# Determinacy without Taylor principle

## Plus: FTPL; beliefs, AD, and inflation

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# Outline

# Indeterminacy in NK Model

- Q: What determines $P$? Can MP regulate AD? Does ZLB trigger a deflationary spiral?
- **Inconvenient truth**: correct answers depend on **equilibrium selection**
  - same path for $i_t \Rightarrow$ multiple equilibrium paths for $\pi_t$ and $y_t$
- **Taylor Principle** vs **Fiscal Theory of Price Level**: a choice of "religion"?

| Standard Paradigm (Leeper) | | |
|---|---|---|
| | Fiscal Policy is | |
| | Ricardian | Non-Ricardian |
| Taylor Principle holds | Determinacy | No equilibrium |
| does not hold | Multiplicity | Determinacy |

# This Paper: A New Perspective

- NK indeterminacy depends on a delicate **"infinite chain"**
  - sunspots matter only because future agents are expected to keep responding *in perpetuity*
- **Small perturbations** in info/coordination $\Rightarrow$ break the chain $\Rightarrow$ **determinacy**
  - always select standard equil (aka MSV solution), even with interest rate pegs

| With Our Perturbations | | |
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- Applied lessons:
  - recast Taylor principle as stabilization instead equil selection
  - push for reformulating FTPL outside the equil selection conundrum

# Outline

# Flexible vs Rigid Prices

- **Flex prices ($\kappa = \infty$):**

  Fisher eq + Taylor rule in $\pi_t$ $\quad\Rightarrow\quad$ $\mathbb{E}_t[\pi_{t+1}] = i_t = \phi\pi_t$ $\quad\Rightarrow\quad$ unique iff $|\phi| > 1$

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- **Rigid prices ($\kappa = 0$):**

  DIS + MC + Taylor rule in $y_t$ $\Rightarrow$ $\mathbb{E}_t[c_{t+1}] - c_t = i_t = \chi c_t$ $\Rightarrow$ unique iff $|1 + \chi| > 1$

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- Same math, but subtle differences:
  - **nominal** vs **real** indeterminacy
  - puts spotlight on **spending decisions** and **Keynesian multipliers**

# Sticky Prices $\approx$ Rigid Prices

- **General NK case** $(0 < \kappa < \infty)$
  - conditional on $\{c_t\}$, no indeterminacy in $\{\pi_t\}$ or $\{p_t\}$
  - useful to stop thinking "nominal indeterminacy translates to real indeterminacy"
  - rather the inverse: **understand AD,** then price path follows from Phillips cure
- What's next: **represent NK economy as a game among consumers**
  - a clear way to think about GE feedbacks and expectations
  - any $\kappa < \infty$ is basically the same as $\kappa = 0$ (but discontinuity at $\kappa = \infty$)
  - shed new light on determinacy, Taylor Principle, FTPL ...

# Outline

# A Simplified NK Economy

- Cashless, nominal bond in zero net supply, zero taxes
- Overlapping generations of consumers, each living two periods:

$$u(C^1_{i,t}) + \beta u(C^2_{i,t+1}) e^{-\rho_t}$$

$$P_t C^1_{i,t} + B_{i,t} = P_t Y_t \qquad P_{t+1} C^2_{i,t+1} = P_t Y_{t+1} + I_t B_{i,t}$$

- Old = "robots" or "hand to mouth"
  - $C^2_{it}$ adjusts to meet second-period budget
- Young = "strategic"
  - optimally choose $(C^1_{it}, B_{it})$ given beliefs about $Y_t$, $I_t$, $P_t$ and $P_{t+1}$.

# The DIS curve

- Log-linearized optimal $c$ for the young:

$$c^1_{i,t} = E_{i,t}\left[\frac{1}{1+\beta}y_t + \frac{\beta}{1+\beta}y_{t+1} - \frac{\beta}{1+\beta}\sigma(i_t - \pi_{t+1} - \rho_t)\right]$$

- Zero agg saving (plus young and old earn same $y$) $\Rightarrow$ $\int c^1_{i,t}di = \int c^2_{i,t}di = c_t = y_t$
- Combining $\Rightarrow$ **a DIS equation, featuring avg beliefs:**

$$c_t \;=\; \bar{E}_t\left[\frac{1}{1+\beta}c_t + \frac{\beta}{1+\beta}c_{t+1} - \frac{\beta\sigma}{1+\beta}(i_t - \pi_{t+1} - \rho_t)\right]$$

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- FIRE $\Rightarrow$ $\bar{E}_t[\cdot] = \mathbb{E}_t[\cdot] \equiv \mathbb{E}[\cdot|\text{full info}]$ $\Rightarrow$ above reduces to familiar RA's Euler:

$$c_t = \mathbb{E}_t[c_{t+1}] - \sigma(i_t - \mathbb{E}_t[\pi_{t+1}] - \rho_t)$$

- Here: stylized Intertemporal Keynesian Cross, with flexible info/beliefs

# The economy in 3 equations

1. DIS equation:

$$c_t = \bar{E}_t \left[ \frac{1}{1+\beta} c_t + \frac{\beta}{1+\beta} c_{t+1} - \frac{\beta\sigma}{1+\beta} (i_t - \pi_{t+1} - \rho_t) \right] \tag{DIS}$$

2. Phillips curve (ad hoc for now):

$$\pi_t = \kappa c_t + \xi_t \tag{PC}$$

3. Taylor rule (with $\phi \geq 0$ for simplicity):

$$i_t = \iota_t + \phi \pi_t \tag{MP}$$

# From 3 eqs to 1 eq (and a game representation)

- Substituting MP and PC in DIS $\Rightarrow$

$$c_t = \bar{E}_t [\; \delta_0 c_t + \delta_1 c_{t+1} + (1-\delta_0)\theta_t \;]$$

where $\delta_0 \equiv \frac{1-\beta\sigma\phi\kappa}{1+\beta} < 1$, $\delta_1 \equiv \frac{\beta+\beta\sigma\kappa}{1+\beta} > 0$ and $\{\theta_t\}$ is a transformation of $\{\rho_t, \xi_t, \iota_t\}$

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- NK economy = **a game among consumers**
  - individual best responses: $c_{i,t} = E_{i,t}[(1-\delta_0)\theta_t + \delta_0 c_t + \delta_1 c_{t+1}]$
  - game summarizes three **GE feedbacks**:

    (1) income$\leftrightarrow$spending (2) output$\leftrightarrow$inflation (3) MP response
  - **MP "regulates" the game**: different $\phi$ map to different $(\delta_0, \delta_1)$ and different bite of beliefs

# Fundamentals, Sunspots, and Equilibrium Definition

- State of nature, or infinite history, at $t$:

$$h^t = \{\theta_{t-k}, \eta_{t-k}\}_{k=0}^{\infty}$$

  - $\theta_t$ = fundamental, $\eta_t$ = sunspot
  - here: both are i.i.d.; in paper: general stochasticity

- Equilibrium concept: linear, stationary, bounded **REE**
  - linear = MA representation

$$c_t = c(h^t) = \sum_{k=0}^{\infty} a_k \eta_{t-k} + \sum_{k=0}^{\infty} \gamma_k \theta_{t-k}$$

  - bounded = $\sup_k \{|a_k|, |\gamma_k|\} < \infty$
  - expectations rational but possibly based on limited info about $h^t$

# Outline

# Standard Paradigm

- **FIRE:** $E_{it}[\cdot] = \mathbb{E}_t^\star[\cdot] \equiv$ RE conditional on full information about $h^t$
- Since both $c_t$ and $\theta_t$ are measurable in $h^t$

$$c_t = \bar{E}_t[\delta_0 c_t + \delta_1 c_{t+1} + (1-\delta_0)\theta_t] \xrightarrow{\text{FIRE}} \boxed{c_t = \theta_t + \delta \mathbb{E}_t^\star[c_{t+1}]}$$

$$\delta \equiv \frac{\delta_1}{1-\delta_0} = \frac{1+\sigma\kappa}{1+\sigma\kappa\phi} > 0 \ \text{ summarizes GE feedbacks under FIRE}$$

- **Fundamental** or **MSV** (minimum state variable) solution:

$$c_t = c_t^F \equiv \theta_t \quad (\text{e.g., } c_t = -\sigma\iota_t)$$

- **Is MSV the only REE?** Depends on $\delta \lessgtr 1$, or equivalently $\phi \gtrless 1$

# Standard Paradigm

## Proposition 1. FIRE

- When $\phi > 1$ (Taylor principle), the MSV solution, $c_t = c_t^F \equiv \theta_t$, is the unique equilibrium
- When $\phi < 1$, there exist **a continuum of equilibria**

$$c_t = (1-b)c_t^F + bc_t^B + ac_t^\eta,$$

where $a, b \in \mathbb{R}$ are arbitrary scalars,

$$\underbrace{c_t^\eta \equiv \sum_{k=0}^{\infty} \delta^{-k} \eta_{t-k}}_{\text{sunspot eq.}} \quad \text{and} \quad \underbrace{c_t^B \equiv -\sum_{k=1}^{\infty} \delta^{-k} \theta_{t-k}}_{\text{backward-looking, pseudo-fundamental eq.}}$$

# Understanding the Multiplicity (when $\phi < 1$, i.e. $\delta > 1$)

- Equilibrium condition:

$$c_{t-1} = \theta_{t-1} + \delta \mathbb{E}^{\star}_{t-1}[c_t]$$

- Solving backwards:

$$\begin{aligned}
\mathbb{E}^{\star}_{t-1}[c_t] &= \delta^{-1}(c_{t-1} - \theta_{t-1}) \\
c_t &= \delta^{-1}(c_{t-1} - \theta_{t-1}) + \eta_t \\
c_t &= \underbrace{-\sum_{k=1}^{\infty} \delta^{-k}\theta_{t-k}}_{\text{backward-looking pseudo-fundamental}} + \underbrace{\sum_{k=0}^{\infty} \delta^{-k}\eta_{t-k}}_{\text{sunspot component}}
\end{aligned}$$

- **Infinite chain**: current agents respond to payoff-irrelevant histories because they expect future agents to do the same, ad infinitum

- **What's next**: small perturbations breaking this chain

# Outline

# Fading Social Memory

- At every $t$, a young consumer learns $(\theta_t, \eta_t)$
- With prob. $\lambda$, she learns nothing more
- With prob. $1-\lambda$, she inherits the info of a random old consumer

**Assumption. Fading Social Memory**

For every $i$ and $t$, information is given by

$$I_{i,t} = \{(\theta_t, \eta_t), \cdots, (\theta_{t-s_{i,t}}, \eta_{t-s_{i,t}})\},$$

where $s_{i,t} \in \{0, 1, \cdots\}$ is an idiosyncratic draw from a geometric distribution with $\lambda \in (0,1)$.

# Determinacy without the Taylor Principle

- For every $k$, mass who know past $k$ shocks is $\mu_k \equiv (1-\lambda)^k$
- As $\lambda \to 0^+$, almost all agents have *arbitrarily long* memory
  - also, nearly perfectly informed about $\{c_{t-k}, \pi_{t-k}\}_{k=0}^{K}$ for $K$ finite but arbitrarily large
- But zero mass of agents has truly *infinite* memory
  - $\lim_{k\to\infty} \mu_k = 0 \; \forall \; \lambda > 0$

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**Proposition 2. Determinacy without the Taylor Principle**

With fading social memory, the **MSV solution** is the **unique REE**

- regardless of $\delta$, or equivalently of $\phi$ (e.g., even with pegs)
- no matter how slow the memory decay is (i.e., how small $\lambda > 0$ is)

# Proof Sketch

- Simplification (general proof in paper):
  - focus on coordination cross time (formally, let $\delta_0 = 0$ and $\delta_1 = \delta$)
  - focus on IRF of $c_t$ to $\eta_0$ (let only shock be $\eta_0$) and look for solutions $c_t = a_t \eta_0$
- Equil. condition:

$$\begin{aligned} c_t &= \delta \bar{E}_t[c_{t+1}] \\ &= \delta \bar{E}_t[a_{t+1}\eta_0] \\ &= \delta a_{t+1} \mu_t \eta_0 \\ &= \delta \mu_t \mathbb{E}_t^*[c_{t+1}] \end{aligned}$$

- Maps to "twin" FIRE economy with modified best response:

$$c_t = \delta \bar{E}_t[c_{t+1}] \quad \longrightarrow \quad c_t = \mu_t \delta \mathbb{E}_t^*[c_{t+1}]$$

- $\lim_{t\to\infty} \mu_t = 0 \Rightarrow \mu_T \delta < 1$ for $T$ large enough $\Rightarrow$ uniqueness after $T$
- By backward induction, uniqueness also before $T$

# Logic

- Key idea: anticipation that social memory will fade
  $\Longrightarrow$ perceived complementarity fades with horizon
  $\Longrightarrow$ determinacy

- In simpler words:
  - I can see the current sunspot very clearly
  - It would make sense to react if all future agents will keep responding to it in perpetuity
  - But I worry that agents far in the future will fail to do so
    - either because they will forget it
    - or because they may worry that agents further into the future will forget it
  - It therefore makes sense to ignore the sunspot

# Outline

# Robustness

- Criticism: sunspot eq. can be represented in **recursive form** as

$$c_t = \eta_t + \delta^{-1} c_{t-1}.$$

  - supported by "short" memory, $I_{i,t} = \{\eta_t, c_{t-1}\}$
  - $c_{t-1}$ serves as memory device/endogenous sunspot

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- Response: Fragility to perturbations that allow direct knowledge of past outcomes

## Proposition 3

Such sunspot equil **unravel** with tiny idiosyncratic noise in observation of $c_{t-1}$ (or $\pi_{t-1}$):

$$I_{i,t} = \{\eta_t, s_{i,t}\}, \qquad s_{i,t} = c_{t-1} + \varepsilon_{i,t}, \qquad \varepsilon_{i,t} \sim \mathcal{N}(0, \sigma)$$

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**Proposition 4**

Even with perfect knowledge of $\{c_{t-k}, \pi_{t-k}\}_{k=0}^{K}$, **uniqueness** provided $K$ is finite and immediate forgetfulness of a tiny component of $\theta_{t-1}$

# Large Class of NK Economies: Same Results

- Intertemporal Keynesian cross (proper DIS):

$$y_t = c_t = \mathscr{C}\left(\left\{\bar{E}_t[y_{t+k}]\right\}_{k=0}^{\infty}, \left\{\bar{E}_t[i_{t+k} - \pi_{t+k+1}]\right\}_{k=0}^{\infty}\right) + \rho_t$$

- Standard NKPC or incomple-info variant:

$$\pi_t = \kappa y_t + \beta \mathbb{E}_t^*[\pi_{t+1}] + \xi_t \qquad \text{or} \qquad \pi_t = \Pi\left(\left\{\bar{E}_t[y_{t+k}]\right\}_{k=0}^{\infty}, \left\{\bar{E}_t[\pi_{t+k}]\right\}_{k=0}^{\infty}\right)$$

- Monetary policy:

$$i_t = \iota_t + \phi_c c_t + \phi_\pi \pi_t + \dots$$

**Proposition 5**

With fading memory ($\lambda > 0$), the equilibrium is **unique** and is given by the **MSV** solution.

# Feedback Rules and Policy Communication

- No need for equilibrium selection via Taylor principle
- No need to communicate
  - either "a threat to blow up interest rate" (Cochrane)
  - or "sophisticated" off-equilibrium policies (Atkeson, Chari & Kehoe)
- Use feedback rules merely for stabilization/replication of optimal contingencies

# A New Take on Animal Spirits

- Despite unique equil, **room for sunspot-like fluctuations** via
  - overreaction to noisy public news (Morris & Shin, 02)
  - shocks to higher-order beliefs (Angeletos & La'O, 13, Benhabib et al, 15)
  - bounded rationality (Angeletos & Sastry, 21)
- The slope of the Taylor rule admits a new function:
  - **regulate complementarity / HOB / bounded rationality** $\Rightarrow$
  - regulates magnitude of sunspot-like fluctuations along the unique equil
- TP recast as a form of **stabilization instead equil selection**

# Fiscal Theory of Price Level (within NK model)

- textbook NK model = 3 equations (DIS+PC+MP)
- add 4th equation:

$$\frac{B_{t-1}}{P_t} = PVS_t$$

- **Q**: how is this equation satisfied? and does it matter for $P_t$, $\pi_t$ and $y_t$?

- **Conventional**: assume TP, fix $P_t$ according to MSV, let $PVS_t$ adjust

- **FTPL**: fiscal authority picks path for $PVS_t$, and path of $P_t$ adjusts to it
  - fully coherent, does *not* require a threat to "blow up" gov budget (Bassetto, Cochrane)
  - breaks Ricardian equivalence "by force of equilibrium selection"
  - very different predictions at ZLB and more generally

# Fiscal Theory of Price Level: Our Prism

**Proposition**

Assume:
1. infinite horizons, individual optimality
2. first-order knowledge of: Phillips curve, $Y = C$, and $B/P = PVS$

Then:
- ✓ same game representation for $c_t$ as when there is no gov
- ✓ gov debt and deficits are payoff irrelevant (sunspots)

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✓ gov debt and deficits are payoff irrelevant (sunspots)

- Corollary: eq. selected by FTPL is not robust to our perturbations

| | Fiscal Policy is | |
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| Taylor holds | Determinacy | No equilibrium |
| does not hold | Determinacy | No equilibrium |

- Caveat: are our assumptions realistic? Even if not: FTPL = debt is a sunspot

# Take-home Messages and Future Work

- General warning: as in global games, multiplicity can strike back with enough CK
- Still, our results
  - shed new light on NK indeterminacy
  - help bypass equil-selection conundrum
- Recast **Taylor principle** as stabilization instead equil selection
- Push **FTPL** outside the equilibrium selection logic
  - example 1: model MP-FP interaction as a game of chicken
  - example 2: model joint regulation of game/beliefs by MP and FP

# Example 2: MP, FP, and Beliefs

- Perpetual youth OLG (survival rate $\omega$) and rigid prices (for simplicity).

- MP and FP: $i_t = \imath_t + \phi y_t$ $\quad$ $\text{surpluses}_t = s_t + \tau_b b_t + \tau_y y_t$

- Implied game among consumers:

$$c_t = \bar{E}_t \left[ \theta_t + \left( \text{mpc} \left( 1 - \tau_y \frac{1-\omega}{1-\omega(1-\tau_b)} \right) - (1 - \text{mpc})\sigma\phi \right) \sum_{k=0}^{+\infty} (\beta\omega)^k c_{t+k} \right]$$

$\theta_t \equiv (\imath_t, s_t, b_t)$ and $\text{mpc} \equiv 1 - \beta\omega$

$c_t$ and $\pi_t$ depend on HOB of $\theta_{t+k}$ $\rightarrow$ beliefs of future interest rates and deficits

- Effective complementarity decreases with both $\phi$ and $\tau_y$ $\Longrightarrow$
more "active" policies complement each other in arresting sunspot-like beliefs

# Outline

# "Fixing" the MSV solution

- Standard approach combines:
  1. Common knowledge about sunspots / payoff-irrelevant history
  2. Common knowledge about fundamentals / payoff-relevant future

- **What we did so far**: preserved (2), relaxed (1) $\Longrightarrow$ determinacy

- **Complement**: relax (2) $\Longrightarrow$ **improve predictions of MSV solution**
  - Woodford, Sims, Mankiw-Reis, Nimark, Mackowiac-Wiederholt ...
  - some of my own earlier work ...
  - different focus, but common thread: HOB anchored to steady state

# "Fixing" the MSV solution (Angeletos & Huo, AER 2021)

- Start with a FIRE model:

$$x_t = \theta_t + \delta \mathbb{E}_t^\star[x_{t+1}]$$

  where $x_t = c_t, I_t, \pi_t$ or asset price$_t$

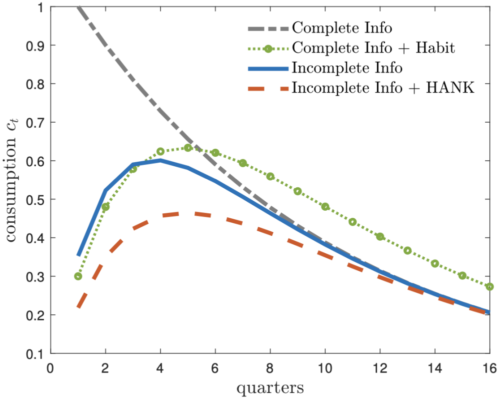
- Introduce noisy info and higher-order uncertainty (or, RI plus imperfect cognition)

- Main result: equivalent to FIRE plus two behavioral distortions:

$$\boxed{x_t = \theta_t + \omega_f \delta \mathbb{E}_t^\star[x_{t+1}] + \omega_b x_{t-1}}$$

  - $\omega_f < 1$ ("myopia") and $\omega_b > 0$ ("anchoring" or "momentum")
  - myopia + habit in $C$, adj cost in $I$, hybrid NKPC, momentum in AP
  - distortions increase with complementarity (e.g., liquidity frictions and slope of Keynesian cross in AD context, or fraction on short-run traders in AP context)
  - disciplined by survey evidence on expectations (e.g., Coibion-Gorodnichenko)

# Example: HANK meets HOB




Response of $c_t$ to an MP shock

- Example from Angeletos & Huo "Myopia and Anchoring"
- See also Auclert et al "Micro Jumps and Macro Humps"

# Frictions in Info/Coordination: Two Birds with One Stone

- Existing literature:
  - make standard solution more palatable empirically
  - reduce forward-guidance puzzle
  - add effects akin to habit in $C$, adjustment costs in $I$, or hybrid NKPC
- Our latest paper:
  - shed new light on NK indeterminacy issue
  - recast Taylor principle as stabilization
  - help push FTPL to new directions