Micro Jumps, Macro Humps: monetary policy and business cycles in an estimated HANK model

Adrien Auclert, Matt Rognlie and Ludwig Straub

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This paper matches the micro and macro of monetary policy

Q: How should we model the effects of monetary policy?
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“Macro time-series” approach
[CEE, ACEL, Maćkowiak-Wiederholt, Smets-Wouters...]

• match **humps** in aggregates
• representative agent (RA)
• use habits, adj. costs, inattention

![Output response to Romer-Romer shock](chart.png)

Quarter

0 2 4 6 8 10 12 14

-0.1 0 0.1 0.2 0.3 0.4 0.5 0.6

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“Micro moments” approach
[Kaplan-Moll-Violante, Auclert-Rognlie-Straub, ...]

- match micro “jumps” (MPCs)
- heterogeneous agents (HA)
- income risk + incomplete markets

\[\frac{\partial C}{\partial y}\]

Consumption

Norwegian lottery data

Quarter

MPC out of unanticipated income

\[\frac{\partial C}{\partial y}\]
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**This paper unifies the two:**
- match *both* humps and jumps
- revisit
  - mon. transmission mechanism
  - sources of business cycles
HA + inattention can match micro & macro

- Standard **RA supply side**:
  - nominal rigidities, indexation
  - investment adj. costs
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- Household side as in **HA**:
  - income risk + illiquid assets
    [Kaplan-Moll-Violante, Bayer et al]
  - inattention of households

What do we learn from matching micro & macro?

- Investment is key for monetary transmission
  - \( I \uparrow \rightarrow Y \uparrow \rightarrow \text{amplified by households' MPCs} \)

- State dependence: monetary pol. \( \sim \) less powerful if \( I \) is constrained

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  [over and above findings from existing studies]
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**Estimate** to IRFs of mon. pol. shock:  
[Rotemberg-Woodford, CEE, ACEL, MW, ...]

→ **hump**-shaped impulse responses  
→ high **MPCs**  
→ **significant inattention**  
→ (very) small **direct effect** of \( r \) on \( C \)
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- *hump*-shaped impulse responses
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**What do we learn** from matching micro & macro?

1. **Investment** is *key* for monetary transmission
   - $I \uparrow \rightarrow Y \uparrow \rightarrow$ amplified by households’ MPCs
   - **state dependence:** mon. pol. $\sim 85\%$ less powerful if $I$ is constrained
HA + inattention can match micro & macro

- **Standard RA supply side:**
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2. **Investment** is key for business cycles [over and above findings from existing studies]
Monetary transmission

Representative agent, no /
Representative agent

In HA: monetary policy transmission operates through
Any shocks that move, comove with and are amplified by C, and the government reacts with I.
Monetary transmission

Representative agent

Heterogeneous agents, no I

Any shocks that move I, comove with & are amplified by C/
Monetary transmission

Representative agent

In HA:
- Any shocks that move, comove with and are amplified by

Heterogeneous agents
Monetary transmission

Representative agent

Heterogeneous agents, estimated

Any shocks that move, comove with and are amplified by.
Monetary transmission

In HA: mon. pol. transmission operates through $l$

Any shocks that move $l$, comove with & are amplified by $C$
Our paper brings together **three literatures**

1. **HA / tractable HA models** (with nominal rigidities)
   - **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, ...

3. **Deviations from rational expectations and monetary policy**
Outline

1. How we match micro jumps & macro humps
2. Inattentive HA model
3. Estimation
4. Result 1: Investment is the transmission mechanism
5. Result 2: Investment drives business cycles
6. Conclusion
How we match micro jumps & macro humps
Heterogeneous-agent models can match (i)MPCs

Standard heterogeneous-agent model in s.s.:

\[ V(a, s) = \max_{c, a'} u(c) + \beta \mathbb{E} [V(a', s') | s] \]

\[ c + a' \leq (1 + r)a + ye(s) \]

\[ a' \geq 0 \]
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**Key Q:** How does average agent dynamically react to unanticipated transitory shock to \(y\)?

→ **intertemporal MPCs**  
[Auclert-Rognlie-Straub 2018]
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[Intertemporal MPCs in the data
[Fagereng-Holm-Natvik 2018, interpolated]]
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Intertemporal MPCs in the data

[Quarter MPC out of unanticipated income \( \frac{\partial C}{\partial y} \)]

Data (FHN)

RA
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\[ \frac{\partial C_t}{\partial y} \]

Data (FHN)

RA

HA

RA habits

HA habits

MPC out of unanticipated income \( \frac{\partial C_t}{\partial y} \)

Quarter

0

0.05

0.1

0.15

0.2

0

2

4

6

8
Inattention preserves (i)MPCs but introduces sluggishness

- Introduce aggregate risk in $r_t, y_t$
- Our approach to humps: sticky expectations
  - agents update expectations w/ Calvo $1 - \theta$
Inattention preserves (i)MPCs but introduces sluggishness

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- Our approach to humps: **sticky expectations**

[\cite{Gabaix-Laibson 2001, Mankiw-Reis 2002, Mankiw-Reis 2006, Carroll-Crawley-Slacalek-Tokuoka-White 2018}]

- agents update expectations w/ Calvo $1 - \theta$; if $k = \#$ periods since last update:

$$V_t (a, s; k) = \max_{c, a'} u(c) + \beta E_{t-k} \left[ \theta V_{t+1} (a', s', k + 1) + (1 - \theta) V_{t+1} (a', s', 0) \right] s$$

$$c + a' \leq (1 + r_t) a + y_t e (s)$$

$$a' \geq 0$$

• note: agents always see current $r_t, y_t \rightarrow$ never violate borrowing constraint!

• Achieves two goals: (i)MPCs are unchanged around the s.s. \rightarrow matches "micro jumps" / two.osf. beliefs about future path of aggregates sluggish \rightarrow matches "macro humps" / eight.osf
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Inattentive HA model
Model overview

- Discrete time with aggregate shocks

- **Heterogeneous-agent** household side
  - two assets + *sticky expectations*

- Standard **New-Keynesian** supply side
  - investment adjustment costs + nominal rigidities + indexation
  - fiscal rule changing labor taxes, monetary policy follows Taylor rule
Households & mutual fund

- Total wealth held by competitive & attentive “mutual fund”, two liabilities:
  - liquid assets (deposits) $a_t$: short-term, pay rate $r_t^{\text{liq}} = r_t - \xi$
  - illiquid assets $a_t^{\text{illiq}}$: pay rate $r_t$, households follow withdrawal rule $d(a_t^{\text{illiq}})$
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- Total wealth held by **competitive & attentive “mutual fund”**, two liabilities:
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- Households are inattentive also w.r.t. value of \( a_t^{\text{illiq}} \). Thus:
  \[
  V_t(a, s; k) = \max_{c, a'} u(c) + \beta \mathbb{E}_{t-k} \left[ \theta V_{t+1}(a', s', k + 1) + (1 - \theta) V_{t+1}(a', s', 0) \right] |s|
  \]
  
  \[
  c + a' \leq (1 + r_t^{\text{liq}})a + y_t e(s) + d \left( \mathbb{E}_{t-k} a_{it}^{\text{illiq}} \right), \quad a' \geq 0
  \]
  
  \[
  a_{it+1}^{\text{illiq}} \leq (1 + r_t) a_{it}^{\text{illiq}} - d \left( \mathbb{E}_{t-k} a_{it}^{\text{illiq}} \right)
  \]

- Allow for six household groups to capture heterogeneity in illiquid assets
Estimation
Two-step estimation procedure

• Split parameters into two categories:

  1. Steady-state relevant parameters [income process, share of liquid assets, ...]
     → calibrate to micro moments, e.g. income distribution, **MPCs**

  2. Impulse-response relevant parameters $\theta, \phi, \zeta^p, \zeta^w, \sigma^m, \rho^m$
     → **estimate** using either limited or full-information method
Two-step estimation procedure

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• Today: match **impulse responses to monetary policy shocks**
  • data on $\{Y_t, C_t, l_t, N_t, P_t, W_t, r_t\}$
Impulse response to monetary policy shock

- Monetary impulse response [Ramey 2016]
- Jordà method using Romer-Romer shocks in original sample (69m3–96m12)
How do we simulate HA + info friction?

- Complicated model! HA + **sticky expectations** ...
- Expand “**sequence-space Jacobian**” method  
  
  \[\text{[Auclert-Bardóczy-Rognlie-Straub 2019]}\]
How do we simulate HA + info friction?

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• Expand “sequence-space Jacobian” method \[\text{[Auclert-Bardóczy-Rognlie-Straub 2019]}\]
  1. Use certainty equivalence → focus on small “MIT shocks”
  2. Break model into blocks: e.g. household block \(\{Y_t, r_t\} \mapsto \{C_t\}\)
  3. Compute each block’s Jacobians [sufficient for simulation!] e.g.
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$$
\begin{pmatrix}
  dC_0 \\
dC_1 \\
dC_2 \\
\vdots
\end{pmatrix}
= 
\begin{pmatrix}
  M_{00} & M_{01} & M_{02} & \cdots \\
  M_{10} & M_{11} & M_{12} & \cdots \\
  M_{20} & M_{21} & M_{22} & \cdots \\
  \vdots & \vdots & \vdots & \ddots
\end{pmatrix}
\begin{pmatrix}
  dY_0 \\
dY_1 \\
dY_2 \\
\vdots
\end{pmatrix}
+ \cdots
$$

- With sticky expectations: manipulate the rational expectation Jacobian!
How do we simulate HA + info friction?

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- Expand **sequence-space Jacobian** method [Auclert-Bardóczy-Rognlie-Straub 2019]
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\[
\begin{pmatrix}
  dC_0 \\
  dC_1 \\
  dC_2 \\
  \vdots
\end{pmatrix} =
\begin{pmatrix}
  M_{00} & (1 - \theta)M_{01} & (1 - \theta)M_{02} & \cdots \\
  M_{10} & (1 - \theta)M_{11} + \theta M_{00} & (1 - \theta)M_{12} + \theta (1 - \theta)M_{01} & \cdots \\
  M_{20} & (1 - \theta)M_{21} + \theta M_{10} & \vdots & \vdots \\
  \vdots & \vdots & \vdots & \ddots \\
\end{pmatrix}
\begin{pmatrix}
  dY_0 \\
  dY_1 \\
  dY_2 \\
  \vdots
\end{pmatrix} + \text{...}
\]

- With sticky expectations: **manipulate the rational expectation Jacobian**!
How fast is this? [single IRF, not incl. steady state]

- Ours
- Other methods

- 0 seconds
- 100 seconds
- 200 seconds
- 300 seconds

- Ours
- Other methods
How fast is this?

[single IRF, not incl. steady state]
How fast is this?

[single IRF, not incl. steady state]
The estimated impulse responses

- **Output**
- **Consumption**
- **Investment**
- **Hours (% of s.s.)**
- **Price level**
- **Nominal wage**
- **Nominal interest rate**
- **Real interest rate**

Data ➤ 90% Confidence Interval ➤ HA Model
Estimates point to significant inattention

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>std. dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>Stickiness of household expectations</td>
<td>0.888</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Investment adjustment cost</td>
<td>7.487</td>
</tr>
<tr>
<td>$\zeta^p$</td>
<td>Calvo price stickiness</td>
<td>0.933</td>
</tr>
<tr>
<td>$\zeta^w$</td>
<td>Calvo wage stickiness</td>
<td>0.920</td>
</tr>
<tr>
<td>$\sigma^m$</td>
<td>Standard deviation of monetary shock</td>
<td>0.047</td>
</tr>
<tr>
<td>$\rho^m$</td>
<td>Persistence of monetary shock</td>
<td>0.903</td>
</tr>
</tbody>
</table>

- Comparable to Coibion Gorodnichenko (2012)
  - find 0.80, 0.86-0.89 for inflation expectations of households, prof. forecasters
How much does inattention matter?

- Sticky expectations are crucial for the hump shape!
Inattention informs the **composition** of consumption

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

\[
dC_t = \sum_s \frac{\partial C_t}{\partial r_s} dr_s + \sum_s \frac{\partial C_t}{\partial Y_s} dY_s + \ldots
\]

- **direct**
- **indirect**

% of s.s. output

Quarter % of s.s. output

Consumption, without inattention

Consumption, with inattention
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**Direct effects** strongly dampened by inattention

**Indirect effects** largely driven by MPCs

→ mostly **unaffected by inattention**!
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  → mostly **unaffected by inattention**!

- **Direct effects** strongly **dampened by inattention**
  → intertemporal substitution ≈ irrelevant for C!

**Graphs:**
- Consumption, without inattention
- Consumption, with inattention
Result 1: Investment is the transmission mechanism
How is monetary policy transmitted in this model?
How is monetary policy transmitted in this model?

Diagram:
- $r$ (r) connected to $C$ (C) and $I$ (I)
- $C$ (C) connected to $Y$ (Y)

Direct channels and indirect channels.
How is monetary policy transmitted in this model?

Direct channels
How is monetary policy transmitted in this model?

Direct channels & indirect channels
The role of investment in the transmission mechanism

Switching off investment entirely...

...dampens HA output by 85% and consumption by 70%!
The role of investment in the transmission mechanism

Switching off investment entirely...

...but has no effect on RA consumption!
Investment is the transmission mechanism in HA

In RA, Y is mostly driven by direct response of C!

Representative agent

Heterogeneous agents

In HA Y is driven by investment!
Result 2: Investment drives business cycles
Bayesian estimation of our inattentive HA model

• Enrich our model to include 7 standard shocks [Smets Wouters 2007, JPT 2010, 2011, ...]
  • supply: TFP, $W$ markup, $P$ markup
  • demand: monetary policy, $G_t$, $C_t$, $I_t$
  • different: discount factor shock for $C_t$, risk premium shock for $I_t$

• Use same model parameters ...

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

• To compare: apply same procedure to RA with habit
Consider baseline RA model

- Decompose forecast error variances $\text{Var}_t(Y_{t+h})$ at business cycle horizons:

In this estimated RA: it’s about markup and TFP shocks [as in Smets Wouters 2007]
Endogenous cov \((C, I)\) in HA $\rightarrow$ investment shocks matter much more!

- Decompose forecast error variances \(\text{Var}_t(Y_{t+h})\) at business cycle horizons:

  \[
  \text{Output} \\
  \text{Quarter} \\
  \begin{array}{c}
  0 \quad 10 \quad 20 \quad 30 \quad 40 \\
  \text{Output} \\
  \end{array}
  \]

  \[
  \text{Consumption} \\
  \text{Quarter} \\
  \begin{array}{c}
  0 \quad 10 \quad 20 \quad 30 \quad 40 \\
  \text{Consumption} \\
  \end{array}
  \]

  - \(I\) shock
  - \(C\) shock
  - \(G\) shock
  - Mon. policy shock
  - \(W\) markup shock
  - TFP shock
  - \(P\) markup shock

Replace RA with HA: **investment shocks** matter a lot more!
• Salient feature of the data: **comovement** of $\text{Cov}_t(C_{t+h}, I_{t+h})$ [Barro-King 1984]

In **HA** investment shocks generate **endogenous** comovement between $C$ and $I$
Conclusion
Conclusion

heterogeneity (micro jumps) + inattention (macro humps) \Rightarrow \text{investment} \begin{cases} \text{drives monetary transmission} \\ \text{drives business cycles} \end{cases}
Extra slides
Role of investment in estimated TA

- **TA** model (share of hand to mouth = 20%) is relatively close to **RA**
Role of investment without inattention

- Without inattention, **investment much less important!**
Why does fiscal policy not matter more?

• With long-term bonds, much less of a windfall from lower $r_t$
  • precise fiscal rule less crucial than with short-term bonds
Role of stock market in monetary transmission

- Stock market goes up, sluggish transmission to $C$
  - shape & magnitude as in Chodorow-Reich Nenov Simsek (2019)