Determinacy without Taylor principle

Plus: FTPL; beliefs, AD, and inflation

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Outline

1. Introduction
2. Preamble: Flexible vs Rigid vs Sticky Prices
3. A simplified NK economy (and our game representation)
4. Standard paradigm
5. Uniqueness with fading social memory
6. Extensions and applied lessons
7. Relation to prior work on info frictions
Indeterminacy in NK Model


- **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”?

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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 ⇒ break the chain ⇒ determinacy
  - always select standard equil (aka MSV solution), even with interest rate pegs

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- Applied lessons:
  - recast Taylor principle as stabilization instead equil selection
  - push for reformulating FTPL outside the equil selection conundrum
Flexible vs Rigid Prices

- **Flex prices** \( (\kappa = \infty) \):
  
  Fisher eq + Taylor rule in \( \pi_t \) \( \Rightarrow \) \( \mathbb{E}_t[\pi_{t+1}] = i_t = \phi \pi_t \) \( \Rightarrow \) unique iff \( |\phi| > 1 \)
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- Fisher eq + Taylor rule in $p_t$ \( \Rightarrow \quad \mathbb{E}_t[p_{t+1}] - p_t = i_t = \chi p_t \quad \Rightarrow \quad \text{unique iff } |1 + \chi| > 1 \)

- Same math, but subtle differences:
  - nominal vs real indeterminacy
  - puts spotlight on spending decisions and Keynesian multipliers
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- **Rigid prices \( \kappa = 0 \):**
  
  DIS + MC + Taylor rule in \( y_t \) \( \Rightarrow \quad E_t[c_{t+1}] - c_t = i_t = \chi c_t \quad \Rightarrow \quad \text{unique iff } |1 + \chi| > 1 \)
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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 ...
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A Simplified NK Economy

- Cashless, nominal bond in zero net supply, zero taxes
- Overlapping generations of consumers, each living two periods:
  \[ u(C_{i,t}^1) + \beta u(C_{i,t+1}^2)e^{-\rho t} \]
  \[ P_t C_{i,t}^1 + B_{i,t} = P_t Y_t \]
  \[ P_{t+1} C_{i,t+1}^2 = P_t Y_{t+1} + I_t B_{i,t} \]

- Old = “robots” or “hand to mouth”
  - \( C_{it}^2 \) adjusts to meet second-period budget

- Young = “strategic”
  - optimally choose \( (C_{it}^1, B_{it}) \) given beliefs about \( Y_t, I_t, P_t \) and \( P_{t+1} \).
The DIS curve

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

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

- Zero agg saving (plus young and old earn same $y$) $\Rightarrow$ $\int c_{i,t}^1 di = \int c_{i,t}^2 di = c_t = y_t$

- 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 $\Rightarrow \bar{E}_t[.] = \mathbb{E}_t[.] \equiv \mathbb{E}[.]|\text{full info}] \Rightarrow$ 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:

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

2. Phillips curve (ad hoc for now):

\[ \pi_t = \kappa c_t + \xi_t \]  \hspace{1cm} (PC)

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

\[ i_t = \iota_t + \phi \pi_t \]  \hspace{1cm} (MP)
From 3 eqs to 1 eq (and a game representation)

- Substituting MP and PC in DIS ⇒

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

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 \( \{\rho_t, \xi_t, t_t\} \)
From 3 eqs to 1 eq (and a game representation)

- Substituting MP and PC in DIS ⇒
  \[ c_t = \bar{E}_t[\delta_0 c_t + \delta_1 c_{t+1} + (1-\delta_0)\theta_t] \]

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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 $= \text{MA representation}$

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

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

- **FIRE:** $E_{it} [\cdot] = \mathbb{E}_t^{\ast} [\cdot] \equiv$ RE conditional on full information about $h^t$

- Since both $c_t$ and $\theta_t$ are measurable in $h^t$

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

$$\delta \equiv \frac{\delta_1}{1 - \delta_0} = \frac{1 + \sigma \kappa}{1 + \sigma \kappa \phi} > 0$$ 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 $\delta \leq 1$, or equivalently $\phi \geq 1$
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,

$$c_t^\eta \equiv \sum_{k=0}^{\infty} \delta^{-k} \eta_{t-k}$$  \hspace{1cm} and \hspace{1cm} $$c_t^B \equiv -\sum_{k=1}^{\infty} \delta^{-k} \theta_{t-k}$$

sunspot eq. \hspace{1cm} backward-looking, pseudo-fundamental eq.
Understanding the Multiplicity (when $\phi < 1$, i.e. $\delta > 1$)

- **Equilibrium condition:**
  \[ c_{t-1} = \theta_{t-1} + \delta E^*_{t-1}[c_t] \]

- **Solving backwards:**
  \[
  E^*_{t-1}[c_t] = \delta^{-1} (c_{t-1} - \theta_{t-1}) \\
  c_t = \delta^{-1} (c_{t-1} - \theta_{t-1}) + \eta_t \\
  c_t = -\sum_{k=1}^{\infty} \delta^{-k} \theta_{t-k} + \sum_{k=0}^{\infty} \delta^{-k} \eta_{t-k}
  \]

  - Backward-looking pseudo-fundamental
  - Sunspot component

- **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
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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

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

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
  - $\lim_{k \to \infty} \mu_k = 0 \ \forall \ \lambda > 0$
Determinacy without the Taylor Principle

- For every $k$, mass who know past $k$ shocks is $\mu_k \equiv (1 - \lambda)^k$

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- But zero mass of agents has truly *infinite* memory
  - $\lim_{k \to \infty} \mu_k = 0 \quad \forall \lambda > 0$

**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:
  \[
  c_t = \delta \bar{E}_t[c_{t+1}]
  = \delta \bar{E}_t[a_{t+1} \eta_0]
  = \delta a_{t+1} \mu_t \eta_0
  = \delta \mu_t \bar{E}_t^*[c_{t+1}]
  \]

- Maps to “twin” FIRE economy with modified best response:
  \[
  c_t = \delta \bar{E}_t[c_{t+1}] \quad \rightarrow \quad c_t = \mu_t \delta \bar{E}_t^*[c_{t+1}]
  \]

- $\lim_{t \to \infty} \mu_t = 0 \Rightarrow \mu_T \delta < 1$ for $T$ large enough $\Rightarrow$ uniqueness after $T$

- By backward induction, uniqueness also before $T$
Logic

- Key idea: anticipation that social memory will fade
  \[\Rightarrow\text{perceived complementarity fades with horizon}\]
  \[\Rightarrow\text{determinacy}\]

- 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
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Robustness

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

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

- supported by “short” memory, \( l_{i,t} = \{\eta_t, c_{t-1}\} \)
- \( c_{t-1} \) 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 \( \pi_{t-1} \)):

\[ l_{i,t} = \{\eta_t, s_{i,t}\}, \quad s_{i,t} = c_{t-1} + \varepsilon_{i,t}, \quad \varepsilon_{i,t} \sim \mathcal{N}(0, \sigma) \]
Robustness

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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):

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

- Standard NKPC or incomple-info variant:

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

- Monetary policy:

\[
i_t = \iota_t + \phi_c c_t + \phi_\pi \pi_t + \ldots
\]

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** ⇒
    - 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)
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)

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

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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: $i_t = \iota_t + \phi y_t$ surpluses$_t = s_t + \tau_b b_t + \tau_y y_t$

- Implied game among consumers:

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

$\theta_t \equiv (\iota_t, s_t, b_t)$ and $mpc \equiv 1 - \beta \omega$

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 $\tau_y$ $\implies$ more “active” policies complement each other in arresting sunspot-like beliefs
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“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) \(\implies\) determinacy

- **Complement**: relax (2) \(\implies\) **improve predictions of MSV solution**
  - Woodford, Sims, Mankiw-Reis, Nimark, Mackowiak-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:
  \[ x_t = \theta_t + \delta E_t^* [x_{t+1}] \]
  where \( x_t = c_t, l_t, \pi_t \) 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:
  \[ x_t = \theta_t + \omega_f \delta E_t^* [x_{t+1}] + \omega_b x_{t-1} \]
  ▶ \( \omega_f < 1 \) ("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

- 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