Lecture 2

Macroeconomics with imperfect coordination

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Outline

1. Overview
2. Imperfect Common Knowledge and the Effects of Monetary Policy
3. The RBC Model and Responses to Technology Shocks
4. The New-Keynesian Model, Forward Guidance, and Imperfect Dynamic Coordination
5. Level-k Thinking in NK models
6. Cognitive Discounting

Macro Applications with Static Best Responses

Imperfect Common Knowledge and the Effects of Monetary Policy (Woodford, 03)

$$p_{i,t} = (1-\alpha)\, E_{i,t}[m_t] + \alpha E_{i,t}[p_t]$$

- Imperfect coordination as source of **nominal rigidity**
- **Inertia in price and inflation responses**

The RBC Model and Responses to Technology Shocks (Angeletos & La'O, 10)

$$y_{i,t} = (1-\alpha)\chi A_{i,t} + \alpha \mathbb{E}_{i,t}[y_t]$$

- Imperfect coordination as source of real rigidity
- **Negative short-run response of employment to productivity shocks** (Gali, 99)
- Inertia in output responses

Dynamic Macro Applications

- Dynamics I: **Learning** (inertia even with static best responses, as in the previous slides)
- Dynamics II: **Forward-looking behavior/best responses**

$$y_t = -\sigma \left\{ \sum_{k=0}^{+\infty} \beta^k \bar{E}_t[r_{t+k}] \right\} + (1-\beta) \left\{ \sum_{k=1}^{+\infty} \beta^{k-1} \bar{E}_t[y_{t+k}] \right\}$$

- Q: How does the economy respond to news about the future?
  - e.g., news about future interest rates
- Imperfect intertemporal coordination and forward guidance puzzle
  - Angeletos & Lian (18, noisy/incomplete info)
  - Farhi & Werning (19, level-k)

Pause for Questions

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Woodford (2003): Imperfect Common Knowledge and the Effects of Monetary Policy

- Optimal price by firm $i \in [0,1]$:

$$p_{i,t} = (1-\alpha)\, E_{i,t}\left[m_t\right] + \alpha E_{i,t}\left[p_t\right],$$

  where $p_t = \int p_{i,t} di$ and $m_t = p_t + y_t$ is the exogenous nominal GDP
  - exogenous money supply (central bank) & constant velocity of money

- Δm_t follows an AR(1) process with innovations v_t:

$$\Delta m_t = \rho \Delta m_{t-1} + v_t$$

- Private signal about m_t

$$x_{i,t} = m_t + \varepsilon_{i,t}$$

Inertia in Higher-order Beliefs

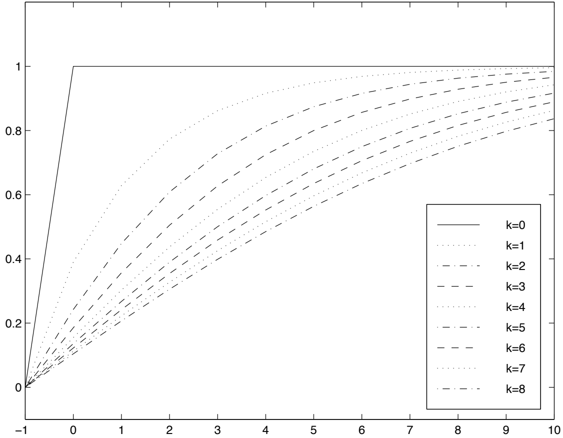
- As in the previous lecture, iterating

$$p_t = (1-\alpha)\sum_{k=1}^{\infty}\alpha^{k-1}\bar{E}_t^k[m_t]$$

- Here, beliefs will adjust over time because of learning
- But beliefs of higher order $\bar{E}_t^k[m_t]$ adjust more sluggishly
  - **with incomplete info, harder to know how much others have learned**

Inertia in Higher-order Beliefs

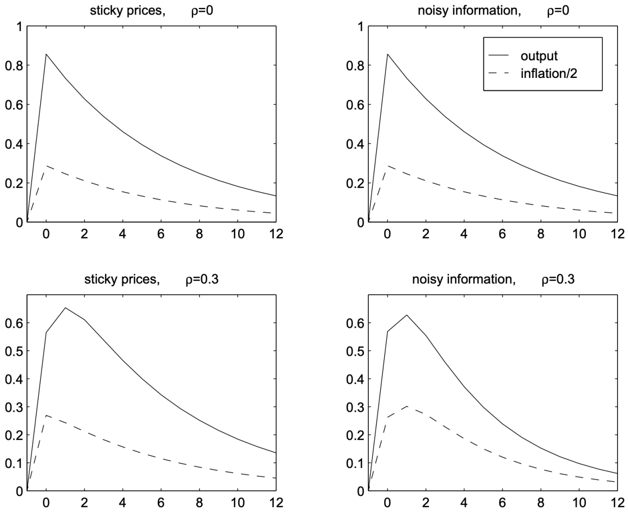
- Use $\rho = 0$ case as an example



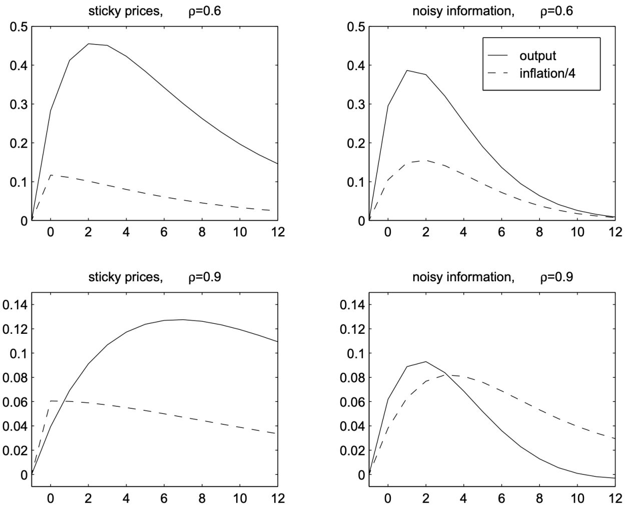
Inertia in the Price Level and Inflation

- The inertia in HOB translates to **inertia in the price level**
  - the more so the stronger the complementarity
- The price level can **adjust very slowly to the monetary shock**
  - even if every agent learns fast about the shock
- When ρ is high enough, one can get empirically desirable property of **inflation inertia**
  - "sticky inflation"
  - it is *impossible* to get this from the Calvo sticky-price

Inertia in Inflation



Inertia in Inflation



Inertia in Medium-Scale DSGE models

Quantitative NK models such as Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007) generate such empirically relevant **inertia in inflation (and output)** by

- (i) adding adjustment costs of investment and habit in consumption
- (ii) replacing the standard NKPC with Hybrid NKPC with "indexing"

But micro-level empirical support of those elements controversial

Imperfect coordination with strong strategic complementarity offers a alternative

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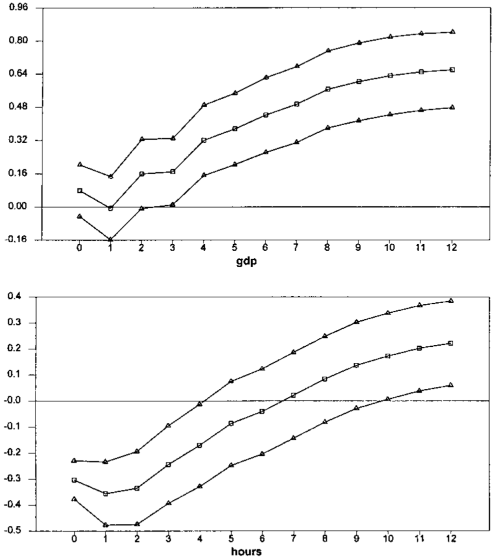
The Gali (1999) Puzzle for RBC Models

- A structural VAR method to estimate IRFs to an identified technology shock in US data
  - the technology shock as the only shock that drives labor productivity in the long run
- **Inertia in the response of output to productivity shocks**
- **Employment may actually *decrease* on impact**
  - completely opposite to RBC models
  - consistent with NK models (with contractionary monetary policy responses)
- Similar finding for Basu, Fernald, Kimball (2006)

The Gali (1999) Puzzles for RBC Models



An Alternative Flexible-Price Model Based on Imperfect Coordination

- Angeletos & La'O (2010). Noisy business cycles. NBER Macroeconomics Annual.
- Baseline RBC model (without investment) + **incomplete info about TFP shocks**
- Inertia in the response of aggregate output
- Even a negative initial response in employment

Decisions and Information

- Optimal production decisions:

$$y_{i,t} = (1-\alpha)\chi A_{i,t} + \alpha \mathbb{E}_{i,t}[y_t],$$

  where $y_t = \int y_{i,t} di$.

- Island structure:
  - knowledge of local TFP $A_{i,t} = A_t + \xi_{i,t}$ serves as a noisy private signal about aggregate TFP
  - also allows a public signal

- Solution: methods of undetermined coefficients + Kalman filter

Predictions (recall employment $n_t = \frac{1}{\theta}(y_t - A_t)$)

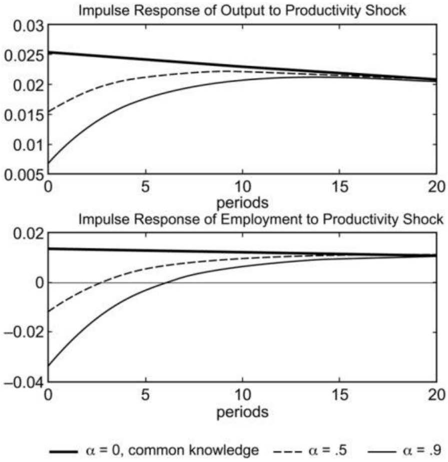


Fig. 1. Impulse responses to a positive innovation in productivity

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Forward Guidance without Common Knowledge (Angeletos & Lian, 2018)

Context: A NK Economy at the ZLB

Forward guidance (FG): the central bank attempts to stimulate AD by committing to keep interest rates low after the economy exits the trap and the ZLB

Forward guidance puzzle: under FIRE, forward guidance is extremely powerful

- Explosive dynamic general-equilibrium effects (y_t and π_t depend on π_{t+k} and y_{t+k})
  - Keynesian multiplier, $\pi - y$ feedback
- Perfect dynamic coordination across **periods**

Main Findings

Key insight:

- Removing common knowledge of the FG news $\Longrightarrow$ imperfect dynamic coordination
- **Anchors expectations** of future y and π
- **Attenuates dynamic GE feedback loops**
- **Attenuation larger the longer these loops (horizon effect)**

Implications:

- Lessen forward guidance puzzle
- Offer rationale for front-loading fiscal stimuli

A More General IS Robust to Incomplete Info

- Individual rationality + individual budget constraint + aggregation:

$$c_t = y_t = -\sigma \left\{ \sum_{k=0}^{+\infty} \beta^k \bar{E}_t[r_{t+k}] \right\} + \underbrace{(1-\beta) \left\{ \sum_{k=1}^{+\infty} \beta^{k-1} \bar{E}_t [y_{t+k}] \right\}}_{\text{Dynamic Keynesian Multiplier}}$$

- **Dynamic beauty contest** among consumers
  - follows from PIH and $c = y$
  - dynamic GE: intertemporal Keynesian income multiplier

- FIRE benchmark $E_{i,t}[\cdot] = \mathbb{E}_t[\cdot]$, where $\mathbb{E}_t[\cdot]$ is FIRE expectation

$$y_t \;=\; -\sigma \mathbb{E}_t[r_t] \;+\; \mathbb{E}_t[y_{t+1}],$$

  where $r_t = i_t - \pi_{t+1}$ is the real rate between t and $t+1$.

- Why no recursive without FIRE?
  - Law of iterated expectation **do not hold** for $\bar{E}_t[\cdots]$

$$\bar{E}_t\left[\cdots \bar{E}_{t_1}\left[\cdots \bar{E}_{t_2}[\cdot]\right]\right] = \bar{E}_t[\cdot]$$

Question of Interest

- To develop intuition, focus on the demand block first
  - treat **real interest rate** $\{r_t\}_{t=0}^{+\infty}$ path exogenous
  - e.g., rigid price or CB directly controls real rate path
- Q: How does y_0 responds to news about $\bar{E}_0[r_T]$?
  - Isolate the effect of **frictional intertemporal coordination**
  - On top of any mechanical effect of first order informational friction

FIRE Benchmark

- FIRE benchmark:

$$E_{i,t}\left[r_{t+k}\right] = r_{t+k} \quad \text{and} \quad E_{i,t}\left[y_{t+k}\right] = y_{t+k}$$

- **Proposition**. Under FIRE,

$$\frac{\partial y_0}{\partial r_T} = \underbrace{-\sigma\beta^T}_{\text{PE}} + \underbrace{(1-\beta)\left\{\sum_{k=1}^{T}\beta^{k-1}\frac{\partial y_k}{\partial r_T}\right\}}_{\text{GE}} = -\sigma$$

  - PE effect of r_T on c_0 *decreases* with T
  - GE effect of r_T on c_0 *increases* with T
  - Total effect independent of T despite declining PE

Incomplete Information

- **Information Structure:**
  - noisy private signals about r_T at $t=0$, $x_i = r_T + \varepsilon_i$
  - no learning

- **Belief anchoring:**

$$\bar{E}_t\left[r_{t+k}\right] = \lambda r_{t+k} \quad \text{and} \quad \bar{E}_t\left[y_{t+k}\right] = \lambda y_{t+k}$$

  - imperfect knowledge about **future aggregate action**

- **GE attenuation** due to imperfect intertemporal coordination:

$$\frac{\partial y_0}{\partial \bar{E}_0\left[r_T\right]} = \underbrace{-\sigma\beta^T}_{\text{PE}} + \underbrace{\lambda(1-\beta)\left\{\sum_{k=1}^{T}\beta^{k-1}\frac{\partial y_k}{\partial \bar{E}_0\left[r_T\right]}\right\}}_{\text{GE}}$$

Results

1. **Attenuation at any horizon**
   - $\phi_T = -\frac{dy_0}{d\bar{E}_0[r_T]}$ bounded between PE effect and CK counterpart:

$$\sigma\beta^T \;<\; \phi_T \;<\; \phi_T^* \equiv \sigma$$

   - "CK maximizes GE effect"

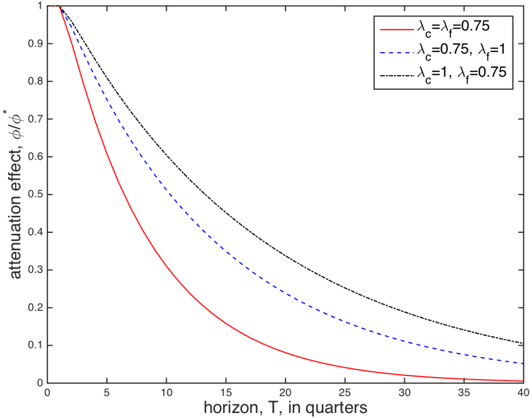
2. **Attenuation increases with the horizon**
   - ϕ_T/ϕ_T^* decreases in T
   - the distant future enters through multiple rounds of GE effects

3. **Attenuation grows without limit**
   - $\phi_T/\phi_T^* \to 0$ as $T \to \infty$ even if noise is tiny

Going Back to the Full NK model

- Demand block (IS):
  - attenuate GE feedback b/w c and y (Keynesian multiplier)
  - anchor **income expectations**
  - arrest response of c to news about future real rates
- Supply block (NKPC):
  - attenuate GE feedback from future to current π
  - anchor **inflation expectations**
  - arrest response of π to news about future marginal costs
- GE feedback b/w demand (IS) and supply (NKPC)
  - joint endogeneity of real rates and real marginal cost
  - attenuate **GE feedback between two blocks**

A Numerical Illustration (based on Gali, 2008)



- Modest info friction: $\lambda_c = \lambda_f = 0.75$ (25% prob that others failed to hear announcement)
- On **top** of any mechanical effect that first order informational friction

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Farhi & Werning (2019)

- As illustrated in the static case in Lecture 1
  - incomplete information and level-k thinking both capture imperfect coordination
  - generate similar predictions for the complementarity case
- Here: how to apply level-k thinking in dynamic NK models (dynamic complementarity)
  - similar predictions regarding the impact of forward guidance

Back to the Demand Block in the NK Model

$$y_t = -\sigma \left\{ \sum_{l=0}^{+\infty} \beta^l \bar{E}_t [r_{t+l}] \right\} + (1-\beta) \left\{ \sum_{l=1}^{+\infty} \beta^{l-1} \bar{E}_t [y_{t+l}] \right\}$$

- Follow Farhi and Werning (2019)
  - treat **real interest rate** path exogenous
  - e.g. rigid price or CB directly controls real rate path
- Level-0 outcomes (no shock, steady state outcomes)

$$y_t^0 = 0$$

Level-1 Outcomes

- Level-1 outcomes (expect all **future** endogenous outcomes are at level 0)

$$y_t^1 = -\sigma \sum_{l=0}^{+\infty} \beta^l r_{t+l} + (1-\beta) \left\{ \sum_{l=1}^{+\infty} \beta^{l-1} y_{t+l}^0 \right\}$$
$$= -\sigma \sum_{l=0}^{+\infty} \beta^l r_{t+l}$$

- Captures PE effects of interest rate changes

Level-k Outcomes

- Level-k outcomes (expect all **future** endogenous outcomes are at level $k-1$)

$$y_t^k = -\sigma \sum_{l=0}^{+\infty} \beta^l r_{t+l} + (1-\beta)\left\{ \sum_{l=1}^{+\infty} \beta^{l-1} y_{t+l}^{k-1} \right\}$$

- Define ϕ_T^k : macro impact of forward guidance at level-k

$$\phi_T^k = -\frac{\partial y_t^k}{\partial r_{t+T}}$$

Results

- Attenuation for any level and any horizon:

$$\underbrace{\phi_T^1}_{\text{PE only}} < \phi_T^k < \underbrace{\phi_T^*}_{\text{Frictionless}},$$

where $\phi_T^* = \lim_{k\to+\infty} \phi_T^k = \sigma$.

- **Attenuation increases with the horizon**

$$\phi_T^k / \phi_T^* \quad \text{decreases} \quad \text{in} \quad T$$

- **Attenuation decreases with the depth of reasoning**

$$\phi_T^k / \phi_T^* \quad \text{increases} \quad \text{in} \quad k$$

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Gabaix (20): Cognitive Discounting

- A more "reduced-form" method to model "anchored" forward looking expectations (**"cognitive discounting"**)

$$E_{i,t}\left[\mathrm{X_{t+k}}\right] = \bar{m}^{k} E_{t}\left[\mathrm{X_{t+k}}\right],$$

  no matter whether X_{t+k} is an exogenous or endogenous aggregate state.

- Extremely tractable and generalizable

- Sharp and empirically relevant predictions

- But micro-foundation delicate

A Behavioral IS Curve

- Applying cognitive discounting, aggregate, and using market clearing $y_t = c_t$

$$y_t = -\sigma \left\{ \sum_{k=0}^{+\infty} \beta^k \bar{m}^k E_t[r_{t+k}] \right\} + \frac{1-\beta}{\beta} \left\{ \sum_{k=1}^{+\infty} \beta^k \bar{m}^k E_t[y_{t+k}] \right\}$$

- Recursively, **a discounted aggregate Euler equation**

$$\begin{aligned} y_t &= -\sigma E_t[r_t] + \bar{m} E_t[y_{t+1}] \\ &= -\sigma \sum_{k=0}^{+\infty} \bar{m}^k E_t[r_{t+k}], \end{aligned}$$

where $M = \bar{m}$.

- Can directly see that the impact of forward guidance attenuated

Pause for Questions