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

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- 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

$$C \text{ response} = \underbrace{\text{direct response to } r}_{>95\%} + \underbrace{\text{indirect effects due to } Y}_{<5\%}$$

- Direct response is everything, pure intertemporal substitution

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- 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

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- Once matched to micro data, HANK delivers realistic:
  - Wealth distribution: small direct effect
  - MPC distribution: large indirect effect (depending on ΔY)

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HANK: <1/3	HANK: >2/3

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

Outline

1. Model

2. Parameterization

3. Results

4. Additional Material
   - Literature
   - Detailed Model Description
   - Simple Model
   - Solution Method
   - Balance Sheet Details
   - Earnings Dynamics
   - Parameter Table
   - Empirical Evidence

Households

- Face uninsured idiosyncratic labor income risk
- Consume and supply labor
- Hold two assets: liquid and illiquid

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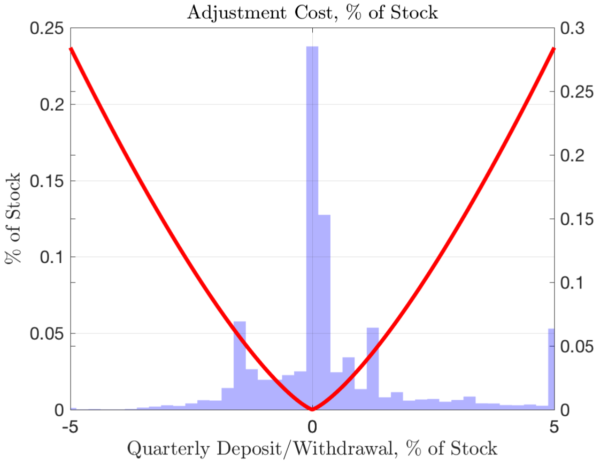
- Hold two assets: liquid and illiquid
- Budget constraints (simplified version)

$$\dot{b}_t = r^b b_t + w z_t \ell_t - c_t - d_t - \chi(d_t, a_t)$$
$$\dot{a}_t = r^a a_t + d_t$$

  - b_t: liquid assets
  - d_t: illiquid deposits ($\gtrless 0$)
  - a_t: illiquid assets
  - χ: transaction cost function

- In equilibrium: $r^a > r^b$
- Full model: borrowing/saving rate wedge, taxes/transfers

Kinked adjustment cost function $\chi(d, a)$



$$\chi(d, a) = \chi_0 |d| + \chi_1 \left| \frac{d}{a} \right|^{\chi_2} a$$

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 capital and labor services
- 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:

$$Y = C + I + G + \chi + \Theta + \text{borrowing costs}$$

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Three key aspects of parameterization

1. Measurement and partition of asset categories into: ▸ 50 shades of K
    - Liquid (cash, bank accounts + government/corporate bonds)
    - Illiquid (equity, housing)

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

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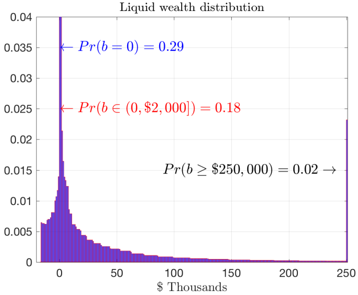
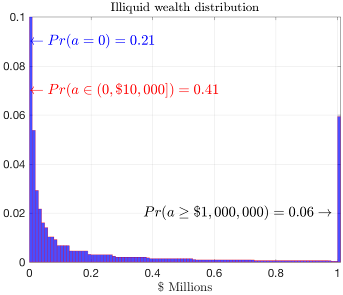
- Production side: standard calibration of NK models
- Separable preferences: $u(c, \ell) = \log c - \frac{1}{2}\ell^2$

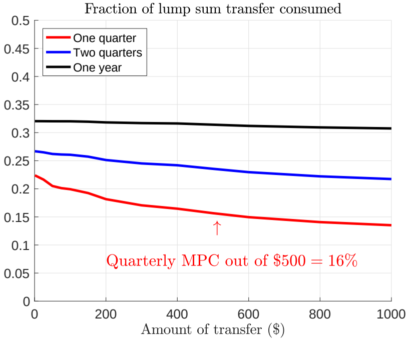
Model matches key feature of U.S. wealth distribution

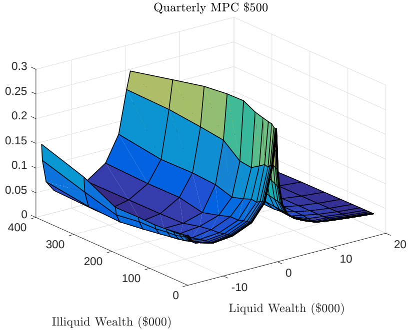




	Data	Model
Mean illiquid assets (rel to GDP)	2.920	2.920
Mean liquid assets (rel to GDP)	0.260	0.263
Poor hand-to-mouth	10%	10%
Wealthy hand-to-mouth	20%	19%
Fraction borrowing	15%	15%

Model generates high and heterogeneous MPCs





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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

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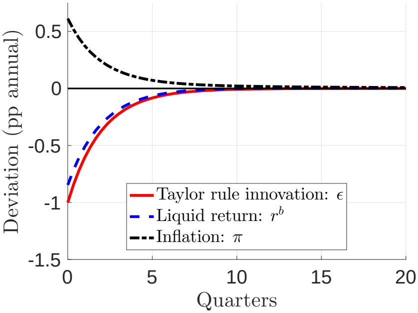

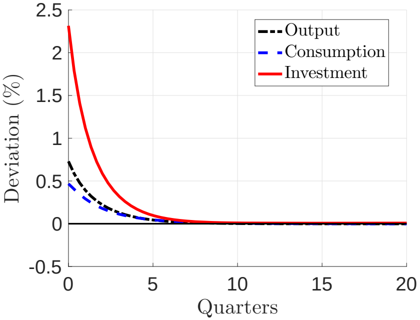

Transmission of monetary policy shock to C

$$dC_0 = \underbrace{\int_0^\infty \frac{\partial C_0}{\partial r_t^b} dr_t^b dt}_{\text{direct}} + \underbrace{\int_0^\infty \left[\frac{\partial C_0}{\partial r_t^a} dr_t^a + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt}_{\text{indirect}}$$

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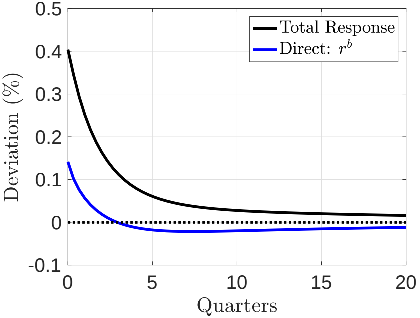
✓

Intertemporal substitution and income effects from $r^b \downarrow$



Kaplan, Moll and Violante (2017)

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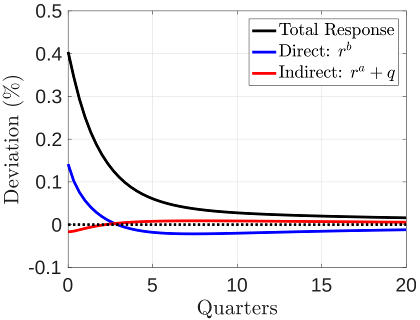
✓

Portfolio reallocation effect from $r^a - r^b \uparrow$



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Kaplan, Moll and Violante (2017)

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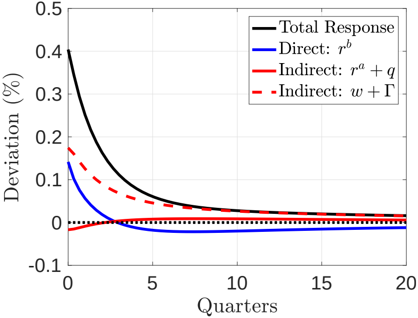
$$\checkmark$$

Labor demand channel from $w \uparrow$



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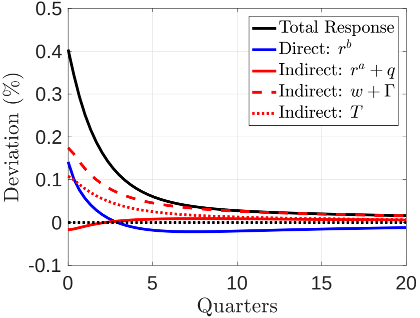
✓

Fiscal adjustment: $T \uparrow$ in response to $\downarrow$ in interest payments on B



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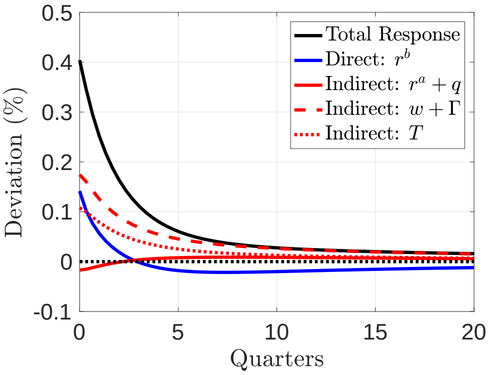
Transmission of monetary policy shock to C

$$dC_0 = \underbrace{\int_0^\infty \frac{\partial C_0}{\partial r_t^b} dr_t^b dt}_{19\%} + \underbrace{\int_0^\infty \left[\frac{\partial C_0}{\partial r_t^a} dr_t^a + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt}_{81\%}$$



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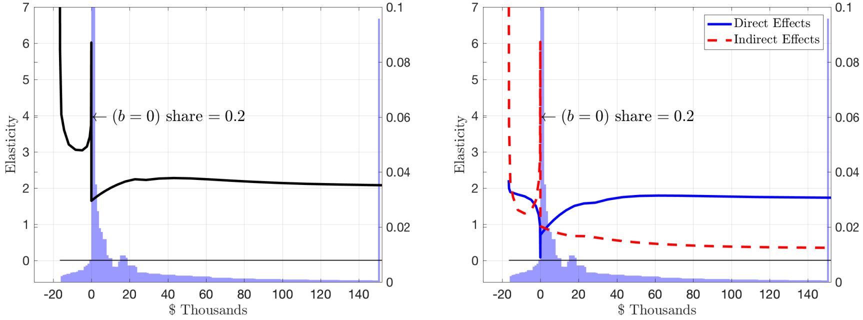
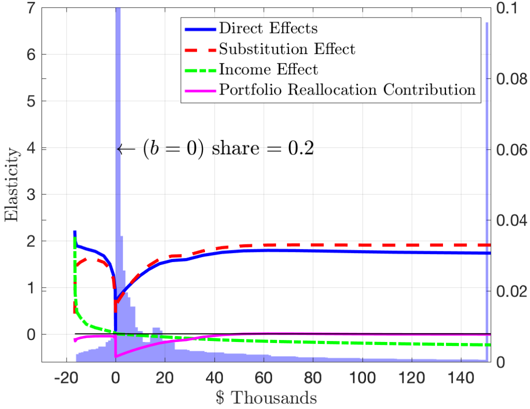
Monetary transmission across liquid wealth distribution



- Total change = c-weighted sum at each liquid wealth level b

Why small direct effects?



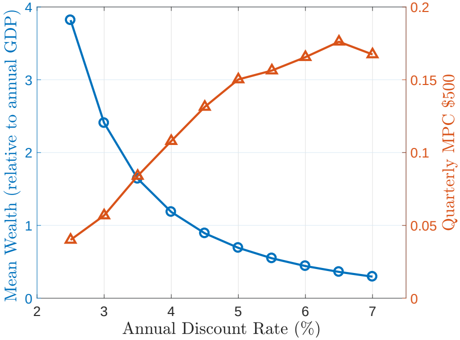
- Income effect: (-) for rich households
- Intertemporal substitution: (+) for non-HtM
- Portfolio reallocation: (-) for those with low but $>$ 0 liquid wealth

Fiscal response important for total effect

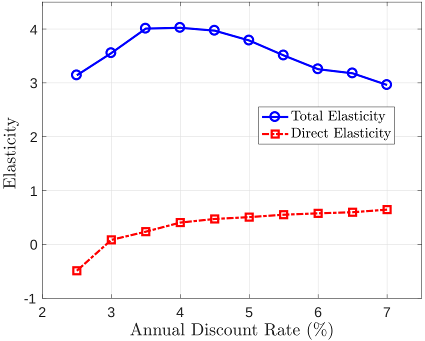
	T adjusts (1)	G adjusts (2)	B^g adjusts (3)
Elasticity of Y_0 to r^b	-3.96	-7.74	-2.17
Elasticity of C_0 to r^b	-2.93	-2.80	-1.68
Share of Direct effects:	19%	21%	42%

- 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

Comparison to one-asset HANK model



(a) Average MPC and Wealth-to-GDP Ratio



(b) Total and Direct Effects

When is HANK $\neq$ RANK? Persistence

- RANK: $\frac{\dot{C}_t}{C_t} = \frac{1}{\gamma}(r_t - \rho) \Rightarrow C_0 = \bar{C} \exp\left(-\frac{1}{\gamma}\int_0^\infty (r_s - \rho) ds\right)$
- Cumulative r-deviation $R_0 := \int_0^\infty (r_s - \rho) ds$ is sufficient statistic
- Persistence η only matters insofar as it affects R_0

$$-\frac{d \log C_0}{d R_0} = \frac{1}{\gamma} = 1 \quad \textbf{for all } \eta$$

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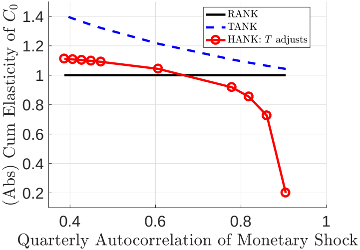
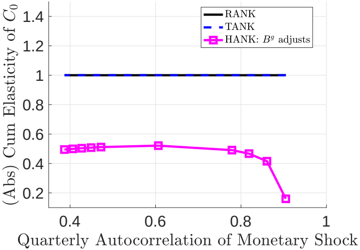
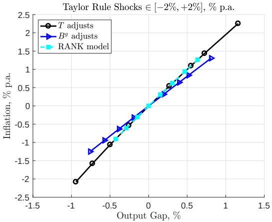
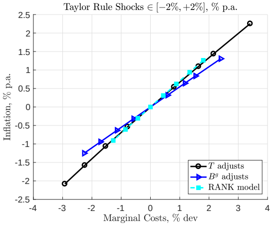




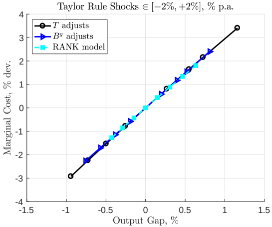
Inflation-output tradeoff same as in RANK



(c) Inflation-Output Gap



(d) Inflation-Marginal Cost



(e) Marginal Cost-Output

Monetary transmission in RANK and HANK

ΔC =	direct response to r	+	indirect GE response
	RANK: 95%		RANK: 5%
	HANK: 1/3		HANK: 2/3

Monetary transmission in RANK and HANK

$$\Delta C \;=\; \text{direct response to } r \;+\; \text{indirect GE response}$$

	direct response to r	indirect GE response
RANK	95%	5%
HANK	1/3	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

$\Rightarrow$ **Q:** Is Fed less in control of C than we thought?

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Literature and contribution

Combine two workhorses of modern macroeconomics:

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

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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

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Households

$$\max_{\{c_t,\ell_t,d_t\}_{t\geq 0}} \mathbb{E}_0 \int_0^\infty e^{-(\rho+\lambda)t} u(c_t,\ell_t)dt \quad \text{s.t.}$$

$$\begin{aligned}
\dot{b}_t &= r^b(b_t)b_t + wz_t\ell_t - d_t - \chi(d_t,a_t) - c_t - \tilde{T}(wz_t\ell_t + \Gamma) + \Gamma \\
\dot{a}_t &= r^a a_t + d_t \\
z_t &= \text{ some Markov process} \\
b_t &\geq -\underline{b}, \quad a_t \geq 0
\end{aligned}$$

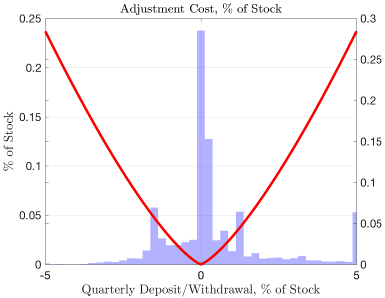
- c_t: non-durable consumption
- b_t: liquid assets
- z_t: individual productivity
- ℓ_t: hours worked
- a_t: illiquid assets
- d_t: illiquid deposits ($\gtrless 0$)
- χ: transaction cost function
- $\tilde{T}$: income tax/transfer
- Γ: income from firm ownership
- no housing – see working paper

Households

- Adjustment cost function

$$\chi(d, a) = \chi_0 |d| + \chi_1 \left| \frac{d}{\max\{a, \underline{a}\}} \right|^{\chi_2} \max\{a, \underline{a}\}$$

- Linear component implies inaction region
- Convex component implies finite deposit rates



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- Adjustment cost function

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- Linear component implies inaction region
- Convex component implies finite deposit rates

- Recursive solution of hh problem consists of:
  1. consumption policy function $c(a, b, z; w, r^a, r^b)$
  2. deposit policy function $d(a, b, z; w, r^a, r^b)$
  3. labor supply policy function $\ell(a, b, z; w, r^a, r^b)$

  $\Rightarrow$ joint distribution of households $\mu(da, db, dz; w, r^a, r^b)$

Firms

Representative competitive final goods producer:

$$Y = \left(\int_0^1 y_j^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \Rightarrow \quad y_j = \left(\frac{p_j}{P} \right)^{-\varepsilon} Y$$

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Monopolistically competitive intermediate goods producers:

- Technology: $y_j = Z k_j^\alpha n_j^{1-\alpha} \quad \Rightarrow \quad m = \frac{1}{Z}\left(\frac{r}{\alpha}\right)^\alpha \left(\frac{w}{1-\alpha}\right)^{1-\alpha}$
- Set prices subject to quadratic adjustment costs:

$$\Theta\left(\frac{\dot{p}}{p}\right) = \frac{\theta}{2}\left(\frac{\dot{p}}{p}\right)^2 Y$$

Firms

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Exact NK Phillips curve:

$$\left(r^a - \frac{\dot{Y}}{Y}\right)\pi = \frac{\varepsilon}{\theta}(m - \bar{m}) + \dot{\pi}, \quad \bar{m} = \frac{\varepsilon-1}{\varepsilon}$$

Intermediate good firm pricing problem

$$\max_{\{p_t\}_{t\geq 0}} \int_0^\infty e^{-r^a t} \left\{ \Pi_t(p_t) - \Theta_t\left(\frac{\dot{p}_t}{p_t}\right) \right\} dt \quad \text{s.t.}$$

$$\Pi(p) = \left(\frac{p}{P} - m\right)\left(\frac{p}{P}\right)^{-\varepsilon} Y$$

$$m = \frac{1}{Z}\left(\frac{r}{\alpha}\right)^{\alpha}\left(\frac{w}{1-\alpha}\right)^{1-\alpha}$$

$$\Theta(\pi) = \frac{\theta}{2}\pi^2 Y$$

Back to firms

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 $\omega\Pi = \omega(1 - m)Y$

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$$\text{total illiquid flow} = rK + \omega\Pi = \alpha mY + \omega(1-m)Y = \alpha Y$$

$$\text{total liquid flow} = wL + (1-\omega)\Pi = (1-\alpha)Y$$

Monetary authority and government

- Taylor rule
$$i = \bar{r}^b + \phi\pi + \epsilon, \quad \phi > 1$$
with $r^b := i - \pi$ (Fisher equation), $\epsilon =$ innovation ("MIT shock")

- Progressive tax on labor income:
$$\tilde{T}(wz\ell + \Gamma) = -T + \tau(wz\ell + \Gamma)$$

- Government budget constraint (in steady state)
$$G - r^b B^g = \int \tilde{T} d\mu$$

- Transition? Ricardian equivalence fails $\Rightarrow$ this matters!

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:

$$Y = C + I + G + \chi + \Theta + \text{borrowing costs}$$

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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(γ), income Y_t, interest rate r_t

$$\Rightarrow \quad C_t(\{r_s, Y_s\}_{s\geq 0})$$

- Monetary policy: sets time path $\{r_t\}_{t\geq 0}$, special case

$$r_t = \rho + e^{-\eta t}(r_0 - \rho), \quad \eta > 0 \qquad (*)$$

- Equilibrium: $C_t(\{r_s, Y_s\}_{s\geq 0}) = Y_t$
- Overall effect of monetary policy

$$-\frac{d \log C_0}{d r_0} = \frac{1}{\gamma\eta}$$

Monetary Policy in RANK

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

$$dC_0 = \underbrace{\int_0^\infty \frac{\partial C_0}{\partial r_t} dr_t dt}_{\text{direct response to } r} + \underbrace{\int_0^\infty \frac{\partial C_0}{\partial Y_t} dY_t dt}_{\text{indirect effects due to } Y}.$$

- In special case (∗)

$$-\frac{d \log C_0}{dr_0} = \frac{1}{\gamma\eta}\left[\underbrace{\frac{\eta}{\rho+\eta}}_{\text{direct response to } r} + \underbrace{\frac{\rho}{\rho+\eta}}_{\text{indirect effects due to } Y}\right].$$

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

$$\Rightarrow \quad \frac{\eta}{\rho+\eta} = 99\%, \qquad \frac{\rho}{\rho+\eta} = 1\%$$

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Kaplan, Moll and Violante (2017)

What if some households are hand-to-mouth?

- "Spender-saver" or Two-Agent New Keynesian (TANK) model
- Fraction Λ are HtM "spenders": $C_t^{sp} = Y_t$
- Decomposition in special case $(*)$

$$-\frac{d\log C_0}{dr_0} = \frac{1}{\gamma\eta}\left[\underbrace{(1-\Lambda)\frac{\eta}{\rho+\eta}}_{\text{direct response to } r} + \underbrace{(1-\Lambda)\frac{\rho}{\rho+\eta} + \Lambda}_{\text{indirect effects due to } Y}\right].$$

- $\Rightarrow$ indirect effects $\approx \Lambda =$ 20-30%

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Kaplan, Moll and Violante (2017)

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 λ^T of income gains transferred to spenders
- Initial consumption restponse in special case $(*)$

$$-\frac{d \log C_0}{d r_0} = \frac{1}{\gamma\eta} + \underbrace{\frac{\lambda^T}{1-\lambda} \frac{B}{\bar{Y}}}_{\text{fiscal redistribution channel}} .$$

- Interaction between non-Ricardian households and debt in positive net supply matters for overall effect of monetary policy

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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 $\Rightarrow$ 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`
  - extension of linearization (Campbell 1998, Reiter 2009)
  - different slopes at each point in state space

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Fifty shades of K

	Liquid	Illiquid	Total
Non-productive	Household deposits net of revolving debt Corp & Govt bonds $B^h = 0.26$		0.26
Productive		Indirectly held equity Directly held equity Noncorp bus equity Net housing Net durables	2.92 K
Total	$-B^g = 0.26$	$A = 2.92$	3.18

- Quantities are multiples of annual GDP
- Sources: Flow of Funds and SCF 2004
- Working paper: part of housing, durables = unproductive illiquid assets

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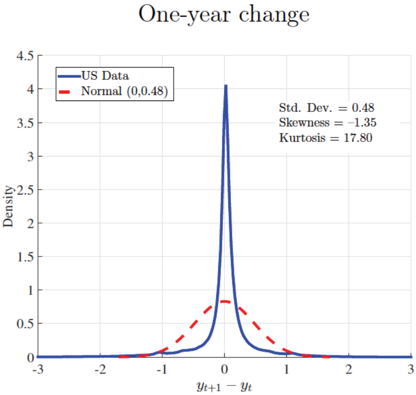
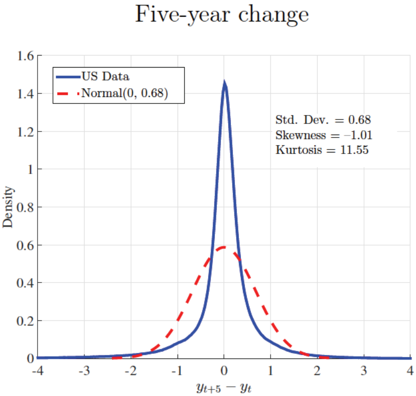
Continuous time earnings dynamics

- Literature provides little guidance on statistical models of high frequency earnings dynamics
- Key challenge: inferring within-year dynamics from annual data
- Higher order moments of annual changes are informative
- Target key moments of one 1-year and 5-year labor earnings growth from SSA data
- Model generates a thick right tail for earnings levels

Leptokurtic earnings changes





Kaplan, Moll and Violante (2017)

Two-component jump-drift process

- Flow earnings ($y = wzl$) modeled as sum of two components:

$$\log y_t = y_{1t} + y_{2t}$$

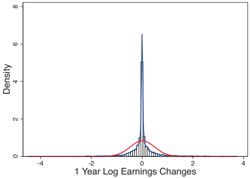
- Each component is a jump-drift with:
  - mean-reverting drift: $-\beta y_{it} dt$
  - jumps with arrival rate: λ_i, drawn from $\mathcal{N}(0, \sigma_i)$
- Estimate using SMM aggregated to annual frequency
- Choose six parameters to match eight moments:

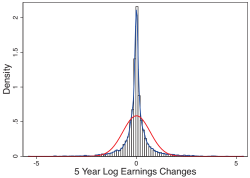
Model distribution of earnings changes

Moment	Data	Model	Moment	Data	Model
Variance: annual log earns	0.70	0.70	Frac 1yr change $< 10\%$	0.54	0.56
Variance: 1yr change	0.23	0.23	Frac 1yr change $< 20\%$	0.71	0.67
Variance: 5yr change	0.46	0.46	Frac 1yr change $< 50\%$	0.86	0.85
Kurtosis: 1yr change	17.8	16.5			
Kurtosis: 5yr change	11.6	12.1			

Transitory component: $\hat{\lambda}_1 = 0.08, \quad \hat{\beta}_1 = 0.76, \quad \hat{\sigma}_1 = 1.74$

Persistent component: $\hat{\lambda}_2 = 0.007, \quad \hat{\beta}_2 = 0.009, \quad \hat{\sigma}_2 = 1.53$





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Description		Value	Target / Source
Preferences			
λ	Death rate	1/180	Av. lifespan 45 years
γ	Risk aversion	1	
φ	Frisch elasticity (GHH)	1	
ψ	Disutility of labor		Av. hours worked equal to 1/3
ρ	Discount rate (pa)	5.1%	Internally calibrated
Production			
ε	Demand elasticity	10	Profit share 10 %
α	Capital share	0.33	
δ	Depreciation rate (p.a.)	7%	
θ	Price adjustment cost	100	Slope of Phillips curve, $\varepsilon/\theta = 0.1$
Government			
τ	Proportional labor tax	0.30	
T	Lump sum transfer (rel GDP)	\$6,900	6% of GDP
$\bar{g}$	Govt debt to annual GDP	0.233	government budget constraint
Monetary Policy			
ϕ	Taylor rule coefficient	1.25	
r^b	Steady state real liquid return (pa)	2%	
Illiquid Assets			
r^a	Illiquid asset return (pa)	5.7%	Equilibrium outcome
Borrowing			
r^{borr}	Borrowing rate (pa)	8.0%	Internally calibrated
$\underline{b}$	Borrowing limit	\$16,500	$\approx 1\times$ quarterly labor inc
Adjustment Cost Function			
χ_0	Linear term	0.04383	Internally calibrated
χ_1	Coef on convex term	0.95617	Internally calibrated
χ_2	Power on convex term	1.40176	Internally calibrated

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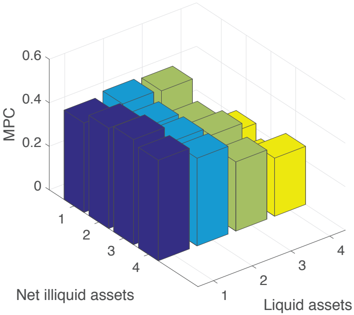
Evidence on MPCs from Norwegian lotteries

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



Source: Fagereng, Holm and Natvik (2016)