# 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

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

- 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 $\Delta Y$)

$$C \text{ response} = \underbrace{\text{direct response to } r}_{} + \underbrace{\text{indirect effects due to } Y}_{}$$

| | direct response to $r$ | indirect effects due to $Y$ |
|---|---|---|
| RANK | >95% | <5% |
| HANK | <1/3 | >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

# HANK: a framework for monetary policy analysis

## Households

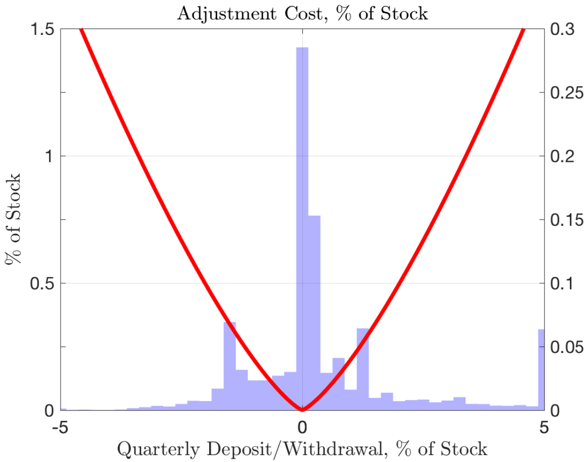
- Face uninsured idiosyncratic labor income risk
- Consume and supply labor
- Hold two assets: liquid and illiquid
- Budget constraints (simplified version)

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

- $b_t$: liquid assets
- $d_t$: illiquid deposits ($\gtrless 0$)
- $a_t$: illiquid assets
- $\chi$: 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 $\Rightarrow$ 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

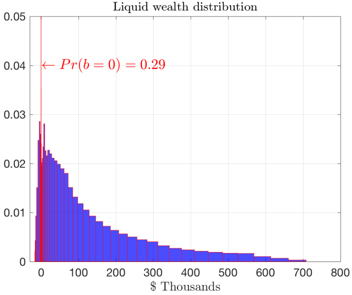
# Parameterization

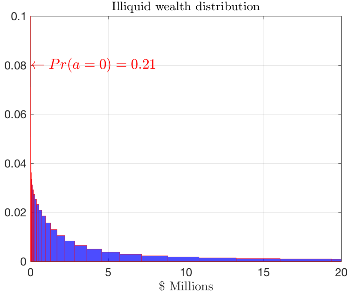
# Three key aspects of parameterization

1. Measurement and partition of asset categories into: ▸ 50 shades of K
    - Liquid (cash, bank accounts + government/corporate bonds)
    - Illiquid (equity, housing)
2. Income process with leptokurtic income changes ▸ income process
    - Nature of earnings risk affects household portfolio
3. Adjustment cost function and discount rate ▸ adj cost function
    - Match mean liquid/illiquid wealth and fraction HtM

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

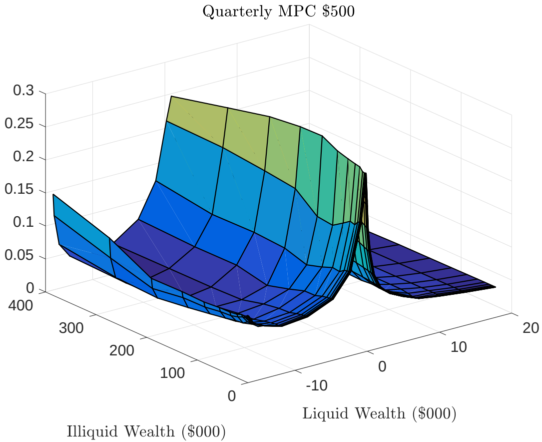
# Model matches key feature of U.S. wealth distribution




| | 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% |

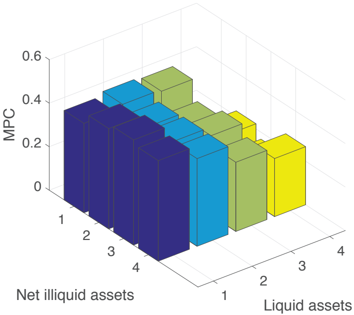
# Model generates high and heterogeneous MPCs




- 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



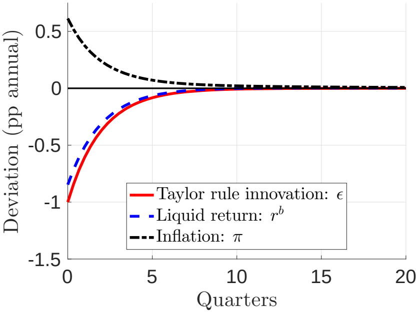

Source: Fagereng, Holm and Natvik (2016)

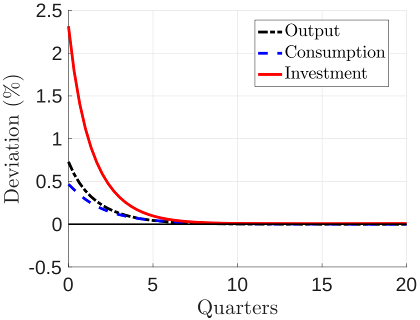
# Results

# 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 $C$

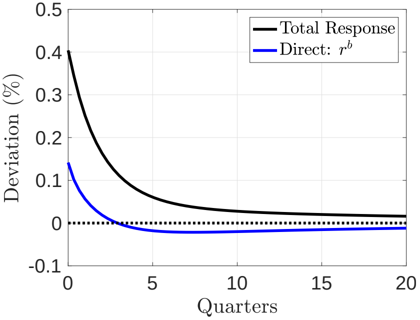
$$dC_0 = \underbrace{\int_0^\infty \frac{\partial C_0}{\partial r_t^b} dr_t^b dt}_{\text{direct}} + \underbrace{\int_0^\infty \left[ \frac{\partial C_0}{\partial r_t^a} dr_t^a + \frac{\partial C_0}{\partial w_t} dw_t + \frac{\partial C_0}{\partial T_t} dT_t \right] dt}_{\text{indirect}}$$

# Transmission of monetary policy shock to $C$

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

✓

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

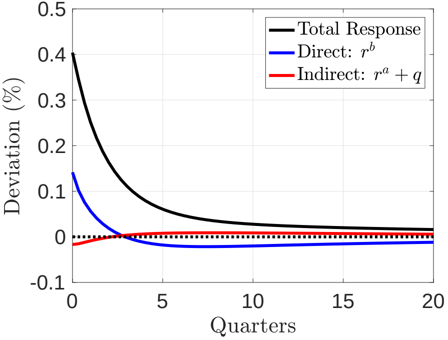


# Transmission of monetary policy shock to $C$

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

✓

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

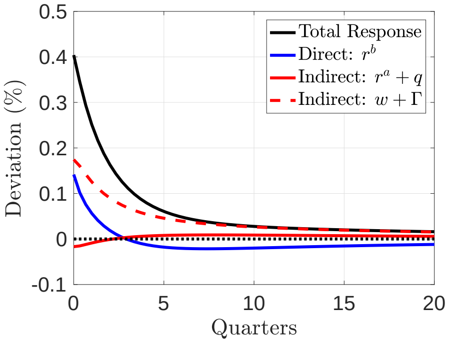


# Transmission of monetary policy shock to $C$

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

✓

Labor demand channel from $w \uparrow$

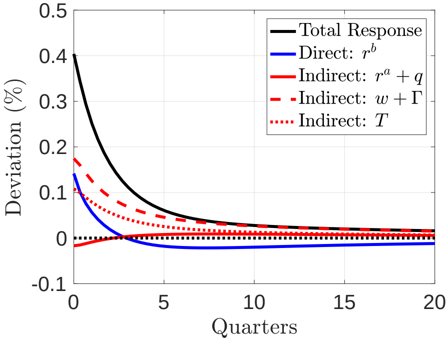


# Transmission of monetary policy shock to $C$

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

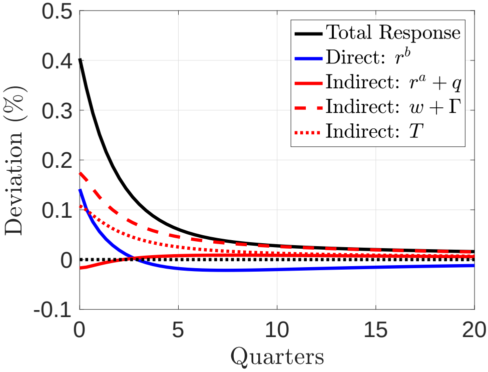
✓

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

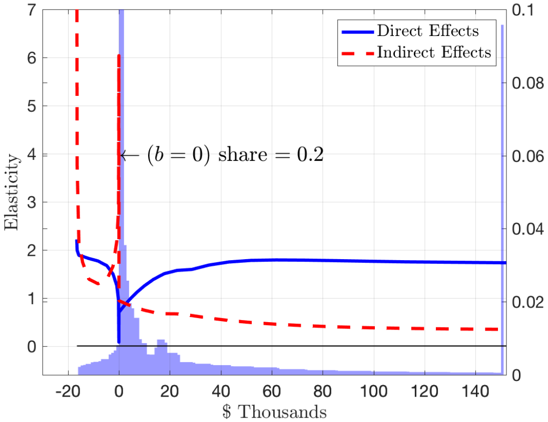


# Transmission of monetary policy shock to $C$

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

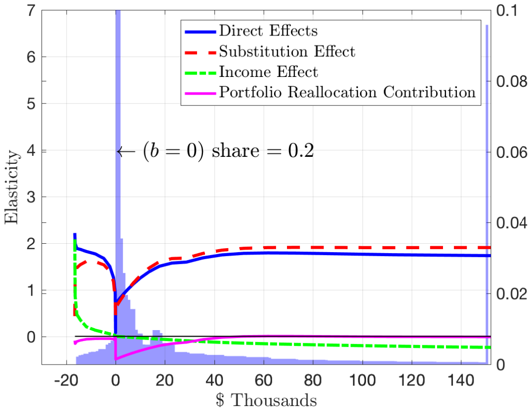


# Monetary transmission across liquid wealth distribution




- 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

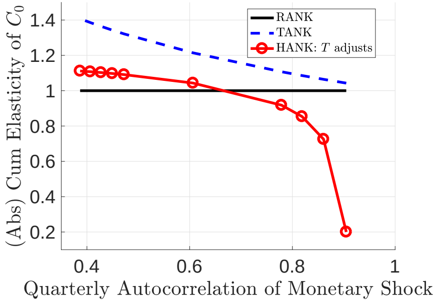
| | $T$ adjusts (1) | $G$ adjusts (2) | $B^g$ adjusts (3) |
|---|---|---|---|
| **Elasticity of $C_0$ to $r^b$** | -2.21 | -2.07 | -1.48 |
| Share of Direct effects: | 19% | 22% | 46% |

- 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

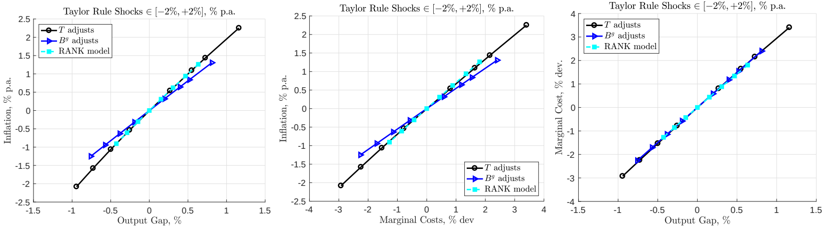
# When is HANK $\neq$ RANK? Persistence

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

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

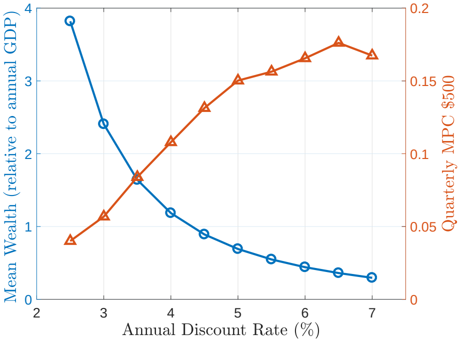


# In Contrast, Inflation-Output Tradeoff same as in RANK

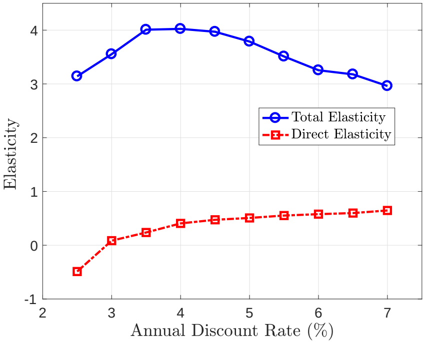



(a) Inflation-Output Gap (b) Inflation-Marginal Cost (c) Marginal Cost-Output

# 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

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

| | 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?
- 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:

$$\Gamma = (1-\omega)\frac{z}{\bar{z}}\Pi$$

- Set $\omega = \alpha \Rightarrow$ neutralize asset redistribution from markups

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

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

# 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 $r_t$

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

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

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

# What if some households are hand-to-mouth?

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

$$-\frac{d \log C_0}{d r_0} = \frac{1}{\gamma\eta} \Bigg[ \underbrace{(1-\Lambda)\frac{\eta}{\rho+\eta}}_{\text{direct response to } r} + \underbrace{(1-\Lambda)\frac{\rho}{\rho+\eta} + \Lambda}_{\text{indirect effects due to } Y} \Bigg].$$

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

# 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 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

# Fifty shades of K

| | Liquid | Illiquid | Total |
|---|---|---|---|
| Non-productive | Household deposits<br>net of revolving debt<br>Corp & Govt bonds<br>$B^h = 0.26$ | $0.6\times$ net housing<br>$0.6\times$ net durables<br>$\omega A = 0.79$ | 1.05 |
| Productive | | Indirectly held equity<br>Directly held equity<br>Noncorp bus equity<br>$0.4\times$ housing, durables<br>$(1-\omega)A = 2.13$ | 2.13<br>$K$ |
| Total | $-B^g = 0.26$ | $A = 2.92$ | 3.18 |

- Quantities are multiples of annual GDP
- Sources: Flow of Funds and SCF 2004

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# Leptokurtic earnings changes (Guvenen et al.)

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

| 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 | | | |

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| | Description | Value | Target / Source |
|---|---|---|---|
| Preferences | | | |
| $\lambda$ | Death rate | 1/180 | Av. lifespan 45 years |
| $\gamma$ | Risk aversion | 1 | |
| $\varphi$ | Frisch elasticity (GHH) | 1 | |
| $\rho$ | Discount rate (pa) | 4.8% | Internally calibrated |
| Production | | | |
| $\varepsilon$ | Demand elasticity | 10 | Profit share 10 % |
| $\alpha$ | Capital share | 0.33 | |
| $\delta$ | Depreciation rate (p.a.) | 7% | |
| $\theta$ | Price adjustment cost | 100 | Slope of Phillips curve, $\varepsilon/\theta = 0.1$ |
| Government | | | |
| $\tau$ | Proportional labor tax | 0.25 | |
| $T$ | Lump sum transfer (rel GDP) | \$6,900 | 6% of GDP |
| $\bar{g}$ | Govt debt to annual GDP | 0.233 | government budget constraint |
| Monetary Policy | | | |
| $\phi$ | 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) | 7.9% | Internally calibrated |
| $\underline{b}$ | Borrowing limit | \$16,500 | $\approx 1\times$ quarterly labor inc |
| Adjustment Cost Function | | | |
| $\chi_0$ | Linear term | 0.04383 | Internally calibrated |
| $\chi_1$ | Coef on convex term | 0.95617 | Internally calibrated |
| $\chi_2$ | Power on convex term | 1.40176 | Internally calibrated |
| $\bar{a}$ | Min $a$ in denominator | \$360 | Internally calibrated |