Inattention, Heterogeneity, Investment:

monetary policy and business cycles revisited

Adrien Auclert, Matt Rognlie and Ludwig Straub

European Central Bank, March 2019

This paper attempts to make HA models ready for quantitative macro analysis

Q: How does monetary policy affect output? What model to use?

Representative agent (RA)

- ✓ simple and fast to use
- ✓ can estimate with habits
  [Christiano-Eichenbaum-Evans, Smets-Wouters]
- ✓ then, matches **macro behavior**
  [*e.g.* impulse response to mon. policy shock]
- ✗ at odds with **micro behavior**
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Representative agent (RA)	**Heterogeneous agents (HA)**
✓ simple and fast to use	✗ difficult and slow to use
✓ can estimate with habits [Christiano-Eichenbaum-Evans, Smets-Wouters]	✗ no way to estimate (habits??)
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Goal: Make **HA models** ready for quantitative macro analysis!

We estimate HA with inattention and find investment to be key

- Start with **HA model** ...
  - Nominal price & wage rigidities
  - **Capital** adjustment costs
    [Hayashi, Tobin]
  - Illiquid assets & high MPCs
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  - **Inattention** of households + firms

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Estimate to IRFs to mon. pol. shock:

→ large estimated inattention
[half-life of 6 quarters]

→ hump-shaped impulse responses

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Implications:

1. **Investment** is *key* for **monetary transmission**
   - responds directly to $r \longrightarrow$ **amplified** by households' indirect response
   - **state dependence:** mon. pol. $\sim$ 90% less powerful if I is constrained

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2. **Investment** is *key* for **business cycles**

Our paper brings together **three literatures**

1. **HA / tractable HA models** (with nominal rigidities)
   - monetary policy: Gornemann-Kuester-Nakajima 2012, McKay-Nakamura-Steinsson 2016, Werning 2016, Ravn Sterk 2018, Kaplan-Moll-Violante 2018, Auclert 2019, ...
   - others: McKay-Reis 2016, Guerrieri-Lorenzoni 2018, Auclert-Rognlie-Straub 2018, Acharya Dogra 2018, Bilbiie 2019, Hagedorn-Manovskii-Mitman 2019, ...
2. **Estimation of RA models**
   - limited info: Rotemberg-Woodford 1997, Christiano-Eichenbaum-Evans 2005, Altig-Christiano-Eichenbaum-Linde 2011, ...
   - full info: Ireland 2004, Smets-Wouters 2007, An-Schorfheide 2007, ...
3. **Deviations from rational expectations and monetary policy**
   - cognitive discounting (Gabaix 2018), lack of common knowledge (Woodford 2003, Angeletos-Lian 2018), rational inattention (Sims 2002, Maćkowiak-Wiederholt 2009, 2015, Zorn 2018), k-level thinking (García-Schmidt-Woodford 2019, Farhi-Werning 2018)
   - sticky information (Gabaix-Laibson 2001, Mankiw-Reis 2002, 2006, Carroll et al 2018...)

Outline

1. Why inattention? (and not habits)
2. Inattentive HA model
3. Estimation
4. Result 1: Investment is the transmission mechanism
5. Result 2: Investment drives business cycles
6. Conclusion

Why inattention? (and not habits)

Habits are **inconsistent** with high MPCs

Standard model of habit formation:

$$V_t(a_{t-1}, c_{t-1}) = \max_{c_t, a_t} u(c_t - \gamma c_{t-1}) + \beta V_{t+1}(a_t, c_t)$$

$$c_t + a_t \leq (1 + r_t)a_{t-1} + y_t$$

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Q: How does average agent dynamically react to unanticipated income shock?

$\rightarrow$ **intertemporal MPCs** $\frac{\partial c_t}{\partial y_0}$

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Intertemporal MPCs in the data
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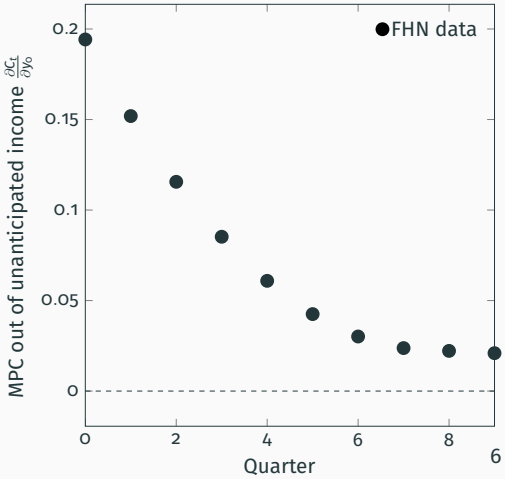

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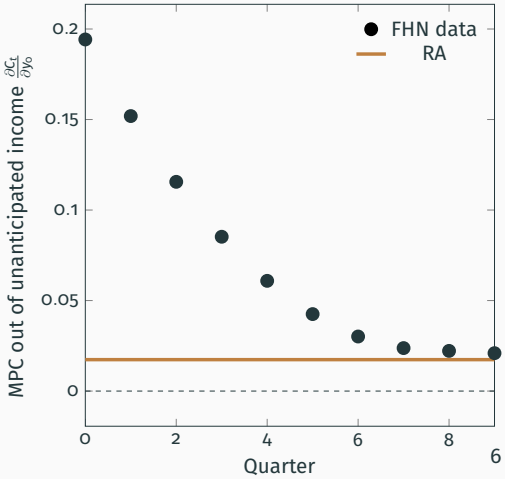

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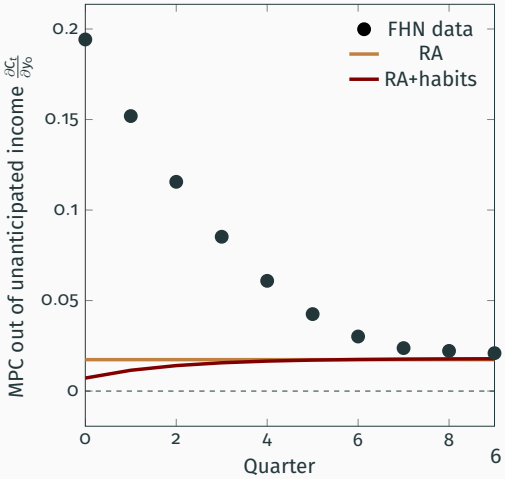

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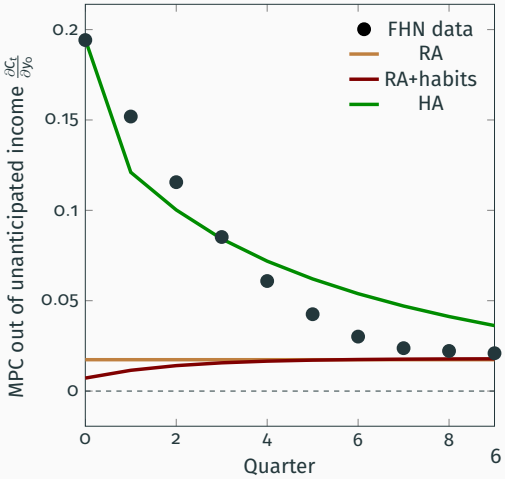

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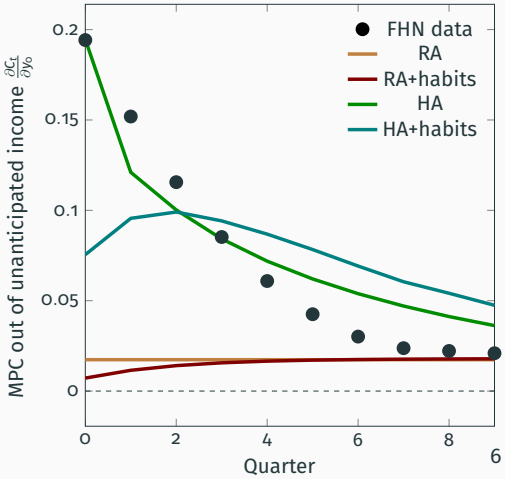

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- Our HA approach: **sticky information**
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Inattentive HA model

Inattentive HA = standard HANK + inattention

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  - idiosyncratic shocks to skills e_{it}
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illiquid: bonds + capital
(priced by **attentive** traders)

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Estimation

Two-step estimation procedure

- Two types of parameters
  1. steady-state relevant parameters $\rightarrow$ calibrated to micro moments, e.g. **MPCs**
  2. impulse-response relevant parameters $\theta^h, \theta^f, \kappa^p, \kappa^w, r_o, \rho_r \rightarrow$ **estimated**

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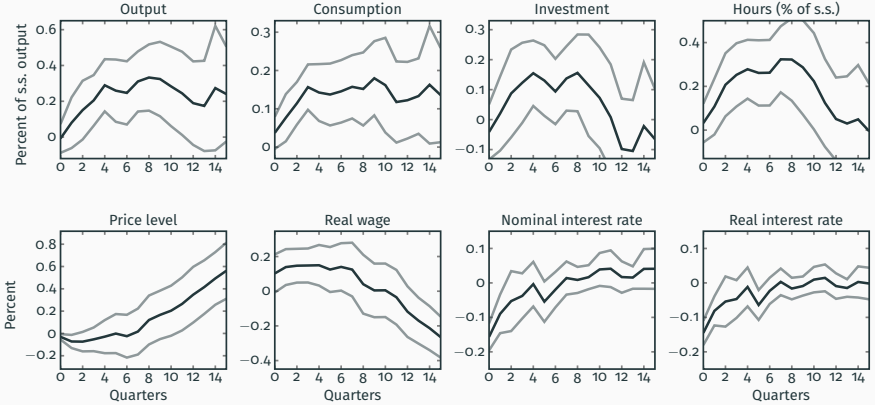
- Estimation to **impulse responses to monetary policy shocks**
  - data on $\{Y_t, C_t, I_t, N_t, P_t, w_t, r_t\}$

Impulse response to monetary policy shock

▸ Details

- Monetary impulse response [Ramey 2016]
- Jordà method using Romer-Romer dates on original sample (69m3–96m12)



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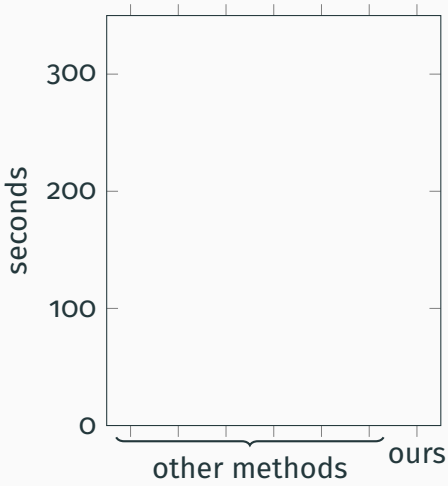
How fast are these methods?

[just transitions, not steady state]



A new methodology for fast simulation and estimation

- Simulating HA models remains **challenging**
- Use new "**sequence space**" methodology
  [Auclert-Rognlie-Straub 2019]
- Idea: reduce model to system of equations, **entirely in aggregates**

$$F_t\left(\{X_s, Z_s\}\right) = 0$$

  - $\{Z_s\}$ is **sequence** of **shocks**
  - $\{X_s\}$ is **sequence** of **aggregates** to solve

$\rightarrow$ Impulse response is $d\mathbf{X} = \mathbf{F}_{\mathbf{X}}^{-1}\,\mathbf{F}_{\mathbf{Z}}\,d\mathbf{Z}$

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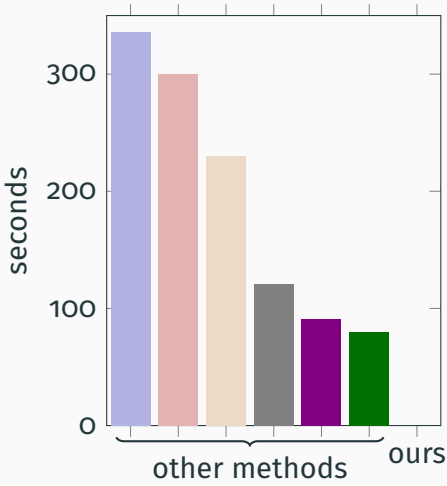

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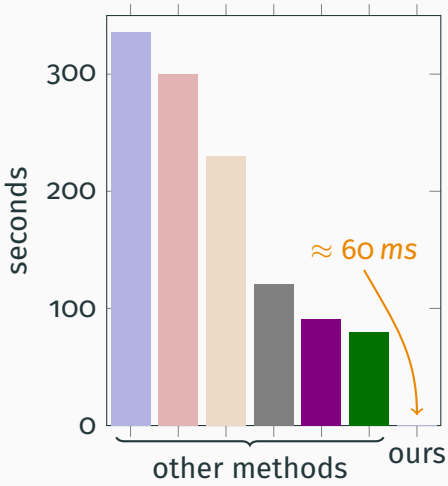
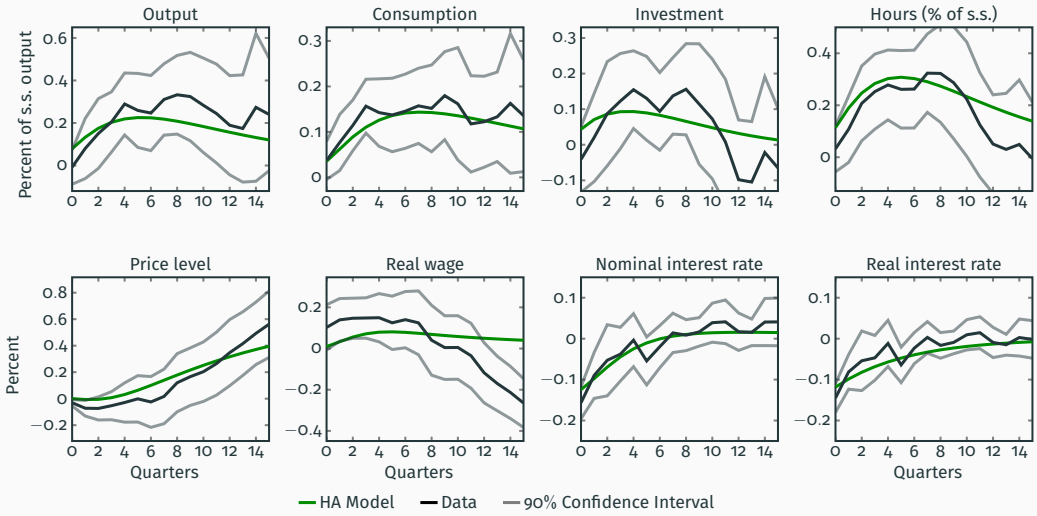


The estimated impulse responses

▸ Alternatives



Calibrated and estimated parameters: significant inattention!

Estimated parameters

Parameter		Value	std. dev.
θ^h	Household inattention	0.911	(0.022)
θ^f	Firm inattention	0.959	(0.008)
κ^p	Price Phillips Curve slope	1.000	(1.256)
κ^w	Wage Phillips Curve slope	0.010	(0.002)
r_0	Intercept of real rate	-0.118	(0.013)
ρ_r	Persistence of real rate	0.833	(0.012)

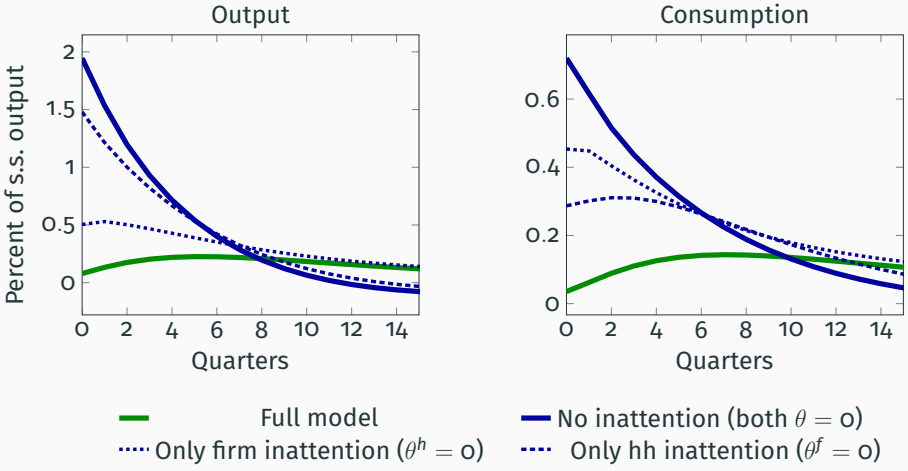
Why does inattention generate humps?

Not obvious that inattention $\Rightarrow$ humps **in model with high MPCs** ...

- e.g. if Y is not hump-shaped, neither is C !

$\rightarrow$ requires **joint inattention** on both C and I [$\neq$ habits, I-adj. costs]

- **Joint** inattention on *C* and *I* is crucial for the hump shape!



Inattention informs the **composition** of consumption

Decompose [Auclert 2019, Kaplan-Moll-Violante 2018, ...]

$$dC_t = \underbrace{\sum_s \frac{\partial \mathcal{C}_t}{\partial r_s} dr_s}_{\text{direct}} + \underbrace{\sum_s \frac{\partial \mathcal{C}_t}{\partial Y_s} dY_s + \dots}_{\text{indirect}}$$

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Indirect effects largely driven by **MPCs**

$\rightarrow$ mostly **unaffected by inattention!**

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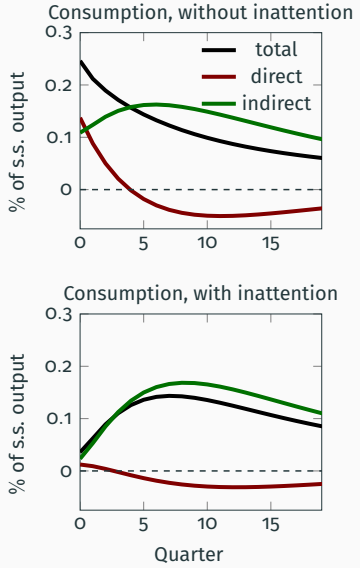

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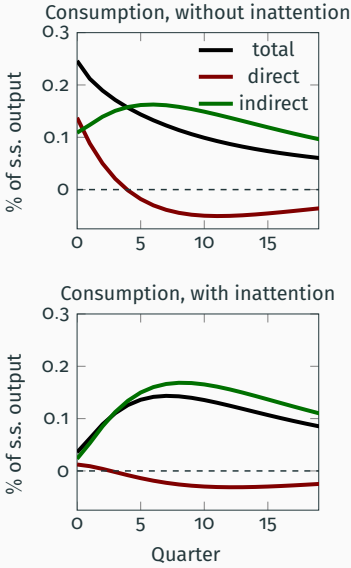
Inattention informs **direct** & **indirect** **effects**



Result 1: Investment is the transmission mechanism

How is monetary policy transmitted in this model?

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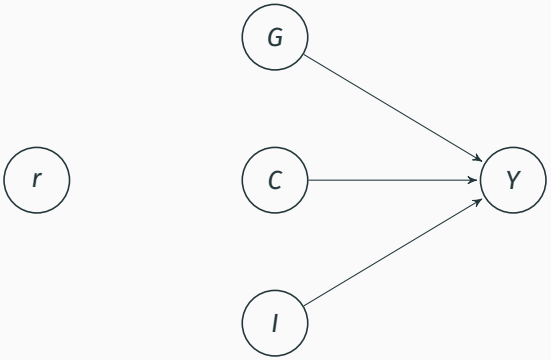

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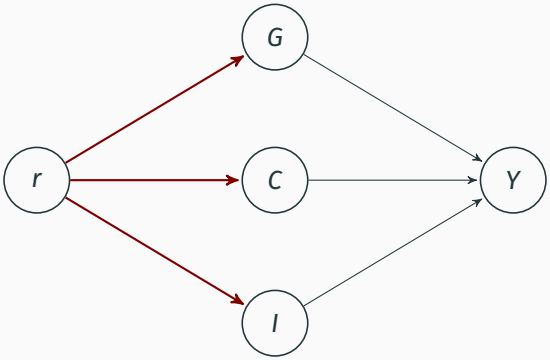

Three direct channels

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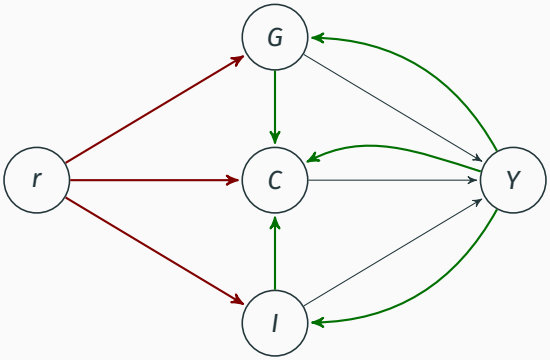
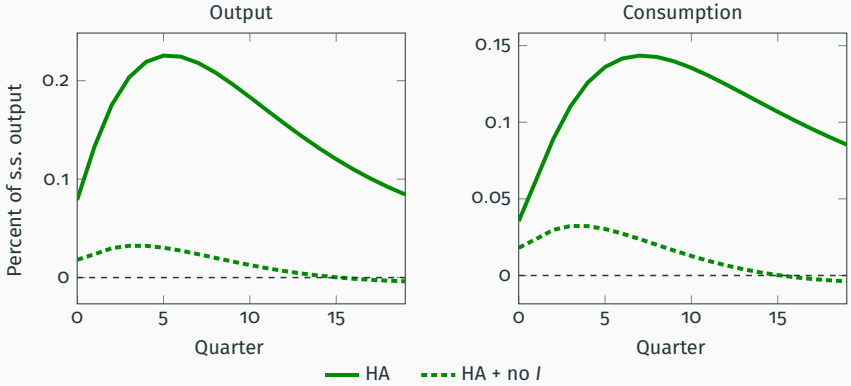


Three direct channels & many indirect channels

The role of investment in the transmission mechanism

Switching off investment entirely...



...dampens HA output by 90% and consumption by 87% !

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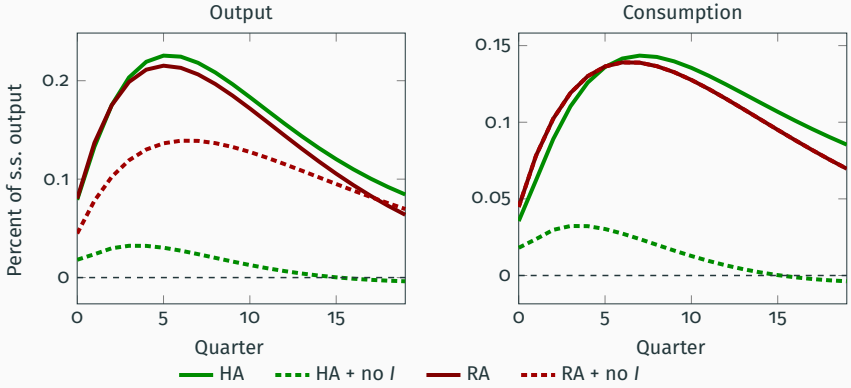
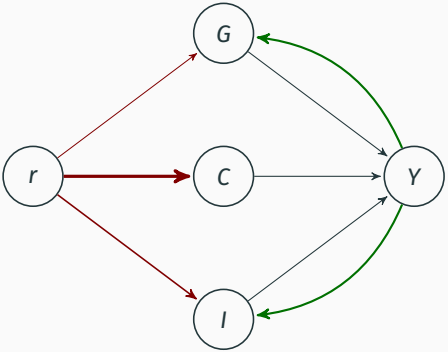


...but has no effect on RA consumption!

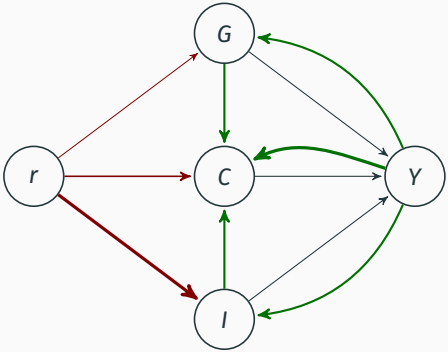
Investment *is* the transmission mechanism in HA

In RA, C only depends on r!

Representative agent



Heterogeneous agents



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Make this precise by evaluating direct channels separately

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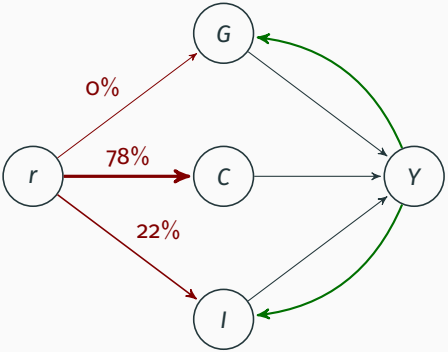

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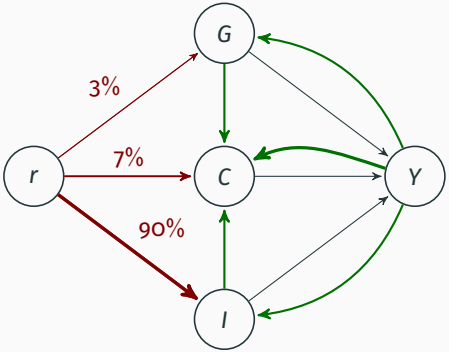

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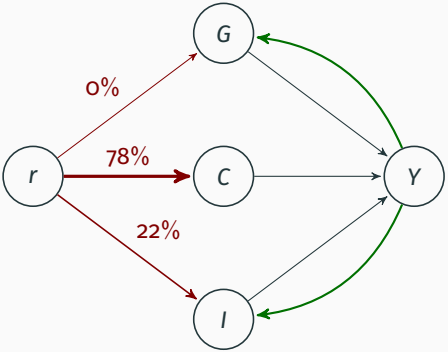

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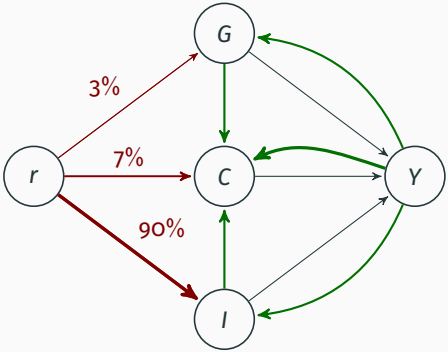


GE response in HA dominated by investment!

Why does it matter that investment transmits monetary policy?

- Causes **state dependence !**
- Suppose economy undergoes boom-bust cycle in investment
- During bust, investment may be low **but also unresponsive**

Why does it matter that investment transmits monetary policy?

- Causes **state dependence !**
- Suppose economy undergoes boom-bust cycle in investment
- During bust, investment may be low **but also unresponsive**

→ In **HA:** monetary policy **pushes on a string** during the bust!

  - Corollary: **natural interest rate plunges**

Result 2: Investment drives business cycles

Bayesian estimation of our inattentive HA model

- Enrich our model to include **7 standard shocks** [Smets Wouters 2007]
  - supply: TFP, W markup, P markup
  - demand: monetary policy, G_t, C_t (discount factor), I_t (user cost)

- Use **same model parameters** ...

... but **estimate all shock parameters** to 7 standard series

- To compare: Apply same procedure to RA with habit

Estimates for HA model

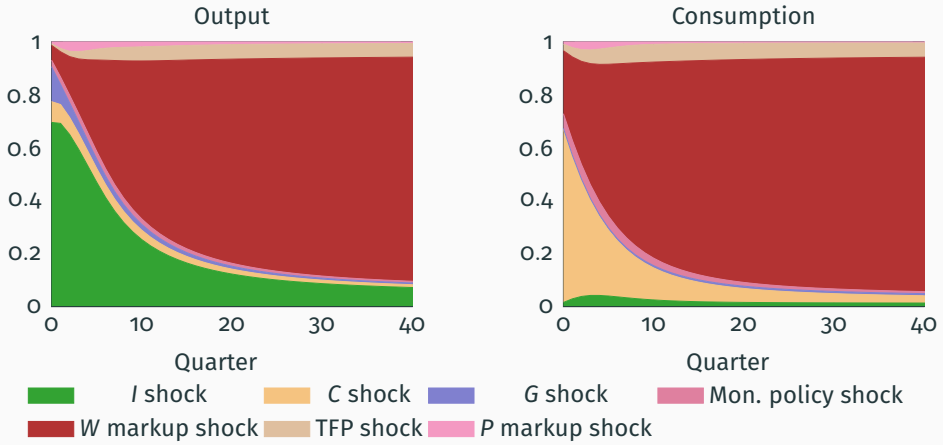
			Posterior					Posterior	
Supply shock		**Prior distribution**	**Mode**	**std. dev**	**Demand shock**		**Prior distribution**	**Mode**	**std. dev**
TFP	s.d.	Invgamma(0.1, 2)	0.319	(0.017)	Mon. policy	s.d.	Invgamma(0.1, 2)	0.382	(0.021)
	AR-1	Beta(0.5, 0.2)	0.097	(0.052)		AR-1	Beta(0.5, 0.2)	0.756	(0.038)
	AR-2	Beta(0.5, 0.2)	0.961	(0.016)	*G* shock	s.d.	Invgamma(0.1, 2)	0.371	(0.020)
W markup	s.d.	Invgamma(0.1, 2)	0.241	(0.014)		AR-1	Beta(0.5, 0.2)	0.950	(0.017)
	AR-1	Beta(0.5, 0.2)	0.774	(0.030)	*C* shock	s.d.	Invgamma(0.1, 2)	3.417	(0.291)
	AR-2	Beta(0.5, 0.2)	0.028	(0.022)		AR-1	Beta(0.5, 0.2)	0.765	(0.026)
P markup	s.d.	Invgamma(0.1, 2)	0.706	(0.041)	*I* shock	s.d.	Invgamma(0.1, 2)	3.952	(0.347)
	AR-1	Beta(0.5, 0.2)	0.773	(0.125)		AR-1	Beta(0.5, 0.2)	0.645	(0.030)
	AR-2	Beta(0.5, 0.2)	0.476	(0.162)					

[AR(1): $x_t = \rho x_{t-1} + \epsilon_t$. AR(2): $x_t - \rho_2 x_{t-1} = \rho_1 \left(x_{t-1} - \rho_2 x_{t-2}\right) + \epsilon_t$. std errors from Laplace approximation around posterior mode]

In RA, it's (almost) all about markup shocks

- Decompose forecast error variances at business cycle horizons

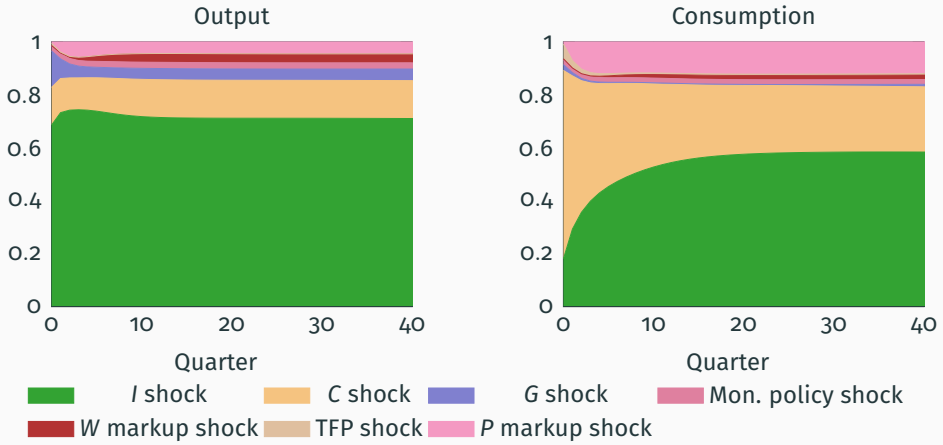
  [Smets Wouters 2007 find 50% accounted for by markup shocks after 40 quarters]



Estimated **RA**: It's all about **markup shocks!**

In HA, it's about investment shocks

- Decompose forecast error variances at business cycle horizons
  [Smets Wouters 2007: 50% accounted for by markup shocks after 40 quarters]



Estimated **HA**: replaces markup shocks with **investment shocks**!

Why is this?

▸ Impulse to investment

- Salient feature of the data: **comovement** of Y, C, I, N
- What generates this comovement in the two models? $\rightarrow$ e.g. $\text{Cov}_t(C_{t+h}, I_{t+h})$

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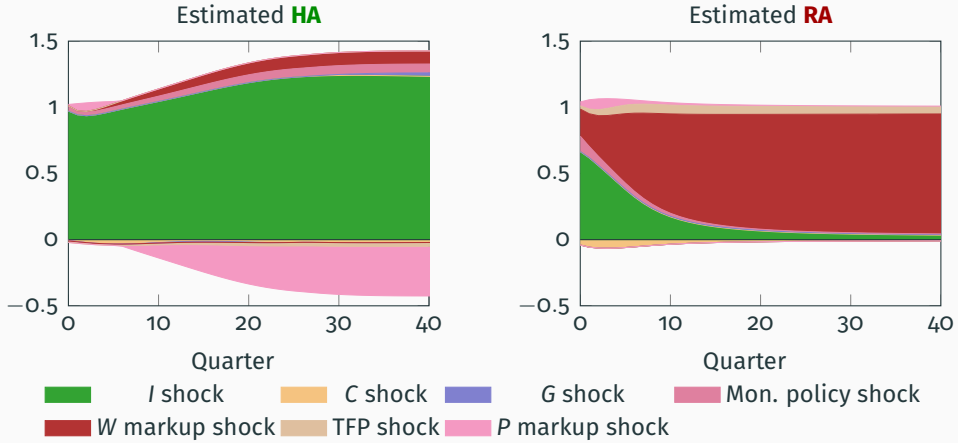
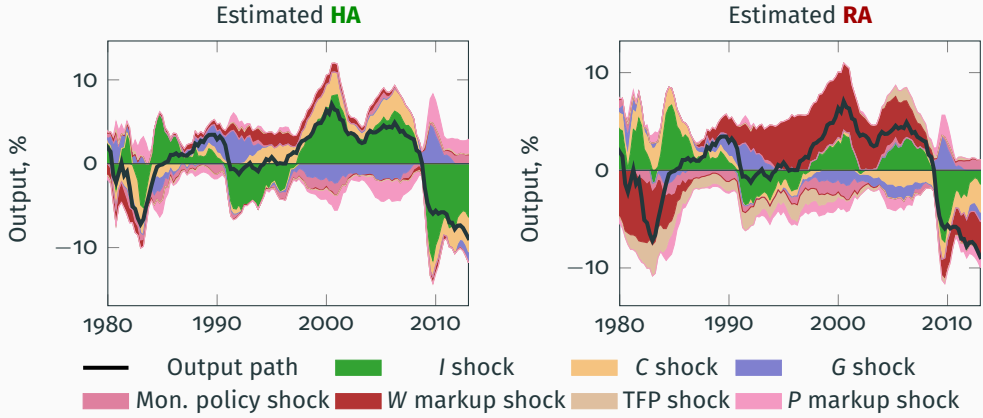


Estimated **HA** generates **endogenous** comovement between C and I

This is key to diagnose the drivers of business cycles

- Estimated **RA**: important role of **markup shocks** for business cycles
- Estimated **HA**: much larger role for **investment shocks**!



Conclusion

Conclusion

inattention + **heterogeneity** $\Rightarrow$ **investment** $\begin{cases} \text{drives monetary transmission} \\ \text{drives business cycles} \end{cases}$

Extra slides

Jordà method using Romer-Romer shocks as instruments

Back

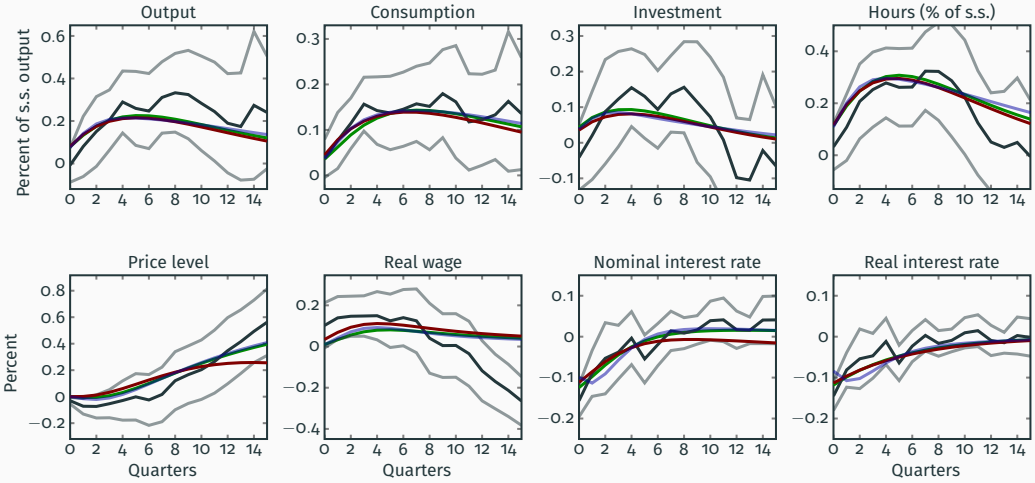
- Obtain monthly time series of Romer-Romer shocks $\{\epsilon_t\}$ (69m3–96m12)
- For each outcome Y, run at monthly level

$$Y_{t+h} = \theta_{Yh}\epsilon_t + X_t + \eta_t$$

  then aggregate θ_{Yh} to quarterly
- Outcomes: logs of
  - Y, C, I : real chained GDP, PCE, Investment
  - n : Hours of all persons in nonfarm business sector
  - p : CPI-all items
  - w : avg hourly earnings of private employees/CPI
  - i : Federal Funds rate
  - $r = i -$ everage one-year-ahead inflation forecast from the SPF
- Controls: lags of Y + lags of IP, unemployment, CPI, Commodity Price Index

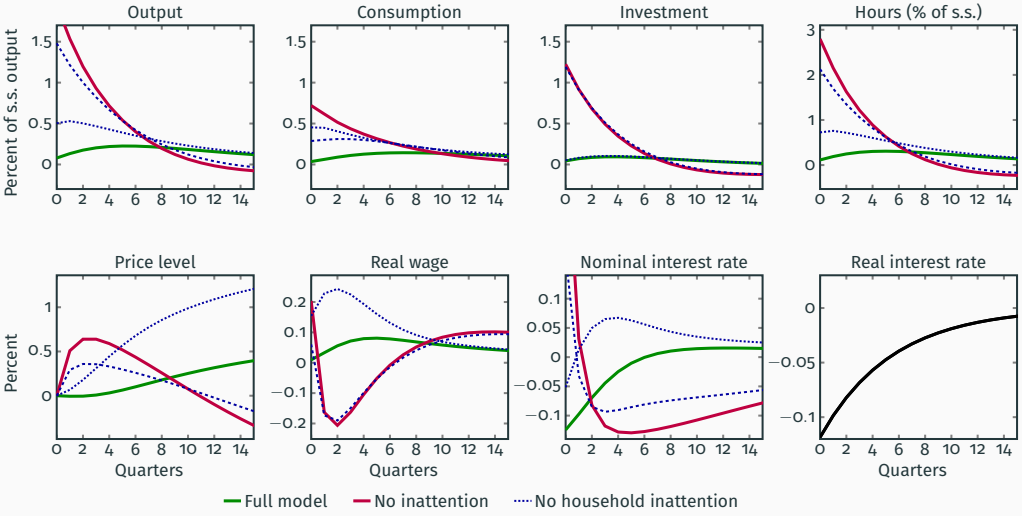
Alternative estimated models

Back



Role of inattention: full impulse response

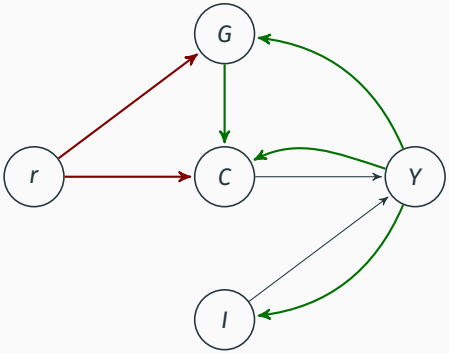
Back



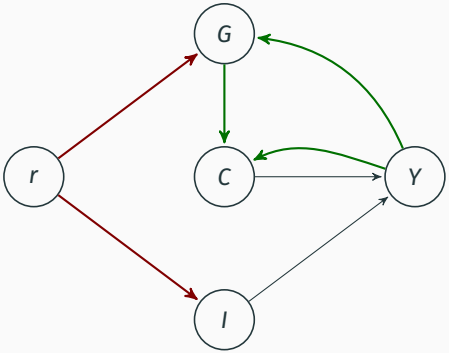
The channels of “HANK” vs our HA model

Back

"HANK"



Our estimated HA model



Estimated impulse responses to investment shocks

Back

- Impulse responses to 1-s.d. investment shock in RA and HA

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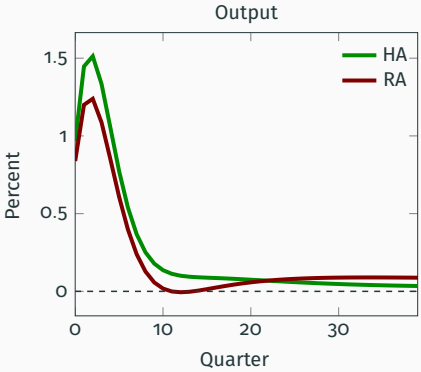
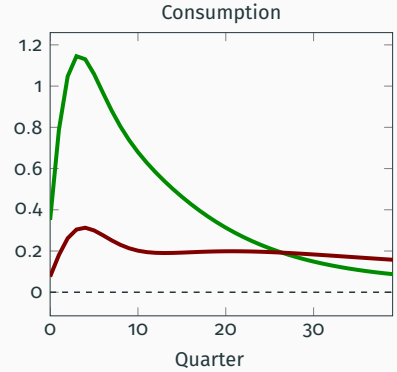
- Impulse responses to 1-s.d. investment shock in RA and HA





Estimated impulse responses to investment shocks

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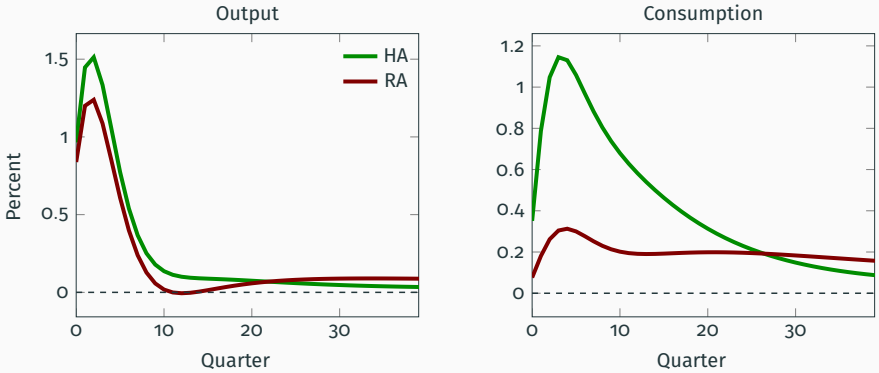
- Impulse responses to 1-s.d. investment shock in RA and HA



- Investment shocks **much more powerful** in HA than in RA
- We should be especially **wary of investment shocks**!
  - … even more so since those may **constrain monetary policy!**

The forward guidance puzzle in our estimated HA model

Back

- In standard RA and HA models: forward guidance puzzlingly powerful
  [McKay-Nakamura-Steinsson, Giannoni-Del-Negro-Patterson, Werning]
- What about our HA model with investment?

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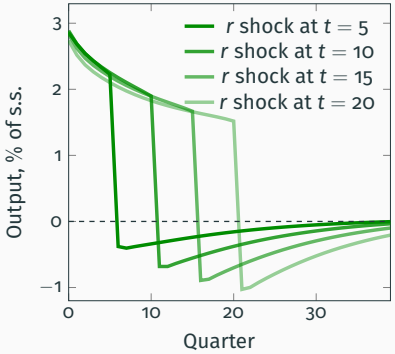
Without inattention

HA + investment amplify the puzzle!



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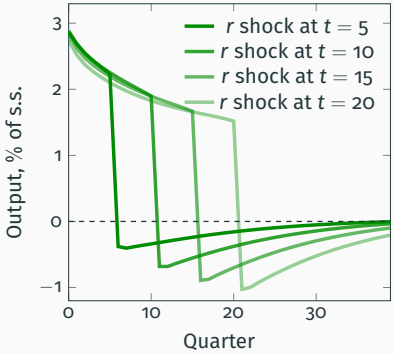
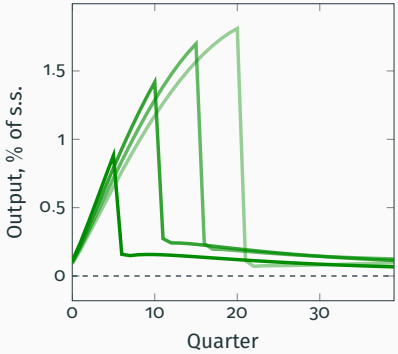


With inattention

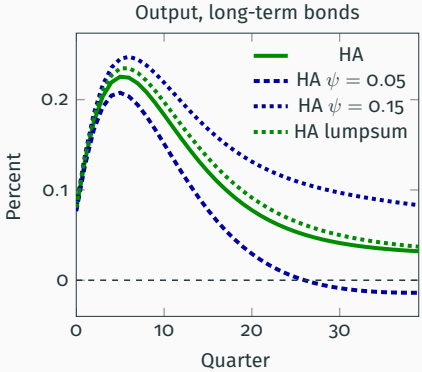
But inattention solves the puzzle

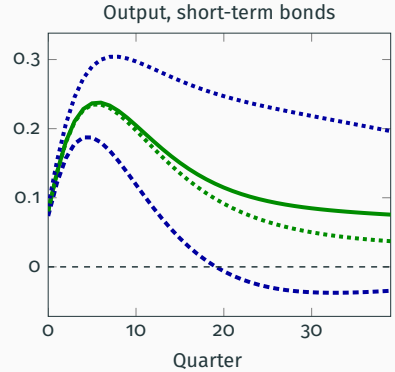


How much does fiscal policy matter?

Back

- Our estimated HA model is highly **non-Ricardian** [unlike RA]
  [Auclert-Rognlie-Straub 2018, Hagedorn-Manovskii-Mitman 2019]
- Fiscal response matters, but **less than with short-term bonds**





- **QE** effective in the model if it **swaps illiquid to liquid assets**
  - not clear it does ... denote $\chi =$ share of illiquid assets converted
- Simulate QE3: $180bn for 2 years, then taper with half-life of 2 years