Sticky Expectations and Consumption Dynamics

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Consumption Dynamics: Macro vs Micro

Macro: Representative Agent Models

- Theory (With Separable Utility):
  - C responds instantly, completely to shock
  - Consequences of uncertainty are trivial
- Evidence: Consumption is too smooth (Campbell & Deaton, 1989)
- Solution: **"Habits" parameter** $\chi^{\textbf{Macro}} \approx 0.6\text{–}0.8$

$$\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \epsilon$$

Micro: Heterogeneous Agent Models

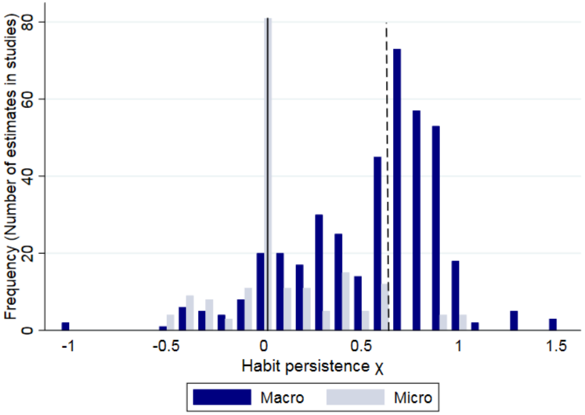
- **Uninsurable risk is essential, changes everything**
- Var of micro income shocks much larger than of macro shocks:

$$\text{var}(\Delta \log \mathbf{p}) \approx 100 \times \text{var}(\Delta \log \mathbf{P})$$

- Evidence: **"Habits" parameter** $\chi^{\textbf{Micro}} \approx 0.0\text{–}0.1$

Persistence of Consumption Growth: Macro vs Micro

- New paper in EER, Havranek, Rusnak, and Sokolova (2017)
  Meta analysis of 597 estimates of χ
- $\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \epsilon$
- $\{\chi^{\text{Macro}}, \chi^{\text{Micro}}\} = \{0.6, 0.1\}$



Claim: It's Not Habits, It's Inattention! (Macro not Micro)

Proposal:
Completely drop habits, replace with macro inattention

Our Setup

- Income Has Idiosyncratic and Aggregate Components
- Idiosyncratic Component Is Perfectly Observed
- **Aggregate Component Is Stochastically Observed**
  - Updating à la Calvo (1983)

Not *ad hoc*

- Identical: Mankiw and Reis (2002), Carroll (2003)
- Similar: Reis (2006), Sims (2003), . . .

Why Macro Inattention Is Plausible

Idiosyncratic Variability Is $\sim 100\times$ Bigger

- If Same Specification Estimated on Micro vs Macro Data
- Pervasive Lesson of All Micro Data

Utility Cost of Inattention Small

- Micro: Critical (and Easy) To Notice You're Unemployed
- Macro: *Not* Critical To Instantly Notice If U $\uparrow$

Literature on C Dynamics and Info Frictions

- C Smoothness: Campbell and Deaton (1989); Pischke (1995); Rotemberg and Woodford (1997)
- Inattention: Mankiw and Reis (2002); Reis (2006); Sims (2003); Maćkowiak and Wiederholt (2015); Gabaix (2014); ...
- Adjustment Costs: Alvarez, Guiso, and Lippi (2012); Chetty and Szeidl (2016)
- Empirical Evidence on Info Frictions: Coibion and Gorodnichenko (2015); Fuhrer (2017); ...
- Macro Habits: Abel (1990); Constantinides (1990); all papers since Christiano, Eichenbaum, and Evans (2005)
- Micro Habits: Dynan (2000); many recent papers

Quadratic Utility Frictionless Benchmark

Hall (1978) Random Walk

- Total Wealth (Human + Nonhuman):

$$\mathbf{o}_{t+1} = (\mathbf{o}_t - \mathbf{c}_t)\mathsf{R} + \zeta_{t+1}$$

- C Euler Equation:

$$\mathrm{u}'(\mathbf{c}_t) = \mathsf{R}\beta\mathbb{E}_t[\mathrm{u}'(\mathbf{c}_{t+1})]$$

- $\Rightarrow$ Random Walk (for $\mathsf{R}\beta = 1$):

$$\Delta\mathbf{c}_{t+1} = \epsilon_{t+1}$$

- Expected Wealth:

$$\mathbf{o}_t = \mathbb{E}_t[\mathbf{o}_{t+1}] = \mathbb{E}_t[\mathbf{o}_{t+2}] = \ldots$$

Sticky Expectations—Individual $\mathbf{c}$

- Consumer who happens to update at t and $t+n$

$$
\begin{aligned}
\mathbf{c}_t &= (\mathsf{r}/\mathsf{R})\mathbf{o}_t \\
\mathbf{c}_{t+1} &= (\mathsf{r}/\mathsf{R})\widetilde{\mathbf{o}}_{t+1} = (\mathsf{r}/\mathsf{R})\mathbf{o}_t = \mathbf{c}_t \\
\vdots &\quad \vdots \\
\mathbf{c}_{t+n-1} &= \mathbf{c}_t
\end{aligned}
$$

- Implies that $\Delta^n \mathbf{o}_{t+n} \equiv \mathbf{o}_{t+n} - \mathbf{o}_t$ is white noise
- So **individual** $\mathbf{c}$ is RW across updating periods:

$$
\mathbf{c}_{t+n} - \mathbf{c}_t = (\mathsf{r}/\mathsf{R}) \underbrace{(\mathbf{o}_{t+n} - \mathbf{o}_t)}_{\Delta^n \mathbf{o}_{t+n}}
$$

Sticky Expectations—Aggregate C

- Pop normed to one, uniformly dist on $[0, 1]$: $\mathbf{C}_t = \int_0^1 \mathbf{c}_{t,i}\,\mathrm{d}i$
- **Calvo (1983)-Type Updating of Expectations:**
  - Probability $\Pi = 0.25$ (per quarter)
- Economy composed of many sticky-$\mathbb{E}$ consumers:

$$\begin{aligned} \mathbf{C}_{t+1} &= (1-\Pi)\underbrace{\mathbf{C}^{\not\pi}_{t+1}}_{=\mathbf{C}_t} + \Pi\mathbf{C}^{\pi}_{t+1} \\ \Delta\mathbf{C}_{t+1} &\approx \underbrace{(1-\Pi)}_{\equiv\chi=0.75}\Delta\mathbf{C}_t + \epsilon_{t+1} \end{aligned}$$

- **Substantial persistence ($\chi = 0.75$) in aggregate C growth**

One More Ingredient . . .

- **Differences: Idiosyncratic vs Aggregate shocks**
  - Idiosyncratic shocks: Frictionless observation
    - I notice if I am fired, promoted, somebody steals my wallet
    - True RW with respect to these
  - Aggregate shocks: Sticky observation
    - May not instantly notice changes in aggregate productivity
- **Result:**
  - Idiosyncratic $\Delta \mathbf{c}$: dominated by frictionless RW part
  - Aggregate $\Delta \mathbf{C}$: highly serially correlated
    Law of large numbers $\Rightarrow$ idiosyncratic part vanishes

Serious Models

Partial Equilibrium/Small Open Economy

- CRRA Utility
- Idiosyncratic Shocks Calibrated From Micro Data
- Aggregate Shocks Calibrated From Macro Data
- Markov Process (Discrete RW) for Aggr Income Growth
  - Handles changing growth 'eras'
- Liquidity Constraint
- Mildly Impatient Consumers

DSGE Heterogeneous Agents (HA) Model

- Same!

Solving the Models

All results are generated using the open-source Econ-ARK toolkit:
`github.com/Econ-ARK/HARK/cAndCwithStickyE`

For a portal to the Econ-ARK project, go to:

- `http://econ-ark.org`

More Econ-ARK/HARK in next session "Econ-Developers Summit" at 11:10 in room G.012 Pio XII

Income Process

- Individual's labor productivity is

$$\boldsymbol{\ell}_{t,i} = \overbrace{\theta_{t,i}\Theta_t}^{\equiv \boldsymbol{\theta}_{t,i}} \overbrace{p_{t,i}P_t}^{\equiv \boldsymbol{p}_{t,i}}$$

- Idiosyncratic and aggregate p evolve according to

$$\begin{aligned} p_{t+1,i} &= p_{t,i}\psi_{t+1,i} \\ P_{t+1} &= \Phi_{t+1}P_t\ \Psi_{t+1} \end{aligned}$$

- **Φ is Markov 'underlying' aggregate pty growth**
  - Discrete (bounded) random walk
  - Calibrated to match postwar US pty growth variation
  - Generates predictability in income growth (for IV regressions)

Blanchard (1985) Mortality and Insurance

- Household survives from t to $t+1$ with probability $(1-\mathrm{D})$:

$$p_{t+1,i} = \begin{cases} 1 & \text{for newborns} \\ p_{t,i}\psi_{t+1,i} & \text{for survivors} \end{cases}$$

- Blanchardian scheme:

$$\mathbf{k}_{t+1,i} = \begin{cases} 0 & \text{if HH } i \text{ dies, is replaced by newborn} \\ \mathbf{a}_{t,i}/(1-\mathrm{D}) & \text{if household } i \text{ survives} \end{cases}$$

- Implies for aggregate:

$$\begin{aligned} \mathbf{K}_{t+1} &= \int_0^1 \left(\frac{1-\mathrm{d}_{t+1,i}}{1-\mathrm{D}}\right) \mathbf{a}_{t,i}\,\mathrm{d}i = \mathbf{A}_t \\ K_{t+1} &= A_t/(\Psi_{t+1}\Phi_{t+1}) \end{aligned}$$

Resources

- Market resources:

$$\mathbf{m}_{t,i} = \underbrace{\mathrm{W}_{\mathbf{t}}\boldsymbol{\ell}_{t,i}}_{\equiv \mathbf{y}_t} + \underbrace{\mathscr{R}_t}_{⅂+\mathrm{r}_t}\mathbf{k}_{t,i}$$

- End-of-Period 'Assets'—Unspent resources:

$$\mathbf{a}_{t,i} \quad = \quad \mathbf{m}_{t,i} - \mathbf{c}_{t,i}$$

- Capital transition depends on prob of survival $1 - \mathrm{D}$:

$$\mathbf{k}_{t+1,i} \quad = \quad \mathbf{a}_{t,i}\big/(1 - \mathrm{D})$$

Frictionless Solution

- For exposition: Assume constant W and $\mathscr{R}$
- Normalize everything by $\boldsymbol{p}_{t,i} \equiv p_{t,i} P_t$, e.g. $m_{t,i} = \mathbf{m}_{t,i} \big/ (p_{t,i} P_t)$
- $\mathrm{c}(m, \Phi)$ is the function that solves:

$$v(m_{t,i}, \Phi_t) = \max_{c} u(c) + \cancel{D}\beta \mathbb{E}_t \left[(\Phi_{t+1} \psi_{t+1,i})^{1-\rho} v(m_{t+1,i}, \Phi_{t+1}) \right]$$

- Level of consumption:

$$\mathbf{c}_{t,i} = \mathrm{c}(m_{t,i}, \Phi_t) \times p_{t,i} P_t$$

Sticky Expectations about Aggregate Income

Calvo Updating of Perceptions of Aggregate Shocks

- *True* Permanent income: $P_{t+1} = \Phi_{t+1} P_t \Psi_{t+1}$
- Tilde ($\widetilde{P}$) denotes perceived variables
- Perception for consumer who has not updated for n periods:

$$\widetilde{P}_{t,i} = \mathbb{E}_{t-n}\left[P_t \middle| \Omega_{t-n}\right] = \Phi_{t-n}^{n} P_{t-n}$$

because Φ is random walk

Sticky Expectations about Aggregate Income

Sequence Within Period

1. Income shocks are realized and every individual sees her true $\mathbf{y}$ and $\mathbf{m}$, i.e. $\mathbf{y}_{t,i} = \widetilde{\mathbf{y}}_{t,i}$ and $\mathbf{m}_{t,i} = \widetilde{\mathbf{m}}_{t,i}$ for all t and i
2. Updating shocks realized: i observes true P_t, Φ_t w/ prob Π; forms perceptions of her normalized market resources $\widetilde{m}_{t,i}$
3. Consumes based on her perception, using $\mathrm{c}(\widetilde{m}_{t,i}, \widetilde{\Phi}_{t,i})$

   Key Assumption:

   - People act as if their perceptions about aggregate state $\{\widetilde{P}_{t,i}, \widetilde{\Phi}_{t,i}\}$ are the true aggregate state $\{P_t, \Phi_t\}$

Behavior under Sticky Expectations

- Normalized resources:
  - $m_{t,i} \equiv \mathbf{m}_{t,i}/(p_{t,i}P_t)$ is *actual*
  - $\widetilde{m}_{t,i} \equiv \mathbf{m}_{t,i}/(p_{t,i}\widetilde{P}_{t,i})$ is *perceived*
- **Usually $\widetilde{m}_{t,i} \neq m_{t,i}$ because P_t not perfectly observed**
  - in levels: $\widetilde{\mathbf{m}}_{t,i} = \mathbf{m}_{t,i}$; but normalized: $\widetilde{m}_{t,i} \neq m_{t,i}$
- Consumers behave according to frictionless consumption function
- But **based on** $\widetilde{m}_{t,i}$ (not $m_{t,i}$):

$$
\begin{aligned}
\widetilde{c}_{t,i} &= \mathrm{c}(\widetilde{m}_{t,i}, \widetilde{\Phi}_{t,i}) \\
\mathbf{c}_{t,i} &= \widetilde{c}_{t,i} \times p_{t,i}\widetilde{P}_{t,i}
\end{aligned}
$$

- Correctly perceive level of their own spending $\mathbf{c}_{t,i}$

DSGE Heterogeneous Agents Model

- Idiosyncratic and aggregate shocks same as PE/SOE
- Endogenous W_t and $\mathscr{R}_t$
- Aggregate market resources M_t is a state variable

$$v(m_{t,i}, M_t, \Phi_t) = \max_c u(c) + \cancel{D}\beta\mathbb{E}_t\left[(\Phi_{t+1}\psi_{t+1,i})^{1-\rho} v(m_{t+1,i}, M_{t+1}, \Phi_{t+1})\right]$$

- Solved using Krusell and Smith (1998)
- Perception dynamics identical to sticky PE/SOE:

$$\mathbf{c}_{t,i} = \mathrm{c}(\widetilde{m}_{t,i}, \widetilde{M}_{t,i}, \widetilde{\Phi}_{t,i}) \times p_{t,i}\widetilde{P}_{t,i}$$

Regressions on Simulated and Actual Data

Dynan (2000)/Sommer (2007) Specification:

$$\Delta \log \mathbf{C}_{t+1} \approx \varsigma + \chi \mathbb{E}[\Delta \log \mathbf{C}_t] + \eta \mathbb{E}[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

- χ: **Extent of habits**
  Data: Micro: $\chi^{\text{Micro}} = 0.1$ (EER 2017 paper)
  Macro: $\chi^{\text{Macro}} = 0.6$
- η: **Fraction of Y going to 'rule-of-thumb' C = Y types**
  Data: Micro: $0 < \eta^{\text{Micro}} < 1$ (Depends . . .)
  Macro: $\eta^{\text{Macro}} \approx 0.5$ (Campbell and Mankiw (1989))
- α: **Precautionary saving (micro) or IES (Macro)**
  Data: Micro: $\alpha^{\text{Micro}} < 0$ (Zeldes (1989))
  Macro: $\alpha^{\text{Macro}} < 0$ (but small)
  [In GE r depends roughly linearly on A]

Micro vs Macro: Theory and Empirics

$$\Delta \log \mathbf{C}_{t+1} \quad \approx \quad \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

	χ	η	α
Micro (Separable)			
Theory	≈ 0	$0 < \eta < 1$	< 0
Data	≈ 0	$0 < \eta < 1$	< 0
Macro			
Theory: Separable	≈ 0	≈ 0	< 0
Theory: CampMan	≈ 0	≈ 0.5	< 0
Theory: Habits	≈ 0.75	≈ 0	< 0

Calibration I

	Macroeconomic Parameters	
γ	0.36	Capital's Share of Income
$\daleth$	$0.94^{1/4}$	Depreciation Factor
σ^2_{Θ}	0.00001	Variance Aggregate Transitory Shocks
σ^2_{Ψ}	0.00004	Variance Aggregate Permanent Shocks
	Steady State of Perfect Foresight DSGE Model	
	$(\sigma_{\Psi} = \sigma_{\Theta} = \sigma_{\psi} = \sigma_{\theta} = \wp = \mathsf{D} = 0,\ \Phi_t = 1)$	
$\breve{K}/\breve{K}^{\gamma}$	12.0	SS Capital to Output Ratio
$\breve{K}$	48.55	SS Capital to Labor Productivity Ratio $(= 12^{1/(1-\gamma)})$
$\breve{\mathsf{W}}$	2.59	SS Wage Rate $(= (1-\gamma)\breve{K}^{\gamma})$
$\breve{\mathsf{r}}$	0.03	SS Interest Rate $(= \gamma\breve{K}^{\gamma-1})$
$\breve{\mathscr{R}}$	1.015	SS Between-Period Return Factor $(= \daleth + \breve{\mathsf{r}})$

Calibration II

		Preference Parameters
ρ	2.	Coefficient of Relative Risk Aversion
β_{SOE}	0.970	SOE Discount Factor
β_{DSGE}	0.986	HA-DSGE Discount Factor ($= \breve{\mathscr{R}}^{-1}$)
Π	0.25	Probability of Updating Expectations (if Sticky)
		Idiosyncratic Shock Parameters
σ_{θ}^{2}	0.120	Variance Idiosyncratic Tran Shocks ($=4\times$ Annual)
σ_{ψ}^{2}	0.003	Variance Idiosyncratic Perm Shocks ($=\frac{1}{4}\times$ Annual)
$\wp$	0.050	Probability of Unemployment Spell
D	0.005	Probability of Mortality

Micro Regressions: Frictionless

$$\Delta \log \mathbf{c}_{t+1,i} \quad = \quad \varsigma + \chi \Delta \log \mathbf{c}_{t,i} + \eta \mathbb{E}_{t,i}[\Delta \log \mathbf{y}_{t+1,i}] + \alpha \bar{a}_{t,i} + \epsilon_{t+1,i}.$$

Model of Expectations	χ	η	α	$\bar{R}^2$
Frictionless				
	0.019			0.000
	(–)			
		0.011		0.004
		(–)		
			−0.190	0.010
			(–)	
	0.061	0.016	−0.183	0.017
	(–)	(–)	(–)	

Micro Regressions: Sticky

$$\Delta \log \mathbf{c}_{t+1,i} \quad = \quad \varsigma + \chi \Delta \log \mathbf{c}_{t,i} + \eta \mathbb{E}_{t,i}[\Delta \log \mathbf{y}_{t+1,i}] + \alpha \bar{a}_{t,i} + \epsilon_{t+1,i}.$$

Model of Expectations	χ	η	α	$\bar{R}^2$
Sticky				
	0.012			0.000
	(–)			
		0.011		0.004
		(–)		
			-0.191	0.010
			(–)	
	0.051	0.015	-0.185	0.016
	(–)	(–)	(–)	

Empirical Results for U.S.

$$\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

Expectations : Dep Var Independent Variables			OLS or IV	2nd Stage $\bar{R}^2$	KP p-val Hansen J p-val
Nondurables and Services					
$\Delta \log \mathbf{C}_t^*$	$\Delta \log \mathbf{Y}_{t+1}$	A_t			
0.468***			OLS	0.216	
(0.076)					
0.830***			IV	0.278	0.222
(0.098)					0.439
	0.587***		IV	0.203	0.263
	(0.110)				0.319
		$-0.17\text{e}{-4}$	IV	-0.005	0.081
		($5.71\text{e}{-4}$)			0.181
0.618***	0.305*	$-4.96\text{e}{-4}$*	IV	0.304	0.415
(0.159)	(0.161)	($2.94\text{e}{-4}$)			0.825
Memo: For instruments $\mathbf{Z}_t, \Delta \log \mathbf{C}_t = \mathbf{Z}_t \zeta,\ \bar{R}^2 = 0.358$					

Notes: Data source is NIPA, 1960Q1–2016Q. Robust standard errors are in parentheses. Instruments $\mathbf{Z}_t = \{\Delta \log \mathbf{C}_{t-2}, \Delta \log \mathbf{C}_{t-3}, \Delta \log \mathbf{Y}_{t-2}, \Delta \log \mathbf{Y}_{t-3}, A_{t-2}, A_{t-3}, \Delta_8 \log \mathbf{C}_{t-2}, \Delta_8 \log \mathbf{Y}_{t-2}$, lags 2 and 3 of differenced Fed funds rate, lags 2 and 3 of the Michigan Index of Consumer Sentiment Expectations$\}$.

Small Open Economy: Sticky

$$\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

Expectations : Dep Var Independent Variables			OLS or IV	2nd Stage $\bar{R}^2$	KP p-val Hansen J p-val
Sticky : $\Delta \log \mathbf{C}^*_{t+1}$ (with measurement error $\mathbf{C}^*_t = \mathbf{C}_t \times \xi_t$);					
$\Delta \log \mathbf{C}^*_t$	$\Delta \log \mathbf{Y}_{t+1}$	A_t			
0.508•••			OLS	0.263	
(0.058)					
0.802•••			IV	0.260	0.000
(0.104)					0.554
	0.859•••		IV	0.198	0.060
	(0.182)				0.233
		−8.26e–4••	IV	0.066	0.000
		(3.99e–4)			0.002
0.660•••	0.192	0.60e–4	IV	0.261	0.359
(0.187)	(0.277)	(5.03e–4)			0.546
Memo: For instruments $\mathbf{Z}_t$, $\Delta \log \mathbf{C}^*_t = \mathbf{Z}_t \zeta$, $\bar{R}^2 = 0.260$; $\text{var}(\log(\xi_t)) = 5.99\text{e–}6$					

Notes: Reported statistics are the average values for 100 samples of 200 simulated quarters each. Bullets indicate that the average sample coefficient divided by average sample standard error is outside of the inner 90%, 95%, and 99% of the standard normal distribution. Instruments $\mathbf{Z}_t = \{\Delta \log \mathbf{C}_{t-2}, \Delta \log \mathbf{C}_{t-3}, \Delta \log \mathbf{Y}_{t-2}, \Delta \log \mathbf{Y}_{t-3}, A_{t-2}, A_{t-3}, \Delta_8 \log \mathbf{C}_{t-2}, \Delta_8 \log \mathbf{Y}_{t-2}\}$.

Small Open Economy: Frictionless

$$\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

Expectations : Dep Var Independent Variables			OLS or IV	2^{nd} Stage $\bar{R}^2$	KP p-val Hansen J p-val
Frictionless : $\Delta \log \mathbf{C}^*_{t+1}$ (with measurement error $\mathbf{C}^*_t = \mathbf{C}_t \times \xi_t$);					
$\Delta \log \mathbf{C}^*_t$	$\Delta \log \mathbf{Y}_{t+1}$	A_t			
0.295•••			OLS	0.087	
(0.066)					
0.660••			IV	0.040	0.237
(0.309)					0.600
	0.457••		IV	0.035	0.059
	(0.209)				0.421
		−6.92e–4	IV	0.026	0.000
		(5.87e–4)			0.365
0.420	0.258	0.45e–4	IV	0.041	0.516
(0.428)	(0.365)	(9.51e–4)			0.529
Memo: For instruments $\mathbf{Z}_t$, $\Delta \log \mathbf{C}^*_t = \mathbf{Z}_t \zeta$, $\bar{R}^2 = 0.039$; var(log(ξ_t)) = 5.99e–6					

Notes: Reported statistics are the average values for 100 samples of 200 simulated quarters each. Bullets indicate that the average sample coefficient divided by average sample standard error is outside of the inner 90%, 95%, and 99% of the standard normal distribution. Instruments $\mathbf{Z}_t = \{\Delta \log \mathbf{C}_{t-2}, \Delta \log \mathbf{C}_{t-3}, \Delta \log \mathbf{Y}_{t-2}, \Delta \log \mathbf{Y}_{t-3}, A_{t-2}, A_{t-3}, \Delta_8 \log \mathbf{C}_{t-2}, \Delta_8 \log \mathbf{Y}_{t-2}\}$.

Heterogeneous Agents DSGE: Sticky

$$\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

Expectations : Dep Var Independent Variables			OLS or IV	2^{nd} Stage $\bar{R}^2$	KP p-val Hansen J p-val
Sticky : $\Delta \log \mathbf{C}^*_{t+1}$ (with measurement error $\mathbf{C}^*_t = \mathbf{C}_t \times \xi_t$);					
$\Delta \log \mathbf{C}^*_t$	$\Delta \log \mathbf{Y}_{t+1}$	A_t			
$0.467^{\bullet\bullet\bullet}$			OLS	0.223	
(0.061)					
$0.773^{\bullet\bullet\bullet}$			IV	0.230	0.000
(0.108)					0.542
	$0.912^{\bullet\bullet\bullet}$		IV	0.145	0.105
	(0.245)				0.187
		$-0.97\text{e–}4^{\bullet}$	IV	0.059	0.000
		(0.56e–4)			0.002
$0.670^{\bullet\bullet\bullet}$	0.171	0.12e–4	IV	0.231	0.460
(0.181)	(0.363)	(0.86e–4)			0.551
Memo: For instruments $\mathbf{Z}_t$, $\Delta \log \mathbf{C}^*_t = \mathbf{Z}_t\zeta$, $\bar{R}^2 = 0.232$; $\text{var}(\log(\xi_t)) = 4.16\text{e–}6$					

Notes: Reported statistics are the average values for 100 samples of 200 simulated quarters each. Bullets indicate that the average sample coefficient divided by average sample standard error is outside of the inner 90%, 95%, and 99% of the standard normal distribution. Instruments $\mathbf{Z}_t = \{\Delta \log \mathbf{C}_{t-2}, \Delta \log \mathbf{C}_{t-3}, \Delta \log \mathbf{Y}_{t-2}, \Delta \log \mathbf{Y}_{t-3}, A_{t-2}, A_{t-3}, \Delta_8 \log \mathbf{C}_{t-2}, \Delta_8 \log \mathbf{Y}_{t-2}\}$.

Heterogeneous Agents DSGE: Frictionless

$$\Delta \log \mathbf{C}_{t+1} = \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

Expectations : Dep Var Independent Variables			OLS or IV	2nd Stage $\bar{R}^2$	KP p-val Hansen J p-val
Frictionless : $\Delta \log \mathbf{C}^*_{t+1}$ (with measurement error $\mathbf{C}^*_t = \mathbf{C}_t \times \xi_t$);					
$\Delta \log \mathbf{C}^*_t$	$\Delta \log \mathbf{Y}_{t+1}$	A_t			
0.189•••			OLS	0.036	
(0.072)					
0.476			IV	0.020	0.318
(0.354)					0.556
	0.368		IV	0.017	0.107
	(0.321)				0.457
		−0.34e–4	IV	0.015	0.000
		(0.98e–4)			0.433
0.289	0.214	0.01e–4	IV	0.020	0.572
(0.463)	(0.583)	(1.87e–4)			0.531
Memo: For instruments $\mathbf{Z}_t$, $\Delta \log \mathbf{C}^*_t = \mathbf{Z}_t \zeta$, $\bar{R}^2 = 0.023$; $\mathrm{var}(\log(\xi_t)) = 4.16\text{e–}6$					

Notes: Reported statistics are the average values for 100 samples of 200 simulated quarters each. Bullets indicate that the average sample coefficient divided by average sample standard error is outside of the inner 90%, 95%, and 99% of the standard normal distribution. Instruments $\mathbf{Z}_t = \{\Delta \log \mathbf{C}_{t-2}, \Delta \log \mathbf{C}_{t-3}, \Delta \log \mathbf{Y}_{t-2}, \Delta \log \mathbf{Y}_{t-3}, A_{t-2}, A_{t-3}, \Delta_8 \log \mathbf{C}_{t-2}, \Delta_8 \log \mathbf{Y}_{t-2}\}$.

Utility Costs of Stickiness

- Simulate expected lifetime utility when market resources nonstochastically equal to W_t at birth under **frictionless**

$$\overline{\mathrm{v}}_0 \equiv \mathbb{E}[\mathrm{v}(\mathrm{W}_t, \cdot)]$$

and **sticky expectations**: $\overline{\widetilde{\mathrm{v}}}_0 \equiv \mathbb{E}[\widetilde{\mathrm{v}}(\mathrm{W}_t, \cdot)]$

- Expectations taken over state variables other than $m_{t,i}$
- Newborn's willingness to pay (as fraction of permanent income) to avoid having sticky expectations:

$$\omega \;=\; 1 - \left(\frac{\overline{\widetilde{\mathrm{v}}}_0}{\overline{\mathrm{v}}_0}\right)^{\frac{1}{1-\rho}}$$

- $\omega \approx 0.05\%$ **of permanent income**
  $\omega_{SOE} = 4.82\text{e–}4$; $\omega_{HA-DSGE} = 4.51\text{e–}4$

Conclusion

Model with 'Sticky Expectations' of aggregate variables can match both micro and macro consumption dynamics

$$\Delta \log \mathbf{C}_{t+1} \approx \varsigma + \chi \Delta \log \mathbf{C}_t + \eta \mathbb{E}_t[\Delta \log \mathbf{Y}_{t+1}] + \alpha A_t + \epsilon_{t+1}$$

	χ	η	α
Micro			
Data	≈ 0	$0 < \eta < 1$	< 0
Theory: Habits	≈ 0.75	$0 < \eta < 1$	< 0
Theory: Sticky Expectations	≈ 0	$0 < \eta < 1$	< 0
Macro			
Data	≈ 0.75	≈ 0	< 0
Theory: Habits	≈ 0.75	≈ 0	< 0
Theory: Habits	≈ 0.75	≈ 0	< 0

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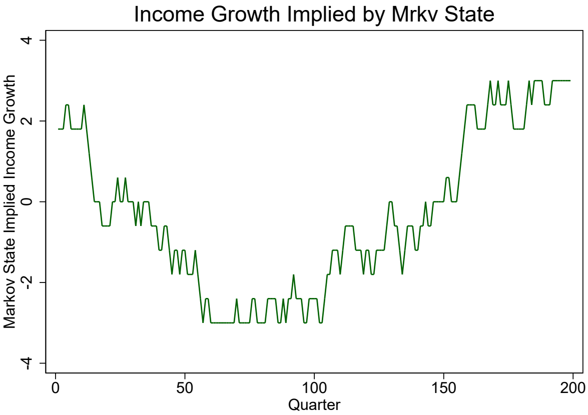
Markov Process for Aggregate Productivity Growth Φ

$$\boldsymbol{\ell}_{t,i} = \theta_{t,i}\Theta p_{t,i}P_t, \quad p_{t+1,i} = p_{t,i}\psi_{t+1,i}, \quad P_{t+1} = \Phi_{t+1}P_t\Psi_{t+1}$$

- Φ_t follows bounded (discrete) RW
- 11 states; average persistence 2 quarters
- Flexible way to match actual pty growth data



Equilibrium

	SOE Model		HA-DSGE Model	
	Frictionless	Sticky	Frictionless	Sticky
Means				
A	7.49	7.43	56.85	56.72
C	2.71	2.71	3.44	3.44
Standard Deviations				
Aggregate Time Series ('Macro')				
$\log A$	0.332	0.321	0.276	0.272
$\Delta \log \mathbf{C}$	0.010	0.007	0.010	0.005
$\Delta \log \mathbf{Y}$	0.010	0.010	0.007	0.007
Individual Cross Sectional ('Micro')				
$\log \mathbf{a}$	0.926	0.927	1.015	1.014
$\log \mathbf{c}$	0.790	0.791	0.598	0.599
$\log p$	0.796	0.796	0.796	0.796
$\log \mathbf{y} \mid \mathbf{y} > 0$	0.863	0.863	0.863	0.863
$\Delta \log \mathbf{c}$	0.098	0.098	0.054	0.055
Cost of Stickiness	4.82e–4		4.51e–4	

Cost of Stickiness

Define (for given parameter values):

$v(\mathrm{W}_t, \cdot)$	Newborns' expected value for frictionless model
$\grave{v}(\mathrm{W}, \cdot)$	Newborns' expected value if $\sigma_\psi^2 = 0$
$\widetilde{v}(\mathrm{W}, \cdot)$	Newborns' expected value from sticky behavior

Fact suggested by theory (and confirmed numerically):

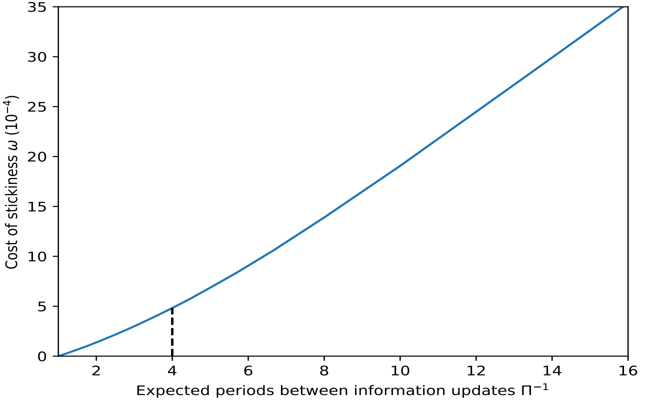
$$v(\mathcal{W}) \approx \grave{v}(\mathcal{W}) - \kappa\sigma_\Psi^2 \quad (1)$$

Guess (and verify) that:

$$\bar{v}(\mathcal{W}) \approx \grave{v}(\mathcal{W}) - (\kappa/\Pi)\sigma_\Psi^2 \quad (2)$$

Cost of Stickiness: ω and Π

Costs of stickiness ω and prob of aggr info updating Π



Notes: The figure shows how the utility costs of updating ω depend on the probability of updating of aggregate information Π in the SOE model.

Cost of Stickiness: Solution

Suppose utility cost of attention is $\iota\Pi$.

- If Newborns Pick Optimal Π, they solve

$$\max_{\Pi} \; \grave{v}(\mathcal{W}) - (\kappa/\Pi)\sigma_{\Psi}^{2} - \iota\Pi. \tag{3}$$

Solution:

$$\Pi \;=\; (\kappa/\iota)^{0.5}\sigma_{\Psi} \tag{4}$$

Optimal Π characteristics:

- Increasing in κ ('importance' to value of perm shocks)
- Increasing in σ_{ψ} ('magnitude' of perm shocks)
- Decreasing as attention becomes more costly: $\iota \uparrow$

Is Muth–Lucas–Pischke Kalman Filter Equivalent?

No.

Muth (1960)–Lucas (1973)–Pischke (1995) Kalman filter

- All you can see is Y
  - Lucas: Can't distinguish agg. from idio.
  - Muth–Pischke: Can't distinguish tran from perm
- Here: Can see own circumstances perfectly
- Only the (tiny) aggregate part is hard to see
- **Signal extraction for aggregate $\mathbf{Y}_t$ gives too little persistence in $\Delta\mathbf{C}_t$:** $\chi \approx 0.17$

Muth–Pischke Perception Dynamics

- Optimal signal extraction problem (Kalman filter): Observe $\mathbf{Y}$ (aggregate income), estimate P, Θ
- Optimal estimate of P:

$$\hat{P}_{t+1} = \Pi \mathbf{Y}_{t+1} + (1 - \Pi)\hat{P}_t,$$

where for signal-to-noise ratio $\varphi = \sigma_\Psi / \sigma_\Theta$:

$$\Pi = \varphi\sqrt{1 + \varphi^2/4} - \varphi^2/2, \tag{5}$$

- But if we calibrate φ using observed macro data
  - $\Rightarrow \Delta \log \mathbf{C}_{t+1} \approx \mathbf{0.17}\ \Delta \log \mathbf{C}_t$
  - **Too little persistence!**