Lumpy Investment, Business Cycles, and Stimulus Policy

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CIGS Conference on Macroeconomic Theory and Policy, June 5th 2018

Motivation

- Want to understand fluctuations in aggregate investment
- At micro level, driven by extensive margin

$\Longrightarrow$ **Does micro-level lumpiness matter for aggregate dynamics?**

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- Benchmark RBC: no, same aggregate outcomes as rep firm
    - Irrelevance driven by GE movements in r_t

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- At micro level, driven by extensive margin

$\implies$ **Does micro-level lumpiness matter for aggregate dynamics?**

- Benchmark RBC: no, same aggregate outcomes as rep firm
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- This paper: yes, different aggregate outcomes than rep firm
  1. Irrelevance results driven by counterfactual r_t dynamics
  2. Build model consistent with empirical r_t dynamics
  3. Show important implications for cycles + stimulus policy

My Contributions

1. **Show irrelevance results driven by counterfactual r_t dynamics**
   - Prove irrelevance in limit of simple model
     - Firms extremely sensitive to interest rates
     - Interest rates adjust to ensure aggregation
   - Two counterfactual implications for real interest rate:
     - $\sigma(r_t)$ low (data: $\sigma(r_t)$ high)
     - r_t and TFP highly correlated (data: negatively correlated)

My Contributions

1. Show irrelevance results driven by counterfactual r_t dynamics

2. **Build model consistent with empirical r_t dynamics**
    - Heterogeneous firms w/ fixed and convex adjustment costs
    - Representative household w/ habit formation
    - Calibrate to micro investment and r_t dynamics
        - Investment demand determined by adjustment costs
        - Investment supply determined by habit formation

        $\Longrightarrow$ breaks extreme sensitivity of investment w.r.t. r_t

My Contributions

1. Show irrelevance results driven by counterfactual r_t dynamics

2. Build model consistent with empirical r_t dynamics

3. **Show important implications for cycles + policy**

   - Investment up to 50% more responsive to shocks in expansions than recessions

     - Lumpy investment source of state dependence

     - Interest rates do not render irrelevant

   - Matches procyclical volatility in aggregate investment data

   - Stimulus policy five times more cost effective if target firms close to extensive margin

Related Literature

Aggregate implications of lumpy investment

- Partial equilibrium: Caballero et al. (1995); Caballero and Engel (1999); Cooper and Haltiwanger (2006); House (2014); Cooper and Willis (2014)
- General equilibrium: Veracierto (2002); Khan and Thomas (2003, 2008); Gourio and Kashyap (2007); Bachmann, Caballero, and Engel (2013); Bachmann and Ma (2016)

Real interest rate dynamics

- Beaudry and Guay (1996); Jermann (1998); Boldrin et al. (2001)

Investment stimulus policy

- House and Shapiro (2008); Zwick and Mahon (2017)

Solution algorithm

- Winberry (2018)

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Aggregation in a Simple Model

- **Representative household** w/ prefs

$$\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\sigma} - 1}{1-\sigma}$$

- **Heterogeneous firms** indexed by $j \in [0, 1]$
    - Produce $y_{jt} = z_t \varepsilon_{jt} k_{jt}^{\alpha}$ where $\alpha < 1$
    - ε_{jt} first-order Markov chain
    - z_t known $\implies$ discount with risk-free r_t
    - Invest $k_{jt+1} = (1-\delta)k_{jt} + i_{jt}$
- **Resource constraint** $Y_t = C_t + I_t$

Aggregation in a Simple Model

Proposition: As $\alpha \to 1$, economy aggregates to rep firm

$$Y_t \to z_t \widetilde{\varepsilon} K_t, \text{ where } \widetilde{\varepsilon} = \max_i \mathbb{E}[\varepsilon' | \varepsilon_i]$$

$$r_t + \delta \to z_t \widetilde{\varepsilon}$$

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$$r_t + \delta \to z_t \widetilde{\varepsilon}$$

- Constant returns $\implies$ profits linear in capital
- r_t adjusts so that highest-productivity firms make zero profits
- Semi-elasticity of investment w.r.t r_t approaches infinity:

$$\frac{\partial i_{jt} / i_{jt}}{\partial r_t} = -\frac{1}{\delta} \frac{1}{1-\alpha} \frac{1+r_t}{r_t+\delta} \to \infty \text{ as } \alpha \to 1$$
$$= 7,695 \text{ with } \delta = 0.025, \alpha = 0.85, r = 0.01$$

Aggregation in a Simple Model with Fixed Costs

- Logic also holds with **fixed cost** $\bar{\xi}$ as long as $\bar{\xi} \to 0$ as $\alpha \to 1$

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- Requirement that $\bar{\xi} \to 0$ not quantitatively restrictive
  - Khan and Thomas (2008): random fixed costs
  - House (2014): if $\delta \to 0$, get infinite elasticity in timing even if $\bar{\xi} > 0$ and $\alpha < 1$

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- Two counterfactual implications for r_t dynamics:
  1. Volatility of r_t small
  2. r_t and z_t move one for one

Counterfactual Implications for r_t Dynamics

	$\sigma(r_t)$	$\rho(r_t, y_t)$	$\rho(r_t, z_t)$
Data	1.73%	-0.11^{*}	-0.20^{***}
(p-value)		(0.09)	(0.001)
RBC Model	0.16%	0.95	0.97

▸ Subsamples   ▸ Rolling Windows

- Data (quarterly and HP-filtered)
    1. r_t = return on 90-day T-bill, adjusted w/ realized inflation
    2. Y_t = real GDP
    3. z_t = Solow residual

- RBC = simple model w/ labor

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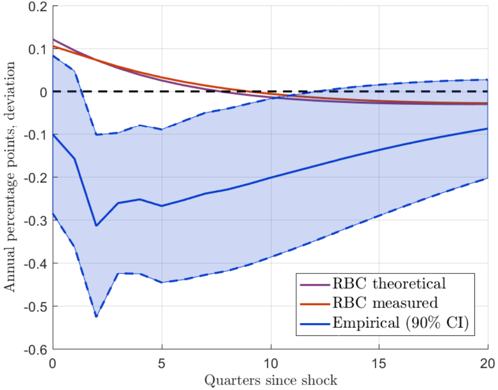

- Impulse response estimated from VAR of $(z_t, r_t)^{\mathrm{T}}$ w/ 3 lags
- Identification: r_t innovation does not affect z_t upon impact

My Contributions

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Heterogeneous Firms: Production and Investment

- **Fixed mass** of firms $j \in [0,1]$

- **Production technology** $y_{jt} = z_t \varepsilon_{jt} k_{jt}^{\theta} n_{jt}^{\nu}$, $\theta + \nu < 1$
  - Aggregate shock $\log z_t = \rho_z \log z_{t-1} + \omega_t^z$
  - Idiosyncratic shock $\log \varepsilon_{jt} = \rho_\varepsilon \log \varepsilon_{jt-1} + \omega_{jt}^{\varepsilon}$

- **Invest** $k_{jt+1} = (1-\delta)k_{jt} + i_{jt}$ subject to two frictions
  - If $\frac{i_{jt}}{k_{jt}} \notin [-a, a]$, fixed cost $-\xi_{jt} w_t$ with $\xi_{jt} \sim U[0, \overline{\xi}]$
  - Quadratic cost $-\frac{\varphi}{2}\left(\frac{i_{jt}}{k_{jt}}\right)^2 k_{jt}$

Heterogeneous Firms: Taxes

- **Tax** rate τ on revenue y_{jt} net of
  1. Labor costs $w_t n_{jt}$
  2. Capital depreciation
     - Stock of depreciation allowances d_{jt}
     - Deduct $\widehat{\delta}$ of $d_{jt} + i_{jt}$ from taxes
     - Carry forward $d_{jt+1} = (1 - \widehat{\delta})(d_{jt} + i_{jt})$
- Total tax bill is

$$\tau \left(y_{jt} - w_t n_{jt} - \widehat{\delta}(d_{jt} + i_{jt}) \right)$$

Heterogeneous Firms: Bellman Equation

$$v(\varepsilon, k, d, \xi; \mathbf{s}) = \tau\widehat{\delta}d + \max_n\{(1-\tau)\left(z\varepsilon k^\theta n^\nu - w(\mathbf{s})n\right)\} + \max\{v^a(\varepsilon, k, d; \mathbf{s}) - \xi w(\mathbf{s}), v^n(\varepsilon, k, d; \mathbf{s})\}$$

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$$+ \max\{v^a(\varepsilon, k, d; \mathbf{s}) - \xi w(\mathbf{s}), v^n(\varepsilon, k, d; \mathbf{s})\}$$

$$v^a(\varepsilon, k, d; \mathbf{s}) = \max_{i\in\mathbb{R}} -(1-\tau\widehat{\delta})i - \frac{\varphi}{2}\left(\frac{i}{k}\right)^2 k + \mathbb{E}[\Lambda(z'; \mathbf{s})v(\varepsilon', k', d', \xi'; \mathbf{s}')]$$
$$\implies i^a(\varepsilon, k, d; \mathbf{s})$$

$$v^n(\varepsilon, k, d; \mathbf{s}) = \max_{i\in[-ak, ak]} -(1-\tau\widehat{\delta})i - \frac{\varphi}{2}\left(\frac{i}{k}\right)^2 k + \mathbb{E}[\Lambda(z'; \mathbf{s})v(\varepsilon', k', d', \xi'; \mathbf{s}')]$$
$$\implies i^n(\varepsilon, k, d; \mathbf{s})$$

Representative Household

- **Preferences** feature habit formation and no wealth effects on labor supply:

$$\mathbb{E}\sum_{t=0}^{\infty}\beta^t \log\left(C_t - X_t - \chi\frac{N_t^{1+\eta}}{1+\eta}\right)$$

- Define law of motion for $S_t = \frac{C_t - X_t}{C_t}$ (Campbell and Cochrane 1999)

$$\log S_t = (1-\rho_S)\log\overline{S} + \rho_S \log S_{t-1} + \lambda \log\left(\frac{C_t}{C_{t-1}}\right)$$

- Habit stock X_t is external

Fixed Parameters

Business cycle parameters		
Parameter	*Description*	*Value*
β	Discount factor	0.99
η	Inverse Frisch elasticity	1/2
θ	Labor share	0.64
ν	Capital share	0.21
δ	Depreciation	0.025
ρ_z	Aggregate TFP AR(1)	0.95
σ_z	Aggregate TFP AR(1)	0.007
Tax parameters		
Parameter	*Description*	*Value*
τ	Tax rate	0.35
$\widehat{\delta}$	Tax depreciation	0.119

Parameters to be Computed

1. **Micro-level heterogeneity**

Parameter	*Description*	*Value*
$\overline{\xi}$	Fixed cost	
a	No fixed-cost region	
φ	Quadratic cost	
ρ_{ε}	Idiosyncratic TFP AR(1)	
σ_{ε}	Idiosyncratic TFP AR(1)	

2. **Habit formation**

Parameter	*Description*	*Value*
$\overline{S}$	Average surplus consumption	
$\rho_{\overline{S}}$	Persistence of surplus consumption	

Empirical Targets

1. **Interest rate dynamics**: projected on history of TFP shocks and HP filtered

Target	*Data*	*Model*
$\sigma(\widehat{r})$	0.48%	
$\rho(\widehat{r},\widehat{y})$	-0.205	

2. **Firm-level investment behavior**: IRS corporate tax data (Zwick and Mahon 2017)

Target	*Data*	*Model*
$\Pr(\frac{i}{k} > 0.2)$	0.144	
$\Pr(\frac{i}{k} \in [0.01, 0.2])$	0.619	
$\Pr(\frac{i}{k} < 0.01)$	0.237	
$\mathbb{E}[\frac{i}{k}]$	0.104	
$\sigma(\frac{i}{k})$	0.160	

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$\Pr(\frac{i}{k} \in [0.01, 0.2])$	0.619	*0.602*
$\Pr(\frac{i}{k} < 0.01)$	0.237	*0.239*
$\mathbb{E}[\frac{i}{k}]$	0.104	*0.106*
$\sigma(\frac{i}{k})$	0.160	*0.121*

Parameters to be Computed

1. **Micro-level heterogeneity**

Parameter	*Description*	*Value*
$\bar{\xi}$	Fixed cost	*0.44*
a	No fixed-cost region	*0.003*
φ	Quadratic cost	*2.69*
ρ_ε	Idiosyncratic TFP AR(1)	*0.94*
σ_ε	Idiosyncratic TFP AR(1)	*0.026*

2. **Habit formation**

Parameter	*Description*	*Value*
$\overline{S}$	Average surplus consumption	*0.65*
$\rho_{\overline{S}}$	Persistence of surplus consumption	*0.95*

▸ Role of Habit Formation and Adjustment Costs

▸ Unconditional Business Cycle Moments

My Contributions

1. Show irrelevance results driven by counterfactual r_t dynamics

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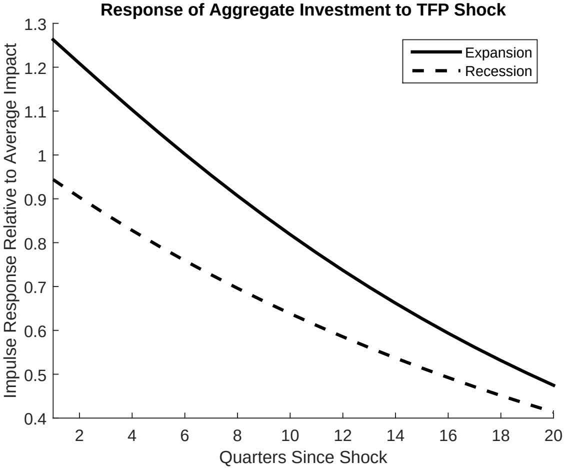
Effect of Aggregate Shock is Time-Varying



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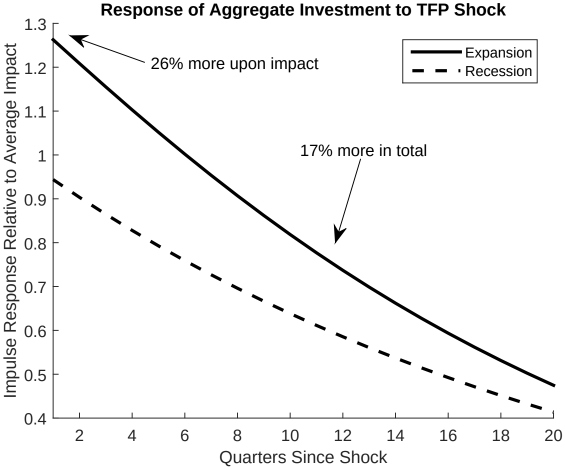

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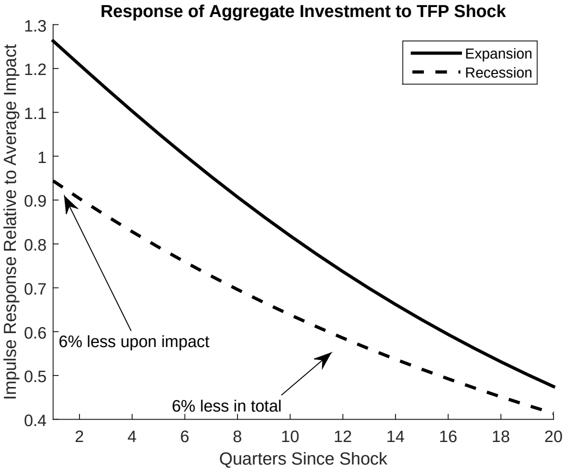

▸ State Dependence Over the Business Cycle

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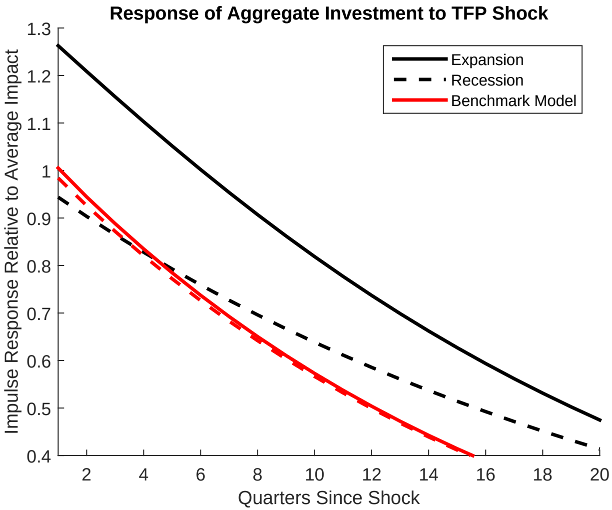


▸ Conditional Heteroskedasticity

Role of Lumpy Investment

- Firms' decision rules feature choice of k^a vs. k^n
  - More likely to adjust if $|k^a - k^n|$ is large
- On average, $k^n < k^a$ due to depreciation
- After history of negative shocks, $k^n \approx k^a$
  - Less likely to adjust
- After history of positive shocks, $k^n << k^a$
  - More likely to adjust

▸ Graphical Intuition

Role of Real Interest Rate Dynamics

- Irrelevance results in previous literature
    1. PE: lumpy investment generates state dependence
    2. Benchmark RBC: no state dependence

- Driven by extreme sensitivity of investment to interest rates

- Extreme sensitivity has counterfactual implications for data

- In order to match data, need to break extreme sensitivity

  $\Longrightarrow$ also break irrelevance results

Adding Investment Stimulus Policy

- **Proposition**: tax depreciation only affects decisions through

$$\text{tax-adjusted price } = 1 - \tau \times \text{PV}_t$$

$$\text{PV}_t = \mathbb{E}_t \sum_{s=0}^{\infty} \left(\prod_{j=0}^{s} \frac{1}{1 + r_{t+j}} \right) (1 - \widehat{\delta})^s \widehat{\delta}$$

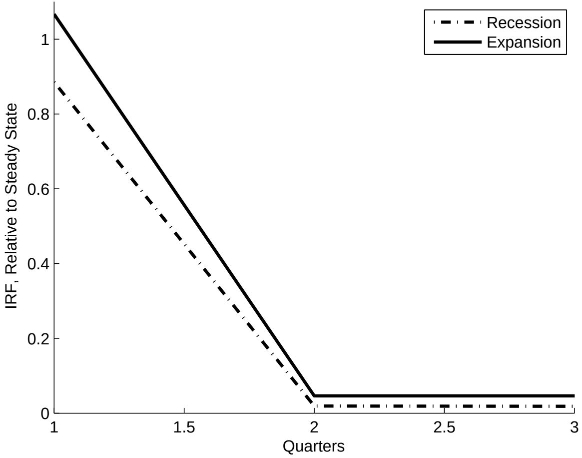
- Model **investment stimulus policy** as shock

$$\widehat{\text{PV}}_t = \text{PV}_t + \text{sub}_t$$

- Simple stochastic process for implicit subsidy

$$\log \text{sub}_t = \log \overline{\text{sub}} + \varepsilon_t$$

Stimulus Policy Less Effective In Recession



▸ Subsidies Required To Overcome State Dependence

Increasing Cost Effectiveness with Micro Targeting

- Avoid subsidizing investment that would have been done anyway

$$\text{cost} = \underbrace{\text{sub}_t \times I_{nopol}}_{\text{inframarginal}\approx 96\%} + \underbrace{\text{sub}_t \times (I_{pol} - I_{nopol})}_{\text{marginal}\approx 4\%}$$

Increasing Cost Effectiveness with Micro Targeting

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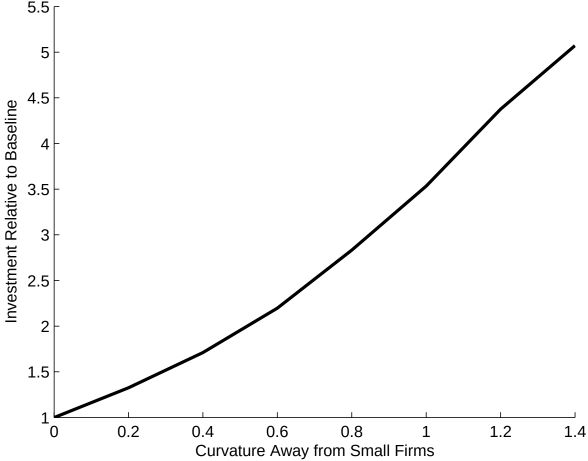
- Lumpy investment $\implies$ want to avoid inframarginal firms
- Particular illustration: avoid subsidizing small firms
  - Growing faster than average $\implies$ more likely to be investing
  - One-time, unexpected subsidy per unit of investment

$$\text{sub}_{jt} = \alpha_1 n_{jt}^{\alpha_2}$$

  - Vary α_2 and solve for budget-equivalent α_1

Increasing Cost Effectiveness



$$\text{sub}_{jt} = \alpha_1 n_{jt}^{\alpha_2}$$

Conclusion

Jointly modeling lumpy investment and real interest rate dynamics important for understanding aggregate investment

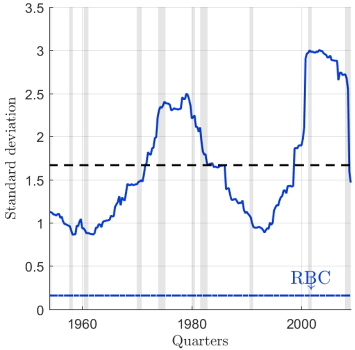
1. Business cycle fluctuations
   - More responsive to productivity shocks in expansions than recessions
2. Investment stimulus policy
   - Less responsive to policy in recessions
   - Firm-level targeting powerful way to increase cost effectiveness

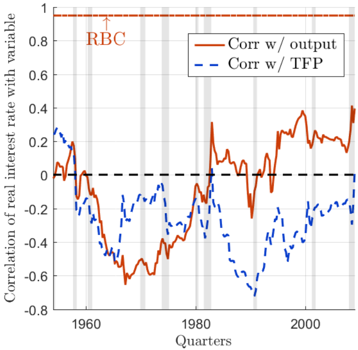
Subsamples ▸ Back

	$\sigma(r_t)$	$\rho(r_t, y_t)$	$\rho(r_t, z_t)$
Whole sample	1.73%	-0.11^{*}	-0.20^{***}
(p-value)		(0.09)	(0.001)
No Volcker	1.13%	0.07	-0.18^{***}
		(0.29)	(0.006)
Pre-1983	1.57%	-0.38^{***}	-0.17^{*}
		(0.00)	(0.06)
Post-1983	1.86%	0.21^{**}	-0.24^{***}
		(0.01)	(0.00)
RBC	0.16%	0.95	0.97

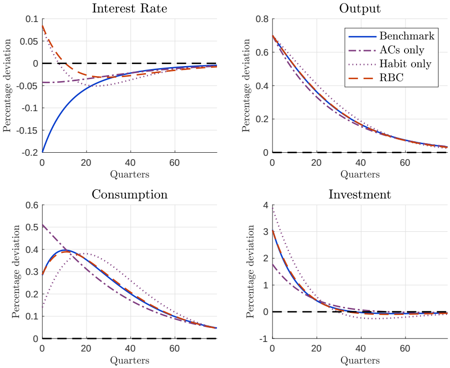
Eight-Year Rolling Windows

Back





Role of Habit and Adjustment Costs ▸ Back



Without habit, Euler equation is $1 + r_t = \frac{1}{\beta} \frac{C_t^{-1}}{\mathbb{E}_t[C_{t+1}^{-1}]}$

- Without ACs, I_t increases enough to increase $C_{t+1}/C_t \implies r_t$ rises
- With ACs, I_t does not increase enough to increase $C_{t+1}/C_t \implies r_t$ falls

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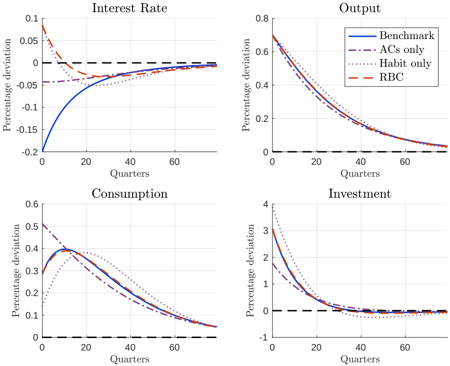
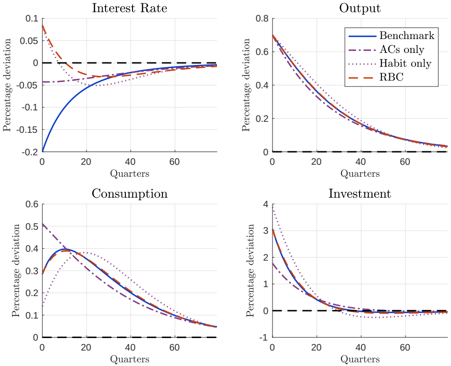


With habit, Euler equation is $1 + r_t = \frac{1}{\beta} \frac{(C_t - X_t)^{-1}}{\mathbb{E}_t[(C_{t+1} - X_{t+1})^{-1}]}$

- Given C_t, stronger habit could generate fall in r_t
- But greater incentive to smooth consumption $\implies$ r_t rises

Role of Habit and Adjustment Costs ▸ Back



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- But greater incentive to smooth consumption $\implies$ r_t rises
- Adjustment costs impede consumption smoothing $\implies$ r_t falls

Can We Find State Dependence in the Data? Back

- Statistical description of aggregate investment rate (Bachmann, Caballero, and Engel 2013)

$$\frac{I_t}{K_t} = \phi_0 + \phi_1 \frac{I_{t-1}}{K_{t-1}} + \sigma_t e_t, e_t \sim N(0,1)$$

$$\sigma_t^2 = \beta_0 + \beta_1 \frac{I_{t-1}}{K_{t-1}}$$

- My model: $\beta_1 > 0$
  - More responsive to shocks in expansions than recessions
- Benchmark RBC model: $\beta_1 \approx 0$
  - Similarly responsive to shocks in expansions as in recessions

Can We Find State Dependence in the Data? Yes ▸ Back

Statistic	Data	Model	Benchmark RBC
$\log\left(\frac{\hat{\sigma}_{90}}{\hat{\sigma}_{10}}\right)$	0.153** (0.031)	0.159	0.017
$\log\left(\frac{\hat{\sigma}_{75}}{\hat{\sigma}_{25}}\right)$	0.082** (0.020)	0.082	0.008

Fitted values from estimating

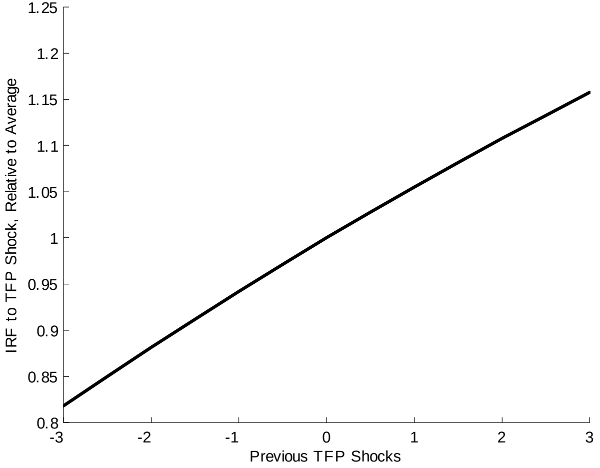
$$\frac{I_t}{K_t} = \phi_0 + \phi_1 \frac{I_{t-1}}{K_{t-1}} + \sigma_t e_t, e_t \sim N(0,1)$$

$$\sigma_t^2 = \beta_0 + \beta_1 \frac{I_{t-1}}{K_{t-1}}$$

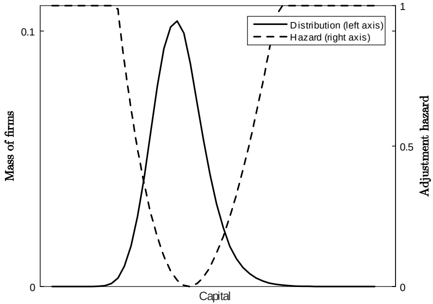
Unconditional Business Cycle Moments ▸ Back

Volatility			Autocorrelation		
Statistic	**Data**	**Model**	**Statistic**	**Data**	**Model**
$\sigma(Y)$	1.57%	1.61%	$\rho(Y, Y_{-1})$	.85	.72
$\sigma(C)/\sigma(Y)$	.53	.66	$\rho(C, C_{-1})$	.88	.72
$\sigma(I)/\sigma(Y)$	2.98	3.31	$\rho(I, I_{-1})$	.91	.71
$\sigma(H)/\sigma(Y)$	1.21	.68	$\rho(H, H_{-1})$	.91	.72
Correlation with Output					
Statistic	**Data**	**Model**			
$\rho(C, Y)$	.84	.99			
$\rho(I, Y)$	.80	.99			
$\rho(H, Y)$	.87	.99			

State Dependence Over the Cycle Back

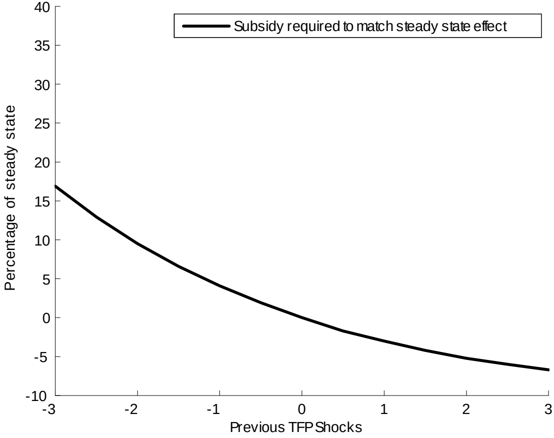


Role of Lumpy Investment ▸ Back



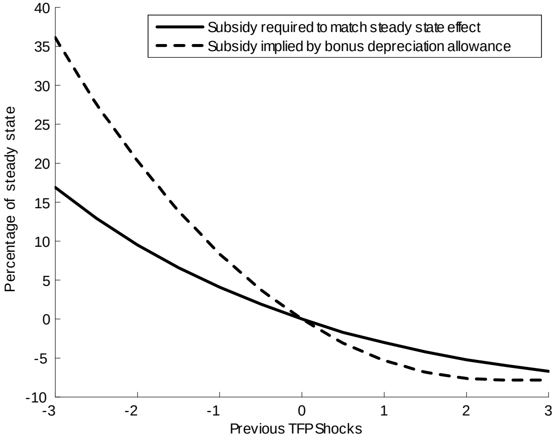
Stimulus Policy Less Effective In Recession

Back



Stimulus Policy Less Effective In Recession

Back



$$\text{sub}_t = \text{BDA}_t(1 - \text{PV}_t)$$