+ (1 - b_F)^2 \theta'^2 + (1 - b_F)^2 (\theta' \rho)^2
\]

and

\[
\frac{[\text{Var}(Y) - \text{Var}(Y_F)]}{\sigma_{\eta}^2} =
\]

\[
2\theta' b_F (\rho^2 + \rho + 1) \quad (\rho - 2\theta' + \theta' b_F + 1)
\]
So

\[
\frac{\text{Var} (Y_F)}{\sigma^2_\eta} = \frac{\rho^6}{(1 - \rho^2)} + \left(1 + \rho + \rho^2 - \theta' (1 + \rho)\right)^2 + \theta'^2 + \left(\theta' \rho\right)^2
\]

\[
\frac{\text{Var} (Y)}{\sigma^2_\eta} = \frac{\rho^6}{(1 - \rho^2)} + \left(1 + \rho + \rho^2 - \left(1 - b_F \theta' (1 + \rho)\right)\right)^2 + \left(1 - b_F\right)^2 \theta'^2 + \left(1 - b_F\right)^2 \left(\theta' \rho\right)^2
\]

and

\[
\frac{[\text{Var} (Y) - \text{Var} (Y_F)]}{\sigma^2_\eta} = 2\theta' b_F \left(\rho^2 + \rho + 1\right) \left(\rho - 2\theta' + \theta' b_F + 1\right)
\]

Compare \(2\theta b_F \left(\rho - 2\theta + \theta b_F + 1\right)\) versus 
\(2\theta' b_F \left(\rho^2 + \rho + 1\right) \left(\rho - 2\theta' + \theta' b_F + 1\right).\)
Simulations

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- \( \rho = 0.9 \)
- \( \theta = 0.7, \theta' = 0.9 \)
Conclusions

- The model seems capable of explaining

  - The declines in both sales and output volatility
  - The relatively larger decline in output volatility
  - The decline in inventory-sales ratio

There is some direct evidence for the mechanism: Shorter lead times for materials orders.

More work to be done on calibration, estimation. Dealing with the "unit root" aspect of the data— to match evidence, model should look at growth rates.
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