Inventories, Markups and Real Rigidities

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New Keynesian Business Cycle Models

- Predictions sensitive to dynamics of costs
  - Real marginal cost volatile: short-lived effect of ΔM
    - Chari-Kehoe-McGrattan
  - Real marginal cost sticky: long-lived effects of ΔM
    - Woodford, Christiano-Eichenbaum-Evans, Smets-Wouters

Example

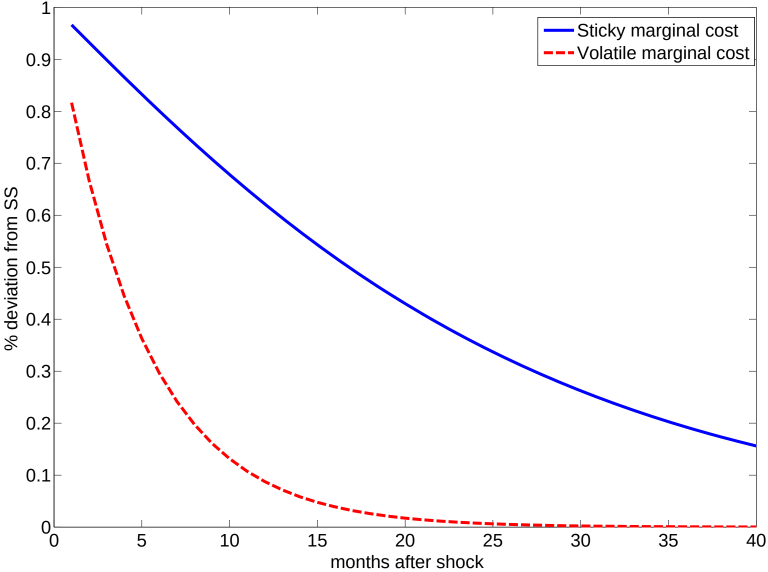
- Calvo firms set prices once every 9 months

- Economy 1: Volatile marginal cost, $\sigma(mc)/\sigma(y) = 3$
  - Labor only factor. Low labor supply elasticity (1/2).

- Economy 2: Sticky marginal cost, $\sigma(mc)/\sigma(y) = 1/10$
  - Intermediate inputs (60% share)
  - Labor supply elasticity $= \infty$
  - Wages change once every 12 months

  - No restrictions on how much labor etc. firms hire

Response of Y to 1% Δ M



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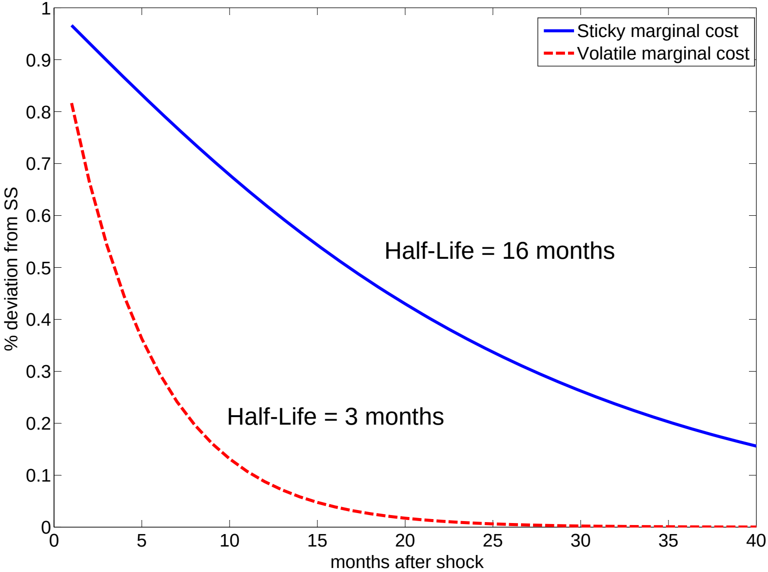

Our Question:

1. How volatile is real marginal cost over cycle?
    - $\sigma(mc)/\sigma(y)$

2. What accounts for slow response P to M?
    - $P =$ markup $\times$ cost
    - Countercyclical markups?
    - Sticky costs?

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Our approach

- Answer question by studying behavior of inventories

  - Price = markup × marginal valuation of inventory:

    $$P = \text{markup} \times V'(inv)$$

  - Buy inventories to equate marginal valuation to cost:

    $$V'(inv) = cost$$

    - cost includes multiplier on quantity constraints etc.

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Our findings

- Data: inventories ≈ constant over cycle
- Model: inventories sensitive to rate of return $(-r + \Delta\text{cost})$
- Need return to holding inventories $(-r + \Delta\text{cost}) \approx$ constant

$$\sigma(mc)/\sigma(y) \approx -\left(U_{cc}/U_c\right) c = 1/EIS$$

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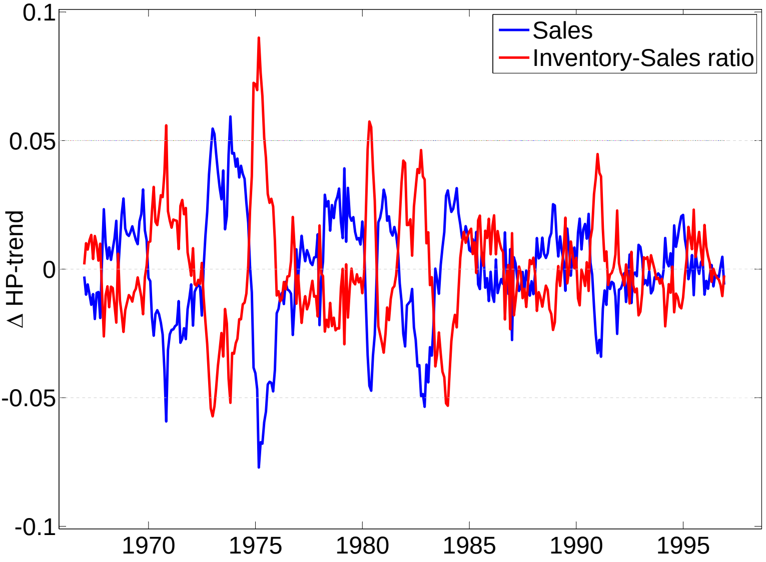
Data

- Bureau of Economic Analysis (NIPA)
  - monthly data: sales, inventories, orders
    - Manufacturing and Trade
    - Retail
  - All real, HP-filtered

Inventory-Sales ratio: Manufacturing & Trade



Inventories procyclical, but much less than sales

	Manufact. & Trade	Retail
$\rho(\ln IS_t, \ln S_t)$	-0.85	-0.62
$\sigma(\ln IS_t)/\sigma(\ln S_t)$	1.01	1.14
$\epsilon_{IS,S}$	-0.86	**-0.71**

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Conditional on monetary shocks

- Project $\ln IS_t, \ln S_t$ on CEE (02) monetary shocks

	Manufact. & Trade	Retail
$\epsilon_{IS,S}$	-0.61	**-0.77**

- Sales up 1% $\Rightarrow$ inventories up only 0.23%

Inventory investment

- Report conditional on CEE shocks.

	Manufact. & Trade	Retail
$\rho(\Delta I_t/S_t, \ln S_t)$	0.48	0.03
$\sigma(\Delta I_t/S_t)/\sigma(\ln S_t)$	0.24	0.62

- Inventory invest. volatile, but accounts small variance sales
  Output ($Y_t = S_t + \Delta I_t$) is 1.2 $\times$ more volatile Sales

Summarize data

- Inventories $\approx$ constant over cycle
- Sales up 1%, inventories up 0.23% - 0.29%

Model Overview

1. Manufacturers
   - Homogenous good. Perfectly competitive. Sell to retailers.

2. Monopolistically competitive retailers
   - Fixed cost of changing prices.
   - Can store goods. Depreciate at δ_z.
     - Choose p and orders before learning uncertain demand.
     - Fixed cost of ordering from manufacturers.
     - No returns (irreversibility).

3. Consumers

4. Uncertainty (let η^t denote history)
   - Aggregate: money growth shocks
   - Idiosyncratic (retailer-specific): taste shocks

Consumers

$$\max_{c_t(i), n_t, \mathbf{B}_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\log c_t - \psi n_t\right]$$

$$\text{s.t.} \int_0^1 p_t(i) c_t(i) di + \int q_t(\eta') B_{t+1}(\eta') d\eta' \leq W_t n_t + B_t + \Pi_t$$

$$c_t = \left(\int_0^1 v_t(i)^{\frac{1}{\theta}} c_t(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}$$

$$c_t(i) \leqslant z_t(i)$$

- $z_t(i)$: stock of inventories of good i
(rationing rule: equal share)
- $v_t(i)$: taste shock

Consumer decision rules

- Standard
- Except:

$$c_t(i) = v_t(i) \left(\frac{p_t(i) + \mu_t(i)}{P_t} \right)^{-\theta} c_t$$

$$P_t = \left[\int_0^1 v_t(i) \left[p_t(i) + \mu_t(i) \right]^{1-\theta} di \right]^{\frac{1}{1-\theta}}$$

- $\mu_t(i)$ multiplier on $c_t(i) \leqslant z_t(i)$

Manufacturers

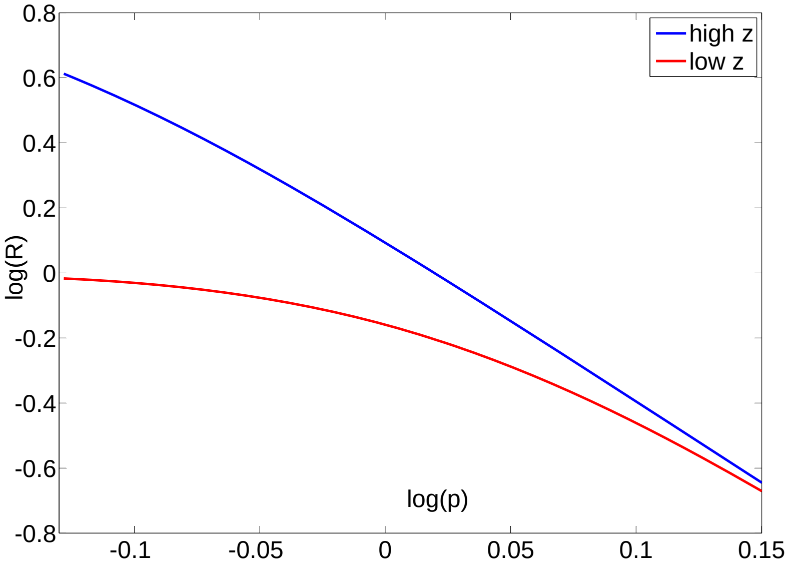
- Produce identical good. Perfect competition.
- Technology
$$y_t = l_t$$
- profits:
$$\pi_t = \omega_t y_t - W_t l_t$$
- perfect competition:
$$\omega_t = W_t$$

Retailer

- Buy good at ω_t, transform into $\frac{1}{a_t(i)}$ final goods
- Fixed price adjusment cost, κ_p, and fixed ordering cost, κ_s
- Choose price $p_t(i)$, orders $z_t(i)$ before learn demand $v_t(i)$
- Expected sales given price p and inventory z:

$$R(p, z) = \int_0^\infty \min\left(v \left(\frac{p}{P} \right)^{-\theta} c, z \right) d\Phi(v)$$

$R(p, z)$



Retailer's dynamic program

$$V(p,s,a;\lambda) = \max(V^{a,a}, V^{a,n}, V^{n,a}, V^{n,n})$$

$$V^{a,a} = \max_{p',z \geq s} \quad p' R(p',z) - a\omega(z-s) - W(\kappa_p + \kappa_s) + EqV(p',s')$$

...

- $s' = \left(z - \min\left(v\left(\frac{p}{P}\right)^{-\theta} c, z\right)\right)(1-\delta_z)$
- $\log v \sim iid\ N(0,\sigma_v^2)$ (let cdf : $\Phi(v)$)

Retailer decision rules

- Simple variation with $\kappa_s = \kappa_p = 0$
  - can return unsold goods next period
- (S, s) economy

Economy with $\kappa_s = \kappa_p = 0$. Can return at $t+1$.

- $qV(s) = \frac{1-\delta_z}{1+i}\omega' s$

- Problem reduces to:

$$\max_{p,z} \quad \left(p - \frac{1-\delta_z}{1+i}\omega'\right) R(p,z) - \left(\omega - \frac{1-\delta_z}{1+i}\omega'\right) z$$

- Let $\quad r_i = \frac{1-\delta_z}{1+i}\frac{\omega'}{\omega}, \qquad v^* = z/\left(\frac{p}{P}\right)^{-\theta} c$:

$$1 - \Phi\left(v^*\right) = \left(1 - r_i\right) / \left(\frac{p}{\omega} - r_i\right)$$

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Inventories more sensitive to costs

$$1 - \Phi\left(v_t^*\right) = \left(1 - r_{i,t}\right) / \left(\frac{p}{\omega} - r_{i,t}\right)$$

- Log-linearize:

$$\Gamma \hat{v}_t{}^* = \left[\left(1 - \bar{\Phi}\right) \frac{\bar{p}}{\bar{\omega}} \left(\hat{p}_t - \hat{\omega}_t\right) + \bar{\Phi} \bar{r} \hat{r}_{i,t}\right]$$

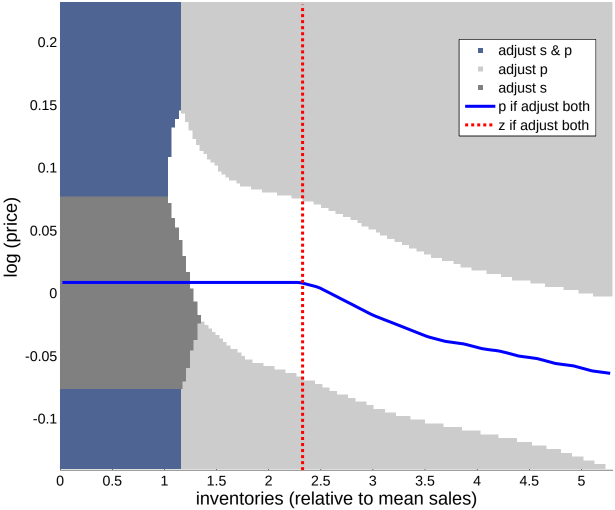
- SS. prob. stockout: $1 - \bar{\Phi} \approx 0$
- $\bar{r} = \beta(1 - \delta_z) \approx 1$

Retailer's decision rules in (S, s) model

$$-\frac{1}{\theta}\left[R(p,z)+pR_p(p,z)\right]=(1-\delta_z)\int_0^{v^*} qV_2(p,s'(v))\,d\Phi(v) + \int_0^{\infty} qV_1(p,s'(v))\,d\Phi(v)$$

$$(1-\delta_z)\int_0^{v^*} qV_2\left(p,s'(v)\right)\,d\Phi(v)=\left[\omega-p\left(1-\Phi\left(v^*\right)\right)\right]$$

Decision rules: Inaction regions



Equilibrium

- 'cash-in-advance': $P_t c_t = M_t$
  - $g_{m,t} = \log(M_t/M_{t-1}) \sim \text{iid } N(0, \sigma_m^2)$
- Aggregate state
  - measure λ over retailers' (p, s, a)
  - $\lambda' = \Gamma(\lambda, g_m)$
- Use Krusell-Smith

Parametrization

- $a_t(i) = \begin{cases} a_{t-1}(i) \text{ with prob. } \rho \\ U[-\bar{a}, \bar{a}] \text{ with prob. } 1-\rho \end{cases}$

- Assigned Parameters

Discount factor, β	$0.935^{\frac{1}{12}}$
Price adjustment cost, κ_p	0.01

Parametrization

- Parameters:

Frequency cost shocks, $1-\rho$	0.11
Size cost shocks, $\bar{a}$	0.085
S.d. taste shocks, σ_v	0.475
Demand elasticity, θ	5
Depreciation rate, δ_z	0.0128
Ordering cost, κ_s	0.0195

- Targets:

	Data	Model
Frequency Δp	0.11	0.11
Mean $\lvert\Delta p\rvert$	0.11	0.11
Corr $\Delta p, \Delta y$	-0.2	-0.2
Inventory-sales ratio	1.40	1.40
Fraction stockouts	0.05	0.05
Frequency orders	0.5	0.5

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Experiments

- Study 3 economies

1. Benchmark: $U(c,l) = \log(c) - \psi l$
   - $\sigma(\omega/p)/\sigma(c) = 1$
   - $r_{i,t}$ constant over cycle
2. Sticky costs (interm. inputs): $\omega = W^{1-\nu} P^{\nu}$, $\nu = 0.75$
   - $\sigma(\omega/p)/\sigma(c) = 0.25$
   - $r_{i,t}$ procyclical
3. Choose ν to account inventory facts

Experiments

	$\frac{\sigma(\omega/p)}{\sigma(c)}$	$\epsilon_{I,S}$	$\epsilon_{\Delta I,S}$
Data		0.23	0.02
Benchmark	1	-1.06	-0.29
Sticky costs	0.25	3.09	0.82
Consistent with I_t	0.79	0.26	0.05

Bottomline: inventories very sensitive to $\Delta r_{i,t}$

Need $\frac{\sigma(\omega/p)}{\sigma(c)}$ slightly < 1 to account data

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Intuition

- FOC for inventory holdings:

$$\beta(1-\delta_z)\int_0^{v^*}\frac{U_c'/P'}{U_c/P}\frac{\omega'}{\omega}\frac{V_2\left(s'(v)\right)}{\omega'}d\Phi(v)=\left[1-\frac{p}{\omega}\left(1-\Phi\left(v^*\right)\right)\right]$$

- $V \approx$ linear
  - irreversibility minor role due to low depreciation
- $\Rightarrow$ Inventories very sensitive to $r_i = \Delta \frac{U_c}{P}\omega$
- Need $\frac{U_c}{P}\omega \approx$ const $\quad \Rightarrow \frac{d\log\frac{\omega}{P}}{d\log c} \approx -\frac{U_{cc}}{U_c}c \; (=1/EIS=1)$
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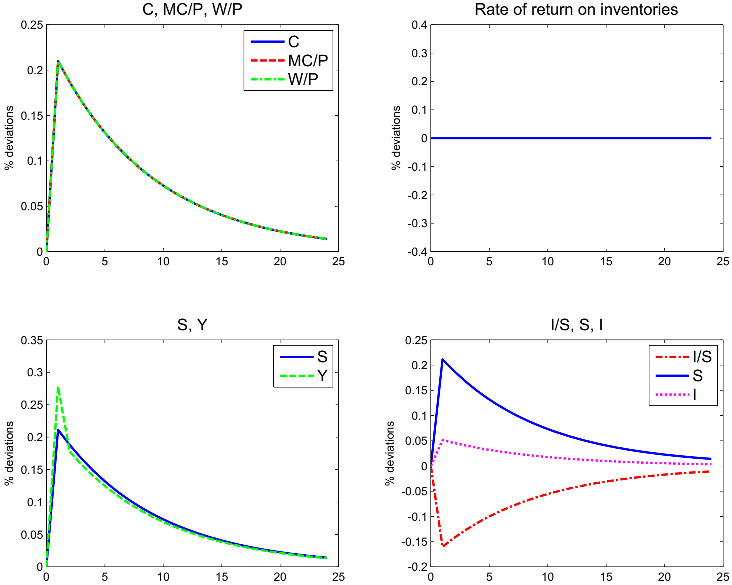
Role of fixed costs of ordering and irreversibility

- Study economy with $\kappa_s = 0$ and returns after 1 period
- Calvo pricing
- Three economies:
  - Benchmark: $\sigma(\omega/p)/\sigma(c) = 1$
  - Sticky costs: $\sigma(\omega/p)/\sigma(c) = 0.25$
  - Volatile costs (lab. sup. elas. = 1/2): $\sigma(\omega/p)/\sigma(c) = 2.3$

Impulse response to M shock. Benchmark.



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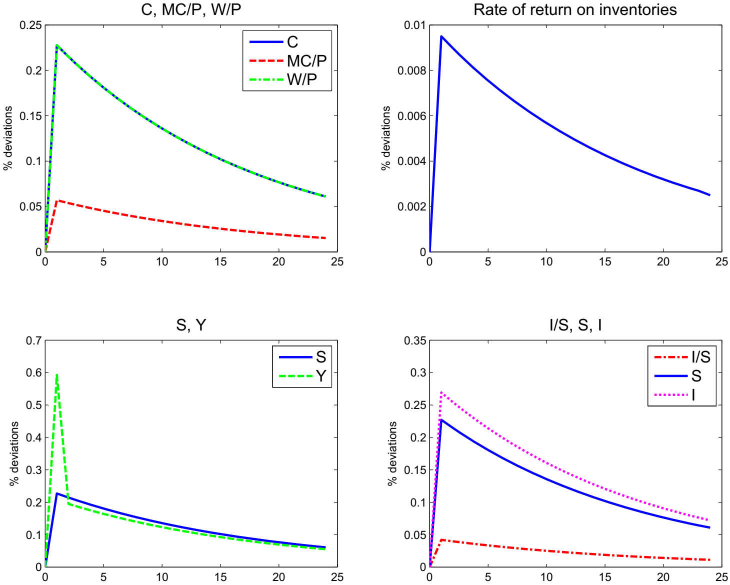

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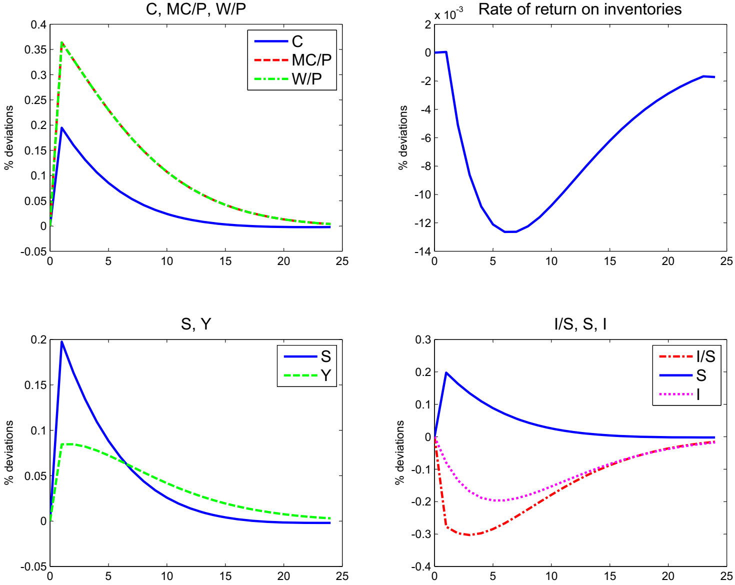

Economy without fixed costs

	$\frac{\sigma(\omega/p)}{\sigma(c)}$	$\epsilon_{I,S}$	$\epsilon_{\Delta I,S}$	HL(c)
Data		0.23	0.02	
Benchmark	1	0.24	0.06	5.9
Sticky costs	0.25	1.2	0.29	12.0
Volatile costs	2.3	-0.8	-0.47	3.3

Bottomline: $\frac{\sigma(\omega/p)}{\sigma(c)} = 1$ best fit

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Reconcile inventories with data factor prices

- Factor prices sticky data
  - labor wedge $\left(\frac{W/P}{MRS_{c,l}}\right)$ countercyclical
  - producer prices change once every 12 months
- Simple fix: quantity adjustment costs
  - E.g., costs of changing size of orders
  - Alternative: quantity constraints

Economy with cost of changing order size

- Earlier: cost of ordering $z_t(i)$ units: $\omega_t z_t(i)$
- Assume now: cost $= \omega_t z_t(i) + \frac{\xi}{2}\left(z_t(i) - \bar{z}\right)^2$
- marginal cost: $\omega_t + \frac{\xi}{2}\left(z_t(i) - \bar{z}\right)$

Motivation for quantity adjustment frictions

- Spanish supermarket data (Aguirregabiria '99)
  - pre-sale stock z_{it}, sales (s_{it}), wholesale costs (ω_{it})

- Regress $\log(z_{it})$ and $\log(z_{it}/s_{it})$ on $\log(\omega_{it})$

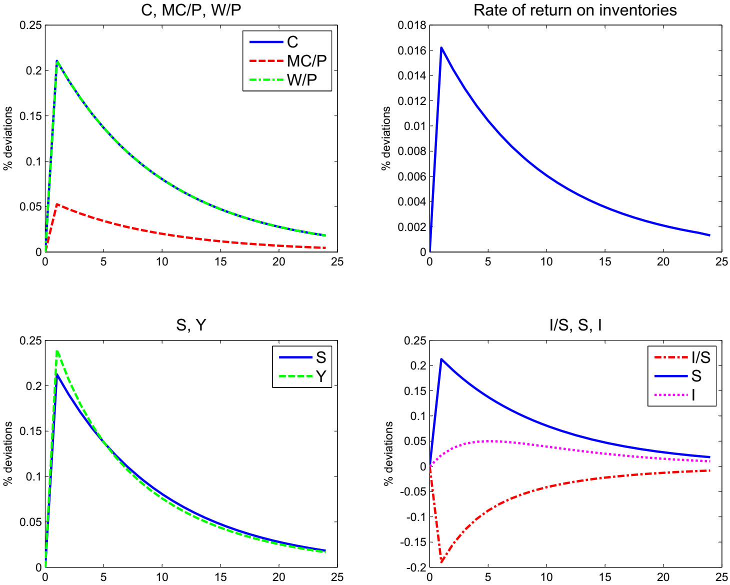
	Data	Benchmark
$\log(z_{it})$	-1.1	-6.6
$\log(z_{it}/s_{it})$	0.05	-1.43
# obs.	33716	

Inventories much more sensitive to costs in model.

Economy with adjustment costs

- Benchmark w/o sticky wages, $\sigma(\omega/p)/\sigma(c) = 1$
- Intermediates, $\sigma(\omega/p)/\sigma(c) = 0.25$
  - Choose adj. cost ξ to match aggregate inventory facts

Economy with adjustment costs



Economy with adjustment costs

	$\frac{\sigma(\omega/p)}{\sigma(c)}$	$\epsilon_{I,S}$	$\epsilon_{\Delta I,S}$	HL(c)
Data		0.23	0.02	
Benchmark	1	0.24	0.06	5.9
Intermed. w/o adj. costs	0.25	1.2	0.29	12.0
Intermed. w/ adj. costs	0.25	0.23	0.07	6.4

Bottomline: similar implications for nominal stickiness

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Conclusions

- Data: inventories mildly procyclical.
- Model: inventories sensitive to $-r + \Delta cost$
  - Need costs increase in booms to prevent firms from responding to lower interest rate and accumulate inventories
- Need countercyclical markups to account P, Y, M, I data
  - Sticky costs alone inconsistent with I data