Monetary Policy According to HANK

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HANK: Heterogeneous Agent New Keynesian models

• Framework for quantitative analysis of the transmission mechanism of monetary policy

• Three building blocks
  1. Uninsurable idiosyncratic income risk
  2. Nominal price rigidities
  3. Assets with different degrees of liquidity
How monetary policy works in RANK

- Total consumption response to a drop in real rates

\[ C \text{ response} = \text{direct response to } r + \text{indirect effects due to } Y \]

\[ >95\% \]  
\[ <5\% \]

- Direct response is everything, pure intertemporal substitution

- However, data suggest:
  1. Low sensitivity of \( C \) to \( r \)
  2. Sizable sensitivity of \( C \) to \( Y \)
  3. Micro sensitivity vastly heterogeneous, depends crucially on household balance sheets
How monetary policy works in HANK

- Once matched to micro data, HANK delivers realistic:
  - wealth distribution: small direct effect
  - MPC distribution: large indirect effect (depending on $\Delta Y$)

\[ C \text{ response} = \text{direct response to } r + \text{indirect effects due to } Y \]

- RANK: >95%  
  HANK: <1/3

- RANK: <5%  
  HANK: >2/3

- Overall effect depends crucially on fiscal response, unlike in RANK where Ricardian equivalence holds
Literature and contribution

Combine two workhorses of modern macroeconomics:

- **New Keynesian models** Gali, Gertler, Woodford
- **Bewley models** Aiyagari, Bewley, Huggett

Closest existing work:

1. **New Keynesian models with limited heterogeneity**
   Campell-Mankiw, Gali-LopezSalido-Valles, Iacoviello, Bilbiie, Challe-Matheron-Ragot-Rubio-Ramirez
   - micro-foundation of spender-saver behavior

2. **Bewley models with sticky prices**
   Oh-Reis, Guerrieri-Lorenzoni, Ravn-Sterk, Gornemann-Kuester-Nakajima, DenHaan-Rendal-Riegler,
   Bayer-Luetticke-Pham-Tjaden, McKay-Reis, McKay-Nakamura-Steinsson, Huo-RiosRull, Werning, Luetticke
   - assets with different liquidity Kaplan-Violante
   - new view of individual earnings risk Guvenen-Karahan-Ozkan-Song
   - **Continuous time approach** Achdou-Han-Lasry-Lions-Moll
Households

- Face uninsured idiosyncratic labor income risk
- Consume and supply labor
- Hold two assets: liquid and illiquid
- Budget constraints (simplified version)

\[
\begin{align*}
\dot{b}_t &= r^b b_t + w z_t \ell_t - c_t - d_t - \chi(d_t, a_t) \\
\dot{a}_t &= r^a a_t + d_t
\end{align*}
\]

- \( b_t \): liquid assets
- \( d_t \): illiquid deposits (\( \geq 0 \))
- \( a_t \): illiquid assets
- \( \chi \): transaction cost function

- In equilibrium: \( r^a > r^b \)
- Full model: borrowing/saving rate wedge, taxes/transfers
Kinked adjustment cost function $\chi(d, a)$
Remaining model ingredients

Illiquid assets: $a = k + qs$

- No arbitrage: $r^k - \delta = \frac{\Pi + \dot{q}}{q} := r^a$

Firms

- Monopolistic intermediate-good producers $\rightarrow$ final good
- Rent illiquid capital and labor services from $hh$
- Quadratic price adjustment costs à la Rotemberg (1982)

Government

- Issues liquid debt ($B^g$), spends ($G$), taxes and transfers ($T$)

Monetary Authority

- Sets nominal rate on liquid assets based on a Taylor rule
Summary of market clearing conditions

- Liquid asset market
  \[ B^h + B^g = 0 \]

- Illiquid asset market
  \[ A = K + q \]

- Labor market
  \[ N = \int z\ell(a, b, z) d\mu \]

- Goods market:
  \[ Y = C + I + G + \chi + \Theta + \text{borrowing costs} \]
Solution Method
Solution Method (from Achdou-Han-Lasry-Lions-Moll)

- Solving het. agent model = solving PDEs
  1. Hamilton-Jacobi-Bellman equation for individual choices
  2. Kolmogorov Forward equation for evolution of distribution

- Many well-developed methods for analyzing and solving these
  - simple but powerful: finite difference method
  - codes: http://www.princeton.edu/~moll/HACTproject.htm

- Apparatus is very general: applies to any heterogeneous agent model with continuum of atomistic agents
  1. heterogeneous households (Aiyagari, Bewley, Huggett,...)
  2. heterogeneous producers (Hopenhayn,...)

- can be extended to handle aggregate shocks (Krusell-Smith,...)
Computational Advantages relative to Discrete Time

1. **Borrowing constraints only show up in boundary conditions**
   - FOCs always hold with “=”

2. **“Tomorrow is today”**
   - FOCs are “static”, compute by hand: $c^{-\gamma} = V_b(a, b, y)$

3. **Sparsity**
   - solving Bellman, distribution = inverting matrix
   - but matrices very sparse (“tridiagonal”)
   - reason: continuous time $\Rightarrow$ one step left or one step right

4. **Two birds with one stone**
   - tight link between solving (HJB) and (KF) for distribution
   - matrix in discrete (KF) is **transpose** of matrix in discrete (HJB)
   - reason: diff. operator in (KF) is **adjoint** of operator in (HJB)
HA Models with Aggregate Shocks: A Matlab Toolbox

• Achdou et al & HANK: HA models with idiosyncratic shocks only

• **Aggregate shocks** ⇒ computational challenge much larger

• Companion project: efficient, easy-to-use computational method
  
  • see “When Inequality Matters for Macro and Macro Matters for Inequality” (with Ahn, Kaplan, Winberry and Wolf)

• open source Matlab toolbox online now – see my website and [https://github.com/gregkaplan/phact](https://github.com/gregkaplan/phact)

• extension of linearization (Campbell 1998, Reiter 2009)

• **different slopes** at each point in state space
Parameterization
Three key aspects of parameterization

1. Measurement and partition of asset categories into:
   - Liquid (cash, bank accounts + government/corporate bonds)
   - Illiquid (equity, housing)

2. Income process with leptokurtic income changes
   - Nature of earnings risk affects household portfolio

3. Adjustment cost function and discount rate
   - Match mean liquid/illiquid wealth and fraction HtM

   - Production side: standard calibration of NK models
   - Standard separable preferences: $u(c, \ell) = \log c - \frac{1}{2}\ell^2$
Model matches key feature of U.S. wealth distribution

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean illiquid assets</td>
<td>2.920</td>
<td>2.920</td>
</tr>
<tr>
<td>(rel to GDP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean liquid assets</td>
<td>0.260</td>
<td>0.263</td>
</tr>
<tr>
<td>(rel to GDP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor hand-to-mouth</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Wealthy hand-to-mouth</td>
<td>20%</td>
<td>19%</td>
</tr>
</tbody>
</table>
Model generates high and heterogeneous MPCs

- Average quarterly MPC out of a $500 windfall: 16%
Evidende on MPCs – Norwegian Lotteries

Figure 4: Heterogeneous consumption responses. Quartiles of liquid and net illiquid assets

Source: Fagereng, Holm and Natvik (2016)
Results
Transmission of monetary policy shock to $C$

Innovation $\epsilon < 0$ to the Taylor rule: \[ i = \bar{r}^b + \phi \pi + \epsilon \]

- All experiments: $\epsilon_0 = -0.0025$, i.e. $-1\%$ annualized
Transmission of monetary policy shock to $C$

\[ dC_0 = \left[ \int_0^\infty \frac{\partial C_0}{\partial r_t^b} dr_t^b dt \right]_{\text{direct}} + \left[ \int_0^\infty \left[ \frac{\partial C_0}{\partial r_t^a} dr_t^a + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt \right]_{\text{indirect}} \]
Transmission of monetary policy shock to $C$

$$dC_0 = \int_0^\infty \frac{\partial C_0}{\partial r^b_t} dr^b_t \, dt + \int_0^\infty \left[ \frac{\partial C_0}{\partial r^a_t} dr^a_t + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] \, dt$$

Intertemporal substitution and income effects from $r^b$ down.
Transmission of monetary policy shock to $C$

$$dC_0 = \int_0^\infty \frac{\partial C_0}{\partial r^b_t} dr^b_t dt + \int_0^\infty \left[ \frac{\partial C_0}{\partial r^a_t} dr^a_t + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt$$

Portfolio reallocation effect from $r^a - r^b \uparrow$
Transmission of monetary policy shock to $C$

\[ dC_0 = \int_0^\infty \partial C_0 \partial r_t^b dt + \int_0^\infty \left[ \partial C_0 \partial r_t^a dt + \partial C_0 \partial w_t dw_t + \partial C_0 \partial T_t dT_t \right] dt \]

✓

Labor demand channel from $w \uparrow$
Transmission of monetary policy shock to $C$

\[ dC_0 = \int_0^\infty \frac{\partial C_0}{\partial r^b_t} dr^b_t dt + \int_0^\infty \left[ \frac{\partial C_0}{\partial r^a_t} dr^a_t + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt \]

Fiscal adjustment: $T \uparrow$ in response to $\downarrow$ in interest payments on $B$
Transmission of monetary policy shock to $C$

\[
dC_0 = \int_0^\infty \frac{\partial C_0}{\partial r_b^t} dr_b^t dt + \int_0^\infty \left[ \frac{\partial C_0}{\partial r_a^t} dr_a^t + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt
\]

19%  

81%
Monetary transmission across liquid wealth distribution

- Total change = \( c \)-weighted sum of (direct + indirect) at each \( b \)
Why small direct effects?

- Intertemporal substitution: (+) for non-HtM
- Income effect: (-) for rich households
- Portfolio reallocation: (-) for those with low but > 0 liquid wealth
Role of fiscal response in determining total effect

<table>
<thead>
<tr>
<th></th>
<th>$T$ adjusts (1)</th>
<th>$G$ adjusts (2)</th>
<th>$B^g$ adjusts (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elasticity of $C_0$ to $r^b$</strong></td>
<td>-2.21</td>
<td>-2.07</td>
<td>-1.48</td>
</tr>
<tr>
<td>Share of Direct effects:</td>
<td>19%</td>
<td>22%</td>
<td>46%</td>
</tr>
</tbody>
</table>

• Fiscal response to lower interest payments on debt:
  
  • $T$ adjusts: stimulates AD through MPC of HtM households
  
  • $G$ adjusts: translates 1-1 into AD
  
  • $B^g$ adjusts: no initial stimulus to AD from fiscal side
When is $\text{HANK} \neq \text{RANK}$? Persistence

- **RANK:** $\frac{\dot{C}_t}{C_t} = \frac{1}{\gamma} (r_t - \rho) \Rightarrow C_0 = \tilde{C} \exp \left( -\frac{1}{\gamma} \int_0^{\infty} (r_s - \rho) \, ds \right)$

- Cumulative $r$-deviation $R_0 := \int_0^{\infty} (r_s - \rho) \, ds$ is sufficient statistic

- Persistence $\eta$ only matters insofar as it affects $R_0$

$$- \frac{d \log C_0}{dR_0} = \frac{1}{\gamma} = 1 \quad \text{for all } \eta$$
In Contrast, Inflation-Output Tradeoff same as in RANK

(a) Inflation-Output Gap  (b) Inflation-Marginal Cost  (c) Marginal Cost-Output
Comparison to One-Asset HANK Model

(d) Average MPC and Wealth-to-GDP Ratio
(e) Total and Direct Effects
Monetary transmission in RANK and HANK

\[ \Delta C = \text{direct response to } r + \text{indirect GE response} \]

- **RANK:** 95%
  - **RANK:** 5%
- **HANK:** 1/3
  - **HANK:** 2/3

- **RANK view:**
  - High sensitivity of \( C \) to \( r \): intertemporal substitution
  - Low sensitivity of \( C \) to \( Y \): the RA is a PIH consumer

- **HANK view:**
  - Low sensitivity to \( r \): income effect of wealthy offsets int. subst.
  - High sensitivity to \( Y \): sizable share of hand-to-mouth agents

\[ \Rightarrow \text{Q: Is Fed less in control of } C \text{ than we thought?} \]

- Work in progress: perturbation methods \( \Rightarrow \) estimation, inference
Illiquid return and monopoly profits

- Illiquid assets = part capital, part equity
  \[ a = k + qs \]
- \( k \): capital, pays return \( r - \delta \)
- \( s \): shares, price \( q \), pay dividends \( \omega \Pi = \omega (1 - m)Y \)

- Arbitrage:
  \[ \frac{\omega \Pi + \dot{q}}{q} = r - \delta := r^a \]

- Remaining \( (1 - \omega)\Pi \)? Scaled lump-sum transfer to hh’s:
  \[ \Gamma = (1 - \omega) \frac{Z}{Z} \Pi \]

- Set \( \omega = \alpha \Rightarrow \) neutralize asset redistribution from markups
  \[ \text{total illiquid flow} = rK + \omega \Pi = \alpha mY + \omega (1 - m)Y = \alpha Y \]
  \[ \text{total liquid flow} = wL + (1 - \omega)\Pi = (1 - \alpha)Y \]
Monetary Policy in Benchmark NK Models

Goal:
• Introduce *decomposition* of \( C \) response to \( r \) change

Setup:
• Prices and wages perfectly rigid \( = 1 \), GDP=labor \( = Y_t \)
• Households: CRRA(\( \gamma \)), income \( Y_t \), interest rate \( r_t \)

\[ \Rightarrow C_t(\{r_s, Y_s\}_{s \geq 0}) \]

• Monetary policy: sets time path \( \{r_t\}_{t \geq 0} \), special case

\[ r_t = \rho + e^{-\eta t}(r_0 - \rho), \quad \eta > 0 \] \( (\ast) \)

• Equilibrium: \( C_t(\{r_s, Y_s\}_{s \geq 0}) = Y_t \)

• Overall effect of monetary policy

\[ - \frac{d \log C_0}{dr_0} = \frac{1}{\gamma \eta} \]
Monetary Policy in RANK

• Decompose $C$ response by totally differentiating $C_0(\{r_t, Y_t\}_{t \geq 0})$

$$dC_0 = \int_0^\infty \frac{\partial C_0}{\partial r_t} dr_t dt + \int_0^\infty \frac{\partial C_0}{\partial Y_t} dY_t dt.$$  

  direct response to $r$  indirect effects due to $Y$

• In special case (*)

$$- \frac{d \log C_0}{dr_0} = \frac{1}{\gamma \eta} \left[ \frac{\eta}{\rho + \eta} + \frac{\rho}{\rho + \eta} \right].$$  

direct response to $r$  indirect effects due to $Y$

• Reasonable parameterizations $\Rightarrow$ very small indirect effects, e.g.
  
  • $\rho = 0.5\%$ quarterly
  • $\eta = 0.5$, i.e. quarterly autocorr $e^{-\eta} = 0.61$

  $$\Rightarrow \frac{\eta}{\rho + \eta} = 99\%, \quad \frac{\rho}{\rho + \eta} = 1\%.$$
What if some households are hand-to-mouth?

• “Spender-saver” or Two-Agent New Keynesian (TANK) model

• Fraction $\Lambda$ are HtM “spenders”: $C^s_t = Y_t$

• Decomposition in special case (*)

\[- \frac{d \log C_0}{d r_0} = \frac{1}{\gamma \eta} \left[ (1 - \Lambda) \frac{\eta}{\rho + \eta} + (1 - \Lambda) \frac{\rho}{\rho + \eta} + \Lambda \right].\]

• $\Rightarrow$ indirect effects $\approx \Lambda = 20\text{-}30\%$
What if there are assets in positive supply?

- Govt issues debt $B$ to households sector

- Fall in $r_t$ implies a fall in interest payments of $(r_t - \rho) B$

- Fraction $\lambda^T$ of income gains transferred to spenders

- Initial consumption response in special case (*)

$$- \frac{d \log C_0}{d r_0} = \frac{1}{\gamma \eta} + \frac{\lambda^T B}{1 - \lambda \bar{Y}}$$

  **fiscal redistribution channel**

- Interaction between non-Ricardian households and debt in positive net supply matters for overall effect of monetary policy
### Fifty shades of $K$

<table>
<thead>
<tr>
<th>Non-productive</th>
<th>Liquid</th>
<th>Illiquid</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household deposits net of revolving debt Corp &amp; Govt bonds $B^h = 0.26$</td>
<td>0.6× net housing 0.6× net durables $\omega A = 0.79$</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Productive</td>
<td>Indirectly held equity  Directly held equity Noncorp bus equity 0.4× housing, durables $(1 - \omega)A = 2.13$</td>
<td>2.13 $K$</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$-B^g = 0.26$</td>
<td>$A = 2.92$</td>
<td>3.18</td>
</tr>
</tbody>
</table>

- Quantities are multiples of annual GDP
- Sources: Flow of Funds and SCF 2004
Leptokurtic earnings changes (Guvenen et al.)

**Key idea:** normally distributed jumps = kurtosis at discrete time intervals

<table>
<thead>
<tr>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance: annual log earns</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Variance: 1yr change</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>Variance: 5yr change</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>Kurtosis: 1yr change</td>
<td>17.8</td>
<td>16.5</td>
</tr>
<tr>
<td>Kurtosis: 5yr change</td>
<td>11.6</td>
<td>12.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance: 1yr change</td>
<td>0.71</td>
<td>0.67</td>
</tr>
<tr>
<td>Frac 1yr change &lt; 20%</td>
<td>0.71</td>
<td>0.67</td>
</tr>
<tr>
<td>Variance: 5yr change</td>
<td>0.86</td>
<td>0.85</td>
</tr>
<tr>
<td>Frac 1yr change &lt; 50%</td>
<td>0.86</td>
<td>0.85</td>
</tr>
<tr>
<td>Description</td>
<td>Value</td>
<td>Target / Source</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Preferences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda$ Death rate</td>
<td>1/180</td>
<td>Av. lifespan 45 years</td>
</tr>
<tr>
<td>$\gamma$ Risk aversion</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>$\varphi$ Frisch elasticity (GHH)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>$\rho$ Discount rate (pa)</td>
<td>4.8%</td>
<td>Internally calibrated</td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\epsilon$ Demand elasticity</td>
<td>10</td>
<td>Profit share 10 %</td>
</tr>
<tr>
<td>$\alpha$ Capital share</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>$\delta$ Depreciation rate (p.a.)</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>$\theta$ Price adjustment cost</td>
<td>100</td>
<td>Slope of Phillips curve, $\epsilon/\theta = 0.1$</td>
</tr>
<tr>
<td><strong>Government</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau$ Proportional labor tax</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>$T$ Lump sum transfer (rel GDP)</td>
<td>$6,900</td>
<td>6% of GDP</td>
</tr>
<tr>
<td>$\bar{g}$ Govt debt to annual GDP</td>
<td>0.233</td>
<td>government budget constraint</td>
</tr>
<tr>
<td><strong>Monetary Policy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi$ Taylor rule coefficient</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>$r^b$ Steady state real liquid return (pa)</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td><strong>Illiquid Assets</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r^a$ Illiquid asset return (pa)</td>
<td>5.7%</td>
<td>Equilibrium outcome</td>
</tr>
<tr>
<td><strong>Borrowing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r^{borr}$ Borrowing rate (pa)</td>
<td>7.9%</td>
<td>Internally calibrated</td>
</tr>
<tr>
<td>$b$ Borrowing limit</td>
<td>$16,500</td>
<td>$\approx 1 \times$ quarterly labor inc</td>
</tr>
<tr>
<td><strong>Adjustment Cost Function</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\chi_0$ Linear term</td>
<td>0.04383</td>
<td>Internally calibrated</td>
</tr>
<tr>
<td>$\chi_1$ Coef on convex term</td>
<td>0.95617</td>
<td>Internally calibrated</td>
</tr>
<tr>
<td>$\chi_2$ Power on convex term</td>
<td>1.40176</td>
<td>Internally calibrated</td>
</tr>
<tr>
<td>$\bar{a}$ Min $a$ in denominator</td>
<td>$360$</td>
<td>Internally calibrated</td>
</tr>
</tbody>
</table>