Asymmetric Inventory Dynamics and Product Market Search

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"...indeed, to a great extent, business cycles are inventory fluctuations. "

Alan Blinder, 1981

"Everything that needs to be said has already been said. But since no one was listening, everything must be said again."

André Gide

Importance of Inventory Investment

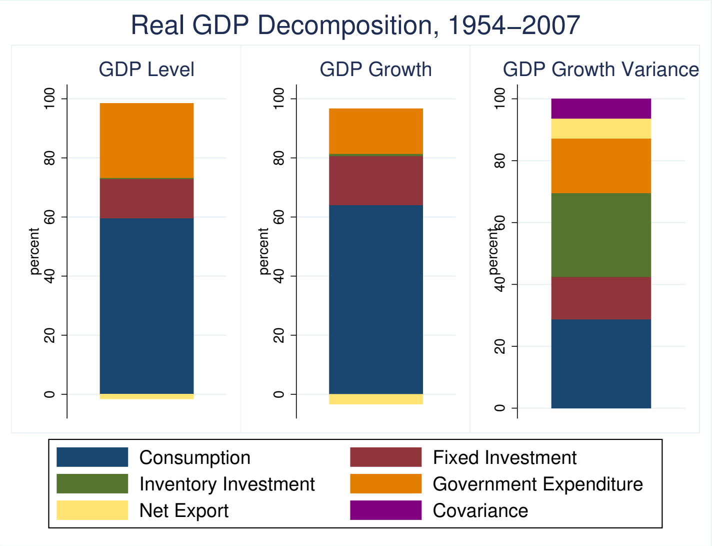


Figure: Importance

Introduction

- Document two stylized facts:
  1. Inventory investment accounts for much larger share of GDP change in recessions but not in expansions.
  2. Inventory-Sales ratio: lagging GDP for 4 quarters .
- Fact 1:
  - That's what makes inventory relevant.
  - Partially known to the lit. but is not accounted for.
- Fact 2:
  - Important conclusions drawn from countercyclicality (Bils Kahn 2000, Midrigran Krytsov 2013, Sarte et al. 2015)
  - Not countercyclical for the last 3 decades.
  - Stylized fact to discipline most models.

Introduction

- Standard inventory models (e.g. Wen 2011) generates no such asymmetry (positive skewness) in importance of inventory investment and the lagging relationship.
- This paper:
  - Based on stockout-avoidance motive for inventory (Kahn 1987).
  - Augment with product market search
  - Disciplined by micro empirical findings on both product market search and inventory.
  - Matches the two facts while consistent with inventory stylized facts.
  - Consistent with data asymmetry: sym. output, neg. skewed employment, pos. skewed markup

Introduction

- HH's search for variety introduce endogenous stock-out risk:
  - HH's procyclical demand for varieties enhances nonlinearity in firms' trade-off between markup and buffer stock size.
  - In recessions, firms are more inclined to lower markup than to expand inventory, vice versa in expansions.
  - HH responds to lowered income by reduce varieties first then
  - Prob. of matching and inventory holding return prolonged firms' hump-shaped stocking response.

Asymmetric Importance

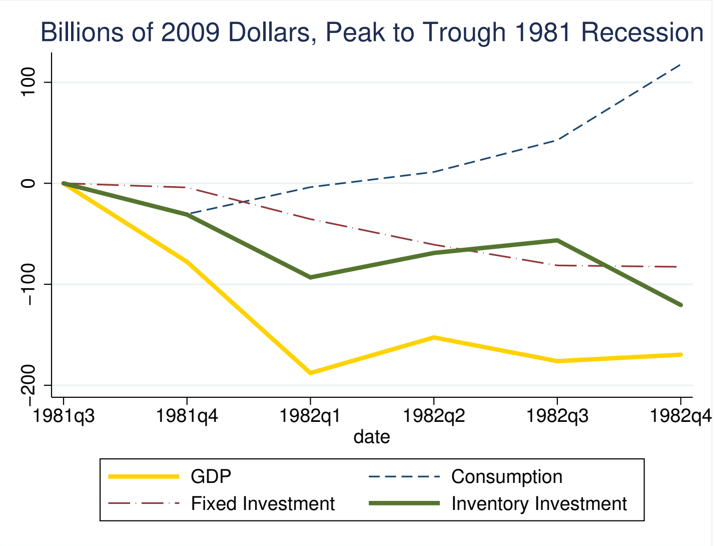


Figure: Asymmetry

Asymmetric Importance

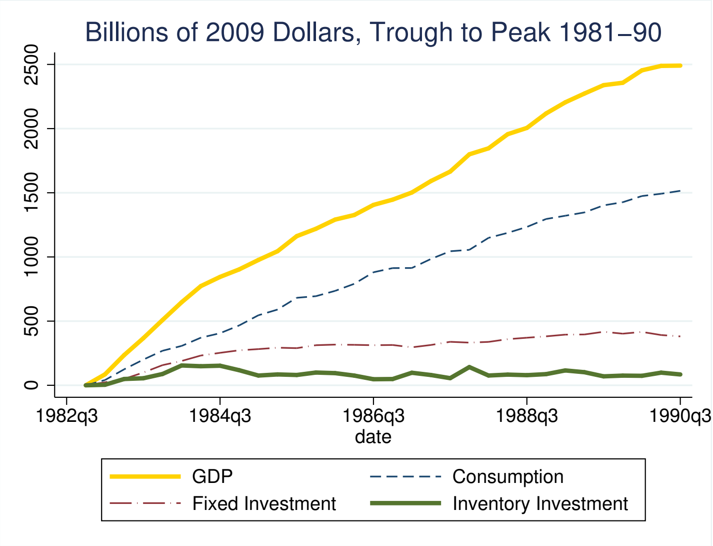


Figure: Asymmetry

Peak-to-trough

Peak	Trough	CIPI Decline	GDP Decline	Share
1948:4	1949:4	-40.66	-30.68	132%
1953:2	1954:2	-24.47	-62.77	39%
1957:3	1958:2	-21.19	-84.98	25%
1960:2	1961:1	-21.38	-9.06	236%
1969:4	1970:4	-35.84	-7.19	498%
1973:4	1975:1	-80.06	-169.95	47%
1980:1	1980:3	-67.26	-142.02	47%
1981:3	1982:4	-120.51	-169.73	71%
1990:3	1991:1	-46.87	-118.38	39%
2001:1	2001:4	-24.09	-40.20	59 %
2007:4	2009:2	-213.07	-636.23	33%
				Avg*:72%

Table: Peak-to-Trough Declines in All Postwar Recessions.

Note: Units in billions of 2009 dollar, annualized quarterly rate.

Trough-to-peak

Trough	Peak	CIPI Increase	GDP Increase	Share
1949:4	1953:2	33.28	588.80	6%
1954:2	1957:3	20.94	345.24	6%
1958:2	1960:2	22.89	320.36	7%
1961:1	1969:4	30.15	1613.21	2%
1970:4	1973:4	76.25	754.12	10%
1975:1	1980:1	33.01	1232.47	3%
1980:3	1981:3	115.93	279.97	41%
1982:4	1990:3	84.35	2490.81	3%
1991:1	2001:2	7.16	3844.74	0.1%
2001:4	2007:4	120.34	2286.52	5%
				Avg: 8%

Table: Trough-to-Peak Increases in All Postwar Expansions

Note:Units in billions of 2009 dollar, annualized quarterly rate.

Asymmetric Importance

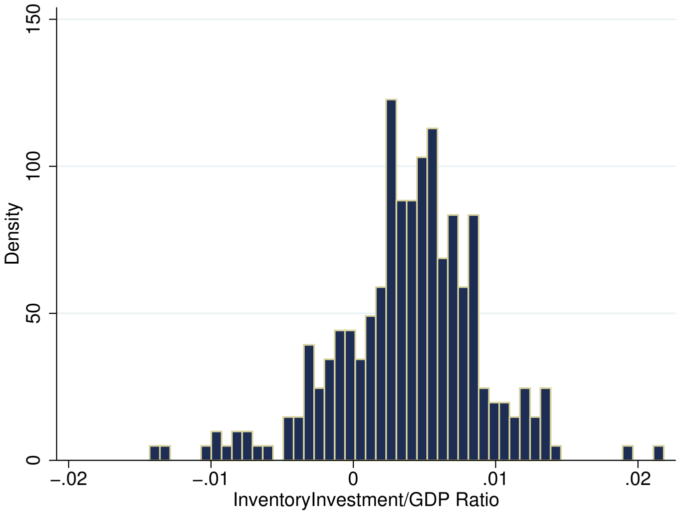
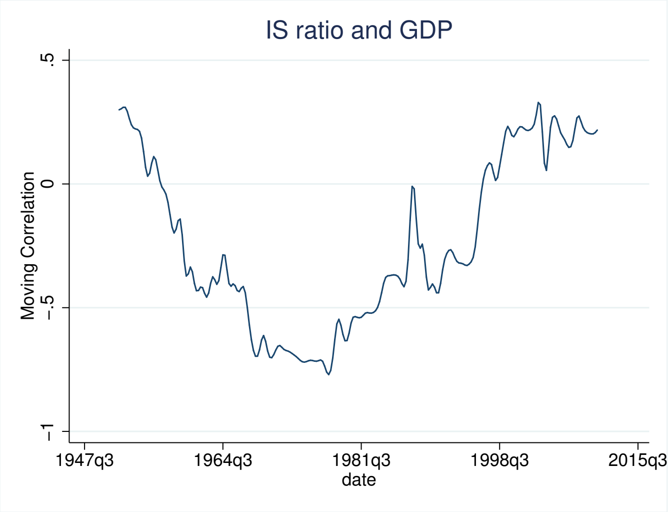


Figure: Asymmetry, Skewness = -0.33

Stylized No More?



corr = -0.24 before 1992, corr = 0.23 after 1992

Figure: HP Filtered, 40 Quarters Moving Window

ISratio Lags GDP

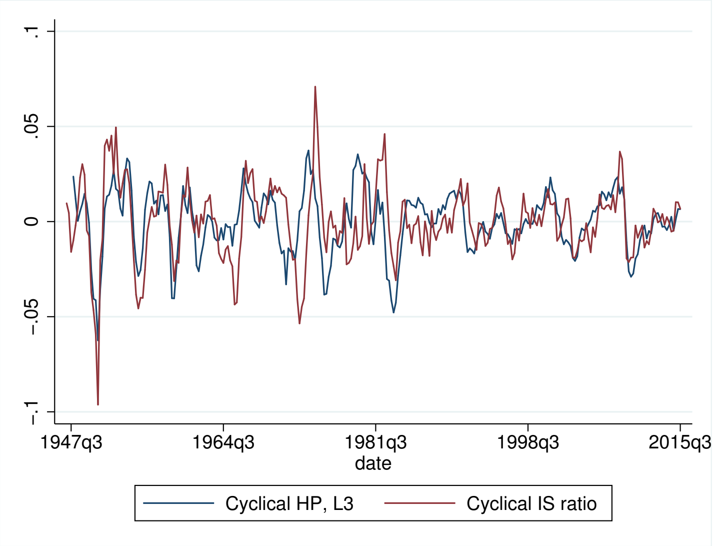


Figure: HP Filtered (1600)

Model

- Intermediate good producer: identical good produced with labor only.
- Variety good producer: differentiated good, produced with intermediate goods.
- Final good producer: pack many varieties into consumption good.
- Household: “love for variety”

Matching

- Search and match protocol similar to labor search framework (Pissrides 1994).
- Measure 1 of HH (search intensity d) matches with measure 1 of varieties.
- Each variety is produced by one monopolistic firm.
- Generate x matches (varieties consumed)

$$x = M(d, 1)$$

and thus the rate at which HH finds varieties

$$\Psi_D \equiv \frac{x}{d} = M(1, \frac{1}{d})$$

Household

- Solves the following Bellman's equation:

$$\mathscr{H}(a,x) = \max_{c,d,n,a',x} u(x^{\rho}c,d,n) + \beta \mathbb{E}\mathscr{H}\left(a',x'\right)$$
$$s.t. \quad a' = Wn + a\left(1+\Pi\right) - \overline{P}cx$$
$$x = \Psi_D d$$

- Consume x varieties with average level c, search for varieties with effort d, work for wage W, receive profit from all firms Π, ,save with stock purchase a' (numeraire).
- Ψ_D exogenous variety finding rate.

Final Good Producer

- Perfectly competitive. Unit measure.
- Produces final good with x varieties dictated by HH, subject to good availability z_i and aggregation technology with idiosyncratic demand shock v_i (to the variety producer)

$$\begin{aligned} \max_{c_i} \quad & \overline{P}xc - \int_0^x P_i c_i di \\ s.t. \quad & c_i \leq z_i \\ & c = \left(\frac{1}{x} \int_0^x v_i^{1-\frac{1}{\rho}} c_i^{\frac{1}{\rho}} di \right)^{\rho} \end{aligned}$$

- Demand for variety i:

$$c_i = \min \left\{ z_i, v_i \left(\frac{P_i}{\overline{P}} \right)^{\frac{\rho}{1-\rho}} c \right\}$$

Variety Producer

- Monopolistic competitive, unit measure.
- Faces discrete shock demand x and continuous demand shock v_i.
- v_i is i.i.d. across time and across varieties. Drawn once by all final good producers.
- Have to decide on pricing and production before knowing these shocks.
- Thus generate the incentive to hold inventories.
- With prob. x, the variety producer have access to final good producer's demand ("matched").

Variety Producer

- Solves the following problem:

$$\mathscr{V}(e_i) = \max_{y_i, p_i, n_i, e_i'} -P_M y_i + x \int \left\{ c_i p_i + \mathbb{E} m' \mathscr{V}(e_i') \right\} F^v(dv_i)$$

$$+ (1 - x)\mathbb{E} m' \mathscr{V}(e_i')$$

$$s.t. \quad c_i = \min \left(v_i \left(\frac{p_i}{\overline{P}} \right)^{\frac{\rho}{1-\rho}} \overline{C}, z_i \right)$$

$$z_i = e_i + y_i$$

$$e_i' = \begin{cases} (1 - \delta_e)\left[e_i + F(n_i) - c_i\right] & \text{"matched"} \\ (1 - \delta_e)\left[e_i + F(n_i)\right] & \text{"unmatched"} \end{cases}$$

- z_i is the amount of good i made available to buyers. Inventory + new orders
- P_M price of intermediate goods, y_i the order

Variety Producer

- Pricing Decision:

$$p_i = \frac{\epsilon_i}{\epsilon_i - 1}(1 - \delta_e)\mathbb{E}m' P_M'$$

where the price elasticity of expected sales is given by:

$$\epsilon_i = \frac{\rho}{1-\rho} \frac{\int_0^{v_i^*} c_i(p_i, n_i, v_i) F^v(dv_i)}{\int_0^{v_i^*} c_i(p_i, n_i, v_i) F^v(dv_i) + \left[1 - F^v(v_i^*)\right] [e_i + F(n_i)]}$$

- The cut-off point of stockout v_i^* is given by:

$$c_i(p_i, n_i, v_i^*) = z_i$$

Variety Producer

- Availability decision:

$$(b - r^I)X(1 - F^v(v_i^*)) = 1 - r^I$$

where

$$b = \frac{p_i}{mc_i} = \frac{p_i}{W/F'(n_i)}$$

and

$$r^I \equiv (1 - \delta_e)\,\mathbb{E}m'\frac{P_M'}{P_M}.$$

- X is endogenous unlike traditional stockout model (constant therein).
- Timing and info. structure -> all variety producers choose the same z_i and p_i.

Intermediate Producer

- Perfectly competitive, unit measure
- Solves the static problem:

$$\max_{n} P^M F(n) - Wn$$

- Helps with exact aggregation despite heterogeneity in variety producers.

Functional Forms

Production Function:

$$F(n) = An^{1-\alpha}$$

Utility (Generalized GHH 1988, search behavior):

$$u(cx^{\rho}, d, n) = \log\left(cx^{\rho} - \zeta \frac{n^{1+\upsilon_n}}{1+\upsilon_n} - \xi d\right)$$

Distribution of idio. demand shock Pareto(v_{min}, σ_V):

$$F_v(v) = 1 - (\frac{v_{min}}{v})^{\sigma_v}$$

Matching function (den Hann et al. 2000):

$$M(D, 1) = \frac{D}{(D^{\iota} + 1^{\iota})^{1/\iota}}$$

Calibration By Steady State

Parameter	Name	Value	Target	Source
υ_n	Labor Elasticity	0.75	Frish Elas.	Chetty 2011
ζ	Labor Disutility	1.5	1/3 time worked	ATUS
v_{min}	Loc. v_i	0.04	Mean 1	
σ_v	Shape v_i	1.05	S.O. Prob=5%	Bils 2004
ρ	Elas. of Subs.	1.17	20% markup	Data
δ_e	Deprec. Inven,	0.015	6% annual	Wen 2011
ι	Match Elasticity	1.18	0.35 elas.	Broda et al 2011
ξ	Search Disutility	0.01	1 hr shopping	ATUS
ρ_A	TFP Pers.	0.96		SF-FED TFP
σ_A	TFP Vola.	0.02		

Table: Calibration

Performance

Stat.	Data	Model	Wen 2011
corr(II/output,output)	0.66	0.58	0.57
AR(1) of IS ratio	0.75	0.89	0.77
corr(ISratio,output)	-0.43	-0.30	-0.68
skew(II/output)	-0.30	-0.46	0.11

Table: Inventory Performance

Performance

- Examine peak-trough share of inventory investment.
- Dating turning points:
  - Treat the model as generating demeaned growth rates
  - Two consecutive periods with GDP growth $<$ -0.8% (Data)
  - Matches share of recessions in data.
- Model depress avg. 4 quarters and expands 13 quarters.
- Peak to trough, inventory investment = 54% of output decline (data 72%).
- Trough to peak, 25% of output expansion (data 8%).

Cycles (< -0.8%, 20% of Periods)

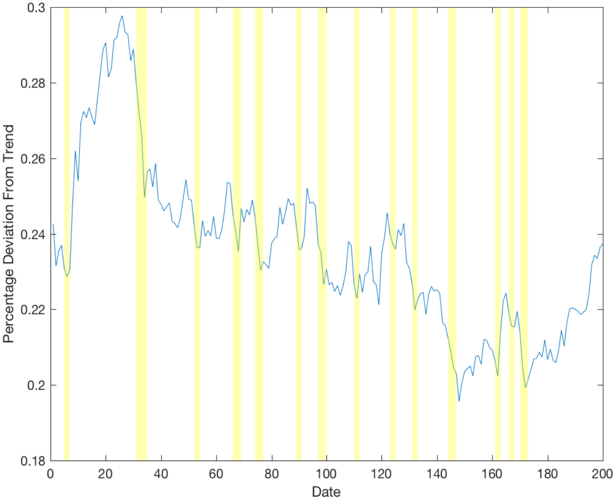


Figure: Yellow Denotes Recession

Lead-Lag

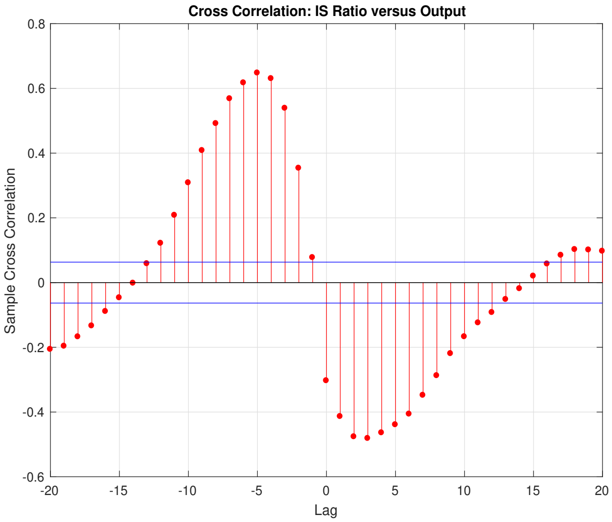


Figure: IS Ratio Lags Output by 5 Quarters (Model)

Lead-Lag

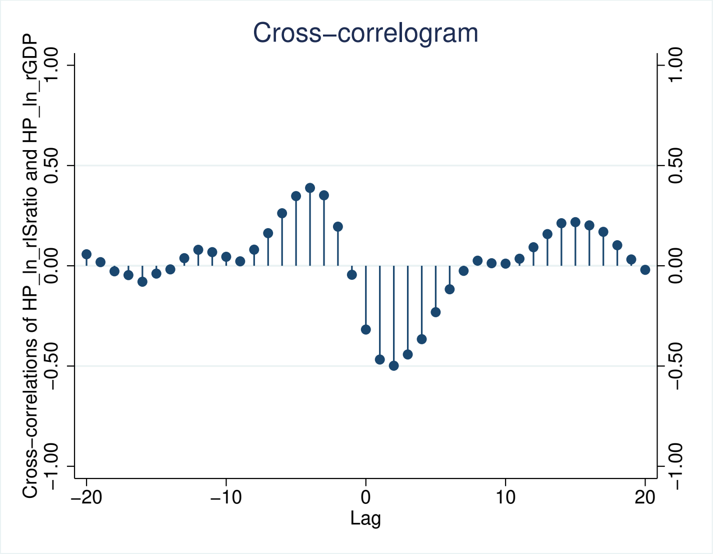


Figure: IS Ratio Lags Output by 5 Quarters (Data)

Lead-Lag

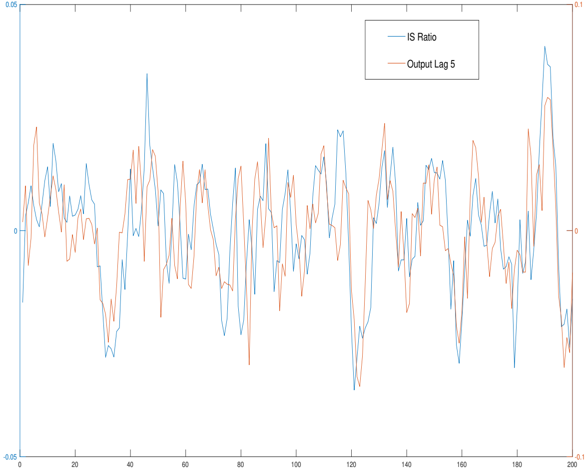


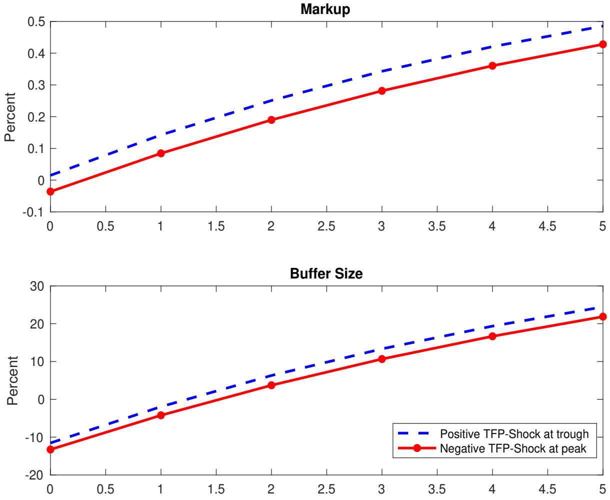
Figure: IS Ratio Lags Output by 5 Quarters (Data)

Role of Product Market Friction

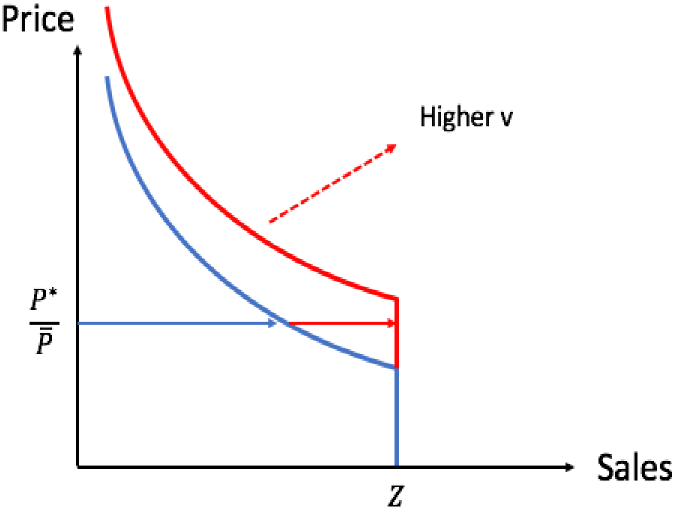
Stat.	$\xi = 0.006$	$\xi = 0.010$	$\xi = 0.012$
$\bar{x}$	0.91	0.88	0.75
P2T Share	0.37	0.92	0.95
T2P Share	2.21	0.09	0.06
skew(II/output)	-0.21	-0.46	-0.51

Table: Inventory Performance

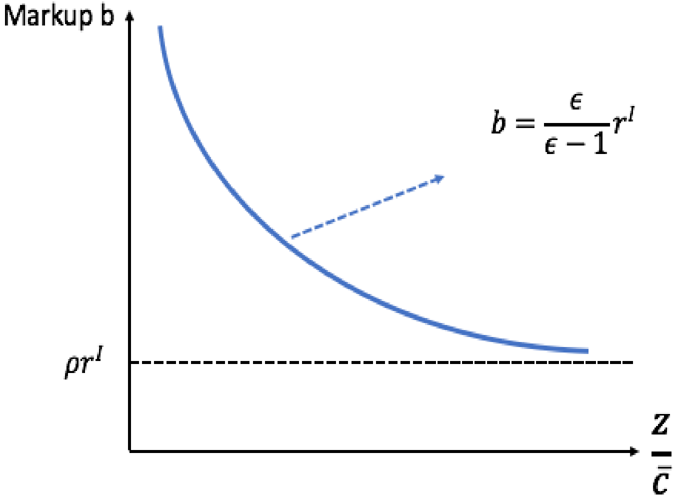
Intuition: Asymmetric Response



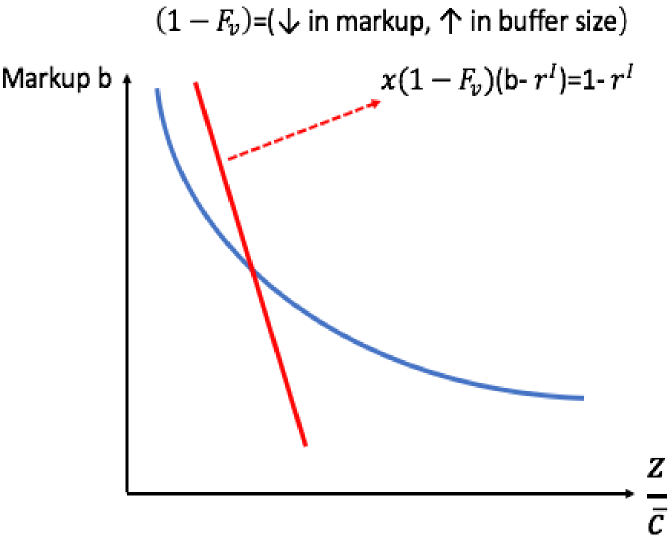
Intuition: Demand Curve



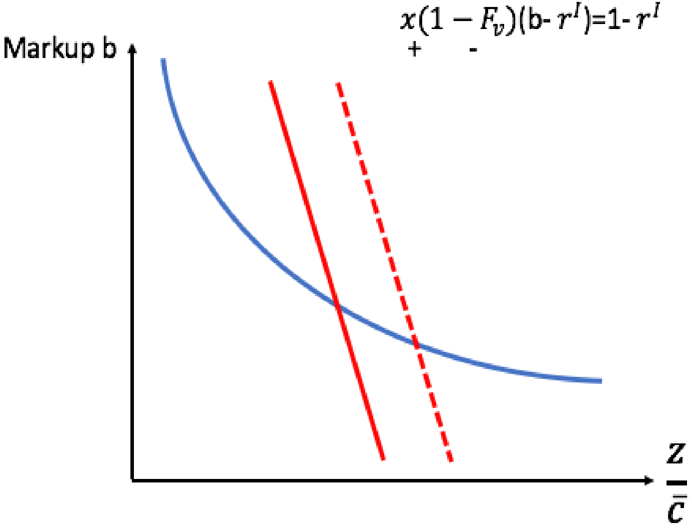
Intuition: Optimal Markup



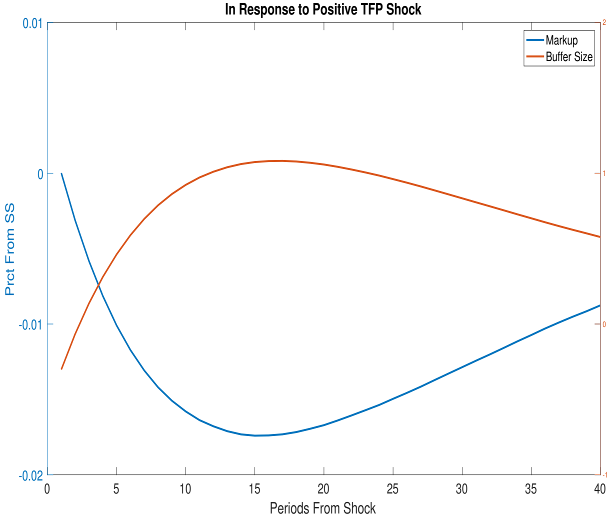
Intuition: Optimal Buffer



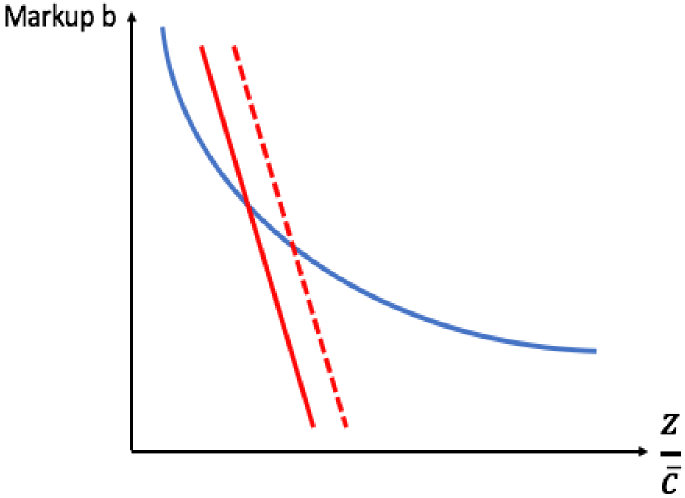
Intuition: Increases X



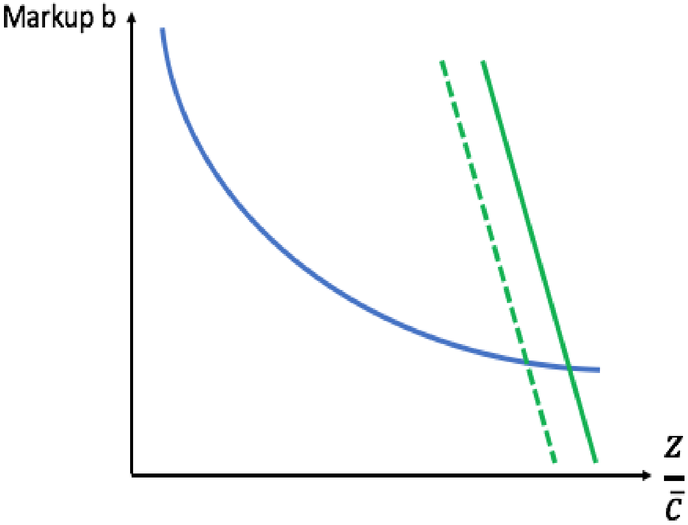
Intuition: Markup and Buffer TS



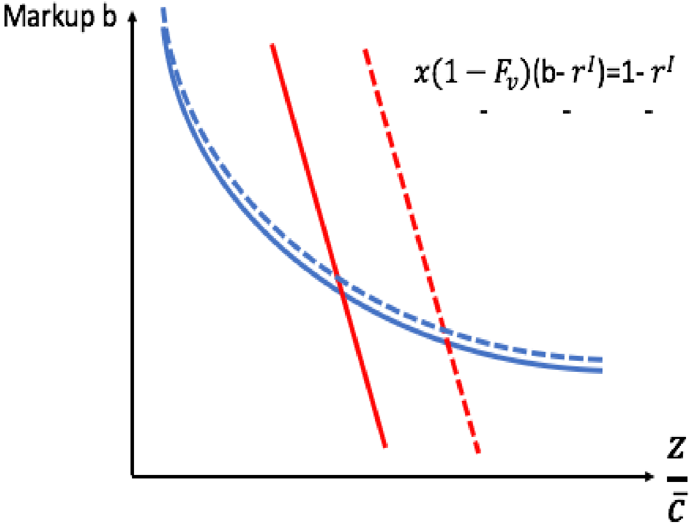
Intuition: Increase X at Trough



Intuition: Increase X at Peak



Intuition: Higher r^l at Peak



How Product Search Matthers

- Nonlinearity exists in stock-out model, but unexplored.
- Allowing movement in x enhances the nonlinearity as peak and trough are further away along markup decision curve
- Generated quantitatively stronger asymmetry in stocking decision.
- With product search, expansion of varieties peaks first then the inventory holding return peak later
- Prolonged impact on buffer stock, thus inventories.

Conclusion

- Two new stylized facts poses challenges to popular DSGE inventory models.
- In turn, questions implications based on unstable stylized facts.
- Product market search friction improve a off-the-shelf inventory' model's ability to be consistent with these two facts.
- Additionally consistent with household shopping empirics:
  - Procyclical search effort
  - Expansion of varieties and expenditure.
- Consistent with observed business cycle asymmetry.
- Bridged production market friction with inventory data.

Backup

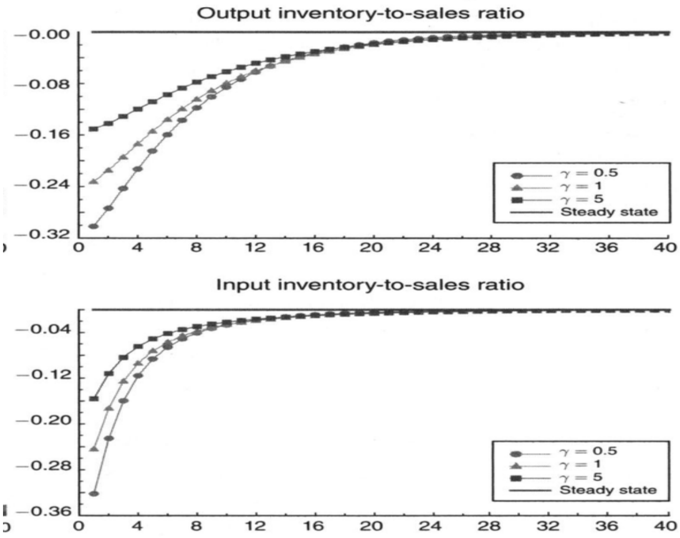


Figure: Wen 2011

Related Literature

Broda et al. 2010:

1. UPC level data of HH consumption varieties (nondurable, 60% of CPI basket).
2. Large turnover of varieties HH consumes (75% common good in 4 year period).
3. Procyclical net product creation driven by product entrance.

Suggests that substantial risk of "out-of-favor" for producers when deciding inventory.