Short-term Planning, Monetary Policy, and Macroeconomic Persistence

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*The views expressed are solely our responsibility and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of anyone else associated with the Federal Reserve System.
Recent **behavioral macro models** emphasize that agents’ expectations can be rooted in human judgement and experimental evidence instead of being assumed fully-rational.

- *Gabaix’s (2018)* limited attention model.
- *Angeletos and Lian’s (2016)* lack of common knowledge.
- *Farhi and Werning’s (2017)* k-level thinking.
- *Woodford’s (2018)* finite planning horizons (FH).

Do “new behavioral” models provide empirically-realistic macro dynamic to study the effects of monetary policy?
Motivation: Macroeconomic Persistence

“The pervasiveness of sluggish responses in the macro data, combined with the implausibility of many of the micro stories underlying adjustment cost models, suggests that we look for a different approach to modeling the sources of inertia in both prices and real variables.”

*Sims (1998), Stickiness.*
Plan of the Presentation

- **Heuristic** description of finite-horizon planning.

- **Preview** of the results.

- **Formal** representation of the *aggregate equilibrium*.
  - Microeconomic heterogeneity.
  - Value function updating and *trend-cycle* decomposition.
  - Short-term planning and monetary policy.
    - A new trend-cycle decomposition.
    - A (modified) Taylor principle.

- **Estimation results**.
  - Two key parameters.
  - Trend-cycle decomposition of US output, inflation, and short-term rate.
  - Individual heterogeneity: *disagreement of expectations*. 
Finite-Horizon Planning: Heuristic
Finite-Horizon (FH) Planning

- The backbone of the model is NK.

- Agents make plans over a finite horizon (FH):
  - Too costly to search all possible decision tree (infinite-horizon state-contingent plan, "Borges' garden of forking paths")
  - They transform an infinite-horizon problem into a sequence of shorter finite-horizon ones (finite future.)
  - They are "boundedly rational" in thinking about the continuation values of their plans.
  - They (learn) update their beliefs on the continuation values of their plans based on past data/experience.

- Agents are forward-looking in thinking about events over their planning horizon, but are also backward looking in thinking about events beyond that point.

- HANK: Rich cross-sectional heterogeneity in the length of planning horizons.
K-Horizon Plan: Time Diagram

\[ t \quad \text{to} \quad t+K \]
K-Horizon Plan: Time Diagram
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- Time horizon from $t$ to $t+K$
- Periods $t+1$, $t+2$, ..., $t+K$ for $K$, $K-1$, $K-2$, ..., 1, 0
- Variable $V_t$
K-Horizon Plan: Time Diagram
The model generates persistence through a novel “trend-cycle decomposition.”

- The “cyclical component” depends on agents’ forward-looking behavior over their planning period (i.e., absent learning).

- The “trend component” reflects how agents update beliefs about their continuation plans (i.e., value functions) to past information.
  - Without habits in consumption, indexation clauses, and interest-rate smoothing.
  - Without purely “backward-looking expectations.”
Preview of the Results
We estimate the FH model using **U.S. quarterly data on output, inflation, and interest rates from 1966 until 2007.**

- About 50 percent of agents plans for the current-quarter, and a small fraction have planning horizons beyond 2yrs.
- Agents update their value functions slowly in response to incoming data.

**Model goodness of fit is substantially better than:**

- The hybrid-NK model and other behavioral macro models (such as *Angeletos and Lian’s (2016)* and *Gabaix’s (2018)*.)
Model generates “substantial persistence” in output, inflation, and interest rates.

- Without any of the usual mechanisms and without “interest-rate smoothing.”

Business cycle matches “conventional wisdom.”

Measure of trend inflation displays similar movements to the SPF measure of longer-term inflation expectations.

“Disagreement about inflation expectations” due to agents’ heterogeneous plans matches the contour derived from the Michigan Survey.
The Formal Model
Households K-Horizon Planning

- HH problem in $t$ is to choose state-contingent plan $C_\tau(s_\tau)$ for periods $t \leq \tau \leq t + k$ to maximize:

$$
\mathbb{E}_t^k \left[ \sum_{\tau=t}^{t+k} \beta^{\tau-t} u(C_\tau, \xi_\tau) + \beta^{k+1} \vartheta(B_{t+k+1}, s_{t+k}) \right]
$$

subject to the budget constraint

$$
B_{\tau+1} = (1 + i_\tau) \left[ \frac{B_{\tau+1}}{\Pi_\tau} + Y_\tau - C_\tau \right]
$$

- The nominal value of government debt maturing in period $\tau$ is deflated by the aggregate price level $P_{\tau-1}$.

- $\vartheta(B_{\tau+1}, s_\tau)$ is the value function used by the HH to evaluate situations in final state $\tau$.

- $\mathbb{E}_t^k[\cdot]$ is the expectation at time $t$ for agents with $k$ forward planning horizon.
Households K-Horizon Planning

- **Optimal plan** for $t \leq \tau \leq t + k$

$$ u_c(C_\tau, \xi_\tau) = \beta \mathbb{E}_t^k \left[ \frac{1 + i_\tau}{\Pi_{\tau+1}} u_c(C_{\tau+1}, \xi_{\tau+1}) \big| \sigma_\tau \right] \quad \text{and} \quad u_c(C_{t+k}, \xi_{t+k}) = \beta (1 + i_{t+k}) \vartheta_B(B_{t+k+1}, s_{t+k}) $$

- **Expectations** in $t \leq \tau \leq t + k$ used in planning:
  
  - Understand the model structure during the planning.
  - For any $j$ periods between $t$ and $t + k$, aggregate conditions in $t + j$ assumed to be determined by $k - j$ horizon forward looking HHs

$$ t \leq \tau \leq t + k : \quad \mathbb{E}_t^k \{ Z_\tau \big| \sigma_\tau \} = E_t \{ Z_{\tau+k-\tau} \} $$

$$ t + 1 \leq \tau \leq t + k : \quad \mathbb{E}_t^k \{ Z_{\tau+1} \big| \sigma_\tau \} = E_\tau \{ Z_{\tau+1}^{t+k-\tau} \} $$

- Assume the same planning horizon for all others.
Households K-Horizon Planning

- **Optimal plan** for $t \leq \tau \leq t + k$ and $1 \leq j \leq k$ the intertemporal decision is given by:

$$
uc(C^j_\tau, \xi_\tau) = \beta E_{\tau} \left[ \frac{(1 + i^j_\tau)}{\Pi_{j-1}^{t+1}} uc(C^{j-1}_{\tau+1}, \xi_{\tau+1}) \right]
$$

$$
uc(C^0_\tau, \xi_\tau) = \beta (1 + i_\tau) \theta_B (B^0_{\tau+1}; s_\tau)
$$

- **Log-linear approx.** (constant $\theta(B) = \frac{u(C, \xi)}{1-\beta}$; $Y = C$):

$$
\tilde{y}^j_t - \xi_t = E_t [\tilde{y}^{j-1}_{t+1} - \xi_{t+1}] - \sigma (i^j_t - E_t \tilde{\pi}^{j-1}_{t+1}), \ 1 \leq j \leq k
$$

$$
\tilde{y}^0_t - \xi_t = -\sigma \tilde{i}^0_t, \ j = 0
$$

- HHs solve this plan at $t$ by **backward induction from** $t + k$. 
Firms K-Horizon Planning

- **Firms choose** $P^f_t$ of good $f$ to maximize:

$$
\mathbb{E}^f_t \left[ \sum_{\tau=t}^{t+k} (\alpha \beta)^{\tau-t} \lambda_{\tau} \phi^f (\tilde{p}^f_t, A_\tau) + (\alpha \beta)^{k+1} \varphi^f (\tilde{p}^f_{t+k}) \right]
$$

where $\tilde{p}^f_t = \frac{P^f_t \prod_{\tau=t}^{t+k-1}}{P_\tau}$.

- **Optimal plan**:

$$
\mathbb{E}^f_t \left[ \sum_{\tau=t}^{t+k} (\alpha \beta)^{\tau-t} \lambda_{\tau} \phi^f (\tilde{p}^f_t, A_\tau) \frac{P^f_t \prod_{\tau=t}^{t+k-1}}{P_\tau} + (\alpha \beta)^{k+1} \varphi^f (\tilde{p}^f_{t+k}) \frac{P^f_t \prod_{\tau=t}^{t+k-1}}{P_{t+k}} \right] = 0
$$

- **Log-linear approximation** (constant $\varphi^f (\tilde{p}^f) = \frac{\lambda \phi^f (\tilde{p}^f)}{1-\alpha \beta}$):

$$
\tilde{\pi}^j_t = \beta E_t [\tilde{\pi}^j_{t+1}] + \kappa (\tilde{y}^j_t + \zeta_t - y^*_t), 1 \leq j \leq k
$$

$$
\tilde{\pi}^0_t = \kappa (\tilde{y}^0_t + \zeta_t - y^*_t), j = 0
$$
Heterogeneous Planning and Aggregation

- Let $\omega_j$ be the fraction of HHs (and Fs) with planning horizon $j$ ($\forall j = 0, 1, 2, ...$). Such that $\sum_j \omega_j = 1$.

- Exponential Distribution: $\omega_j = (1 - \rho) \rho^j$, $0 < \rho < 1$

**Aggregates:**

$$\tilde{y}_t = (1 - \rho) \sum \rho^j \tilde{y}_t^j \quad \tilde{\pi}_t = (1 - \rho) \sum \rho^j \tilde{\pi}_t^j$$
Cyclical Dynamics (Constant Value Functions)

- **NK-FH model (cycle):**

\[
\begin{align*}
\tilde{y}_t & = \rho E_t[\tilde{y}_{t+1}] - \sigma \left[ \tilde{i}_t - \rho E_t(\tilde{\pi}_{t+1}) \right] \\
\tilde{\pi}_t & = \beta \rho E_t[\tilde{\pi}_{t+1}] + \kappa \tilde{y}_t + \kappa(\xi_t - y^*_t) \\
\tilde{i}_t & = i^*_t + \phi_\pi \tilde{\pi}_t + \phi_y \tilde{y}_t
\end{align*}
\]

and the baseline NK model if \( \rho \to 1 \).

- **In a more compact form:**

\[
\tilde{x}_t = \rho M E_t\{\tilde{x}_{t+1}\} + Nu_t
\]

where \( \tilde{x}_t = (\tilde{y}_t, \tilde{\pi}_t)' \).

\[
M = \frac{1}{\delta} \begin{pmatrix} 1 & \sigma(1 - \beta \phi_\pi) \\ \kappa & \kappa \sigma + \beta(1 + \sigma \phi_y) \end{pmatrix}
\]

\[
\delta = 1 + \sigma(\phi_y + \kappa \phi_\pi).
\]
Modified Taylor Principle

\[ 1 - \frac{\rho \beta}{\kappa} \phi_y + \phi_\pi > \rho \]
Modified Taylor Principle

\[ \frac{1 - \beta \rho}{\kappa} \phi_y + \phi_\pi > \rho \]
Updating the value function leads to changes in trends:

\[ \tilde{y}_t = y_t - \tilde{\zeta}_t - \bar{y}_t = (1 - \rho) \sum_j \rho^j (y^j_t - \bar{y}^j_t) - \tilde{\xi}_t \]

\[ \tilde{\pi}_t = \pi_t - \bar{\pi}_t = (1 - \rho) \sum_j \rho^j (\pi^j_t - \bar{\pi}^j_t) \]

\[ \tilde{i}_t = i_t - \bar{i}_t = (1 - \rho) \sum_j \rho^j (i^j_t - \bar{i}^j_t) \]

Without updating the value functions: \( \bar{y}_t = \bar{\pi}_t = \bar{i}_t = 0. \)
Trend Component and Value Function Updating

- Time-varying trends arise from adjustment in agents’ beliefs about the continuation values of their plans.

- The zero (last bit of planning) condition depends upon the aggregate value functions of households ($\nu_t$) and firms ($\tilde{\nu}_t$):

  $$\bar{y}_{t+k}^0 = -\sigma \bar{i}_{t+k}^0 + \nu_t$$
  $$\bar{\pi}_{t+k}^0 = \kappa \bar{y}_{t+k}^0 + (1 - \alpha) \beta \tilde{\nu}_t$$

- For any planning horizon $j \geq 1$ and any date between $t$ and $t + j$, updating (shooting backward algorithm):

  $$\bar{y}_{t+j}^j = \bar{y}_{t+j}^{j-1} - \sigma [\bar{i}_{t+j}^j - \bar{\pi}_{t+j}^{j-1}] \text{ and } \bar{\pi}_{t+j}^j = \beta \bar{\pi}_{t+j}^{j-1} + \kappa \bar{y}_{t+j}^j$$

- How do the value functions evolve? Agent’s learning.
Value Function Updating: Learning

- **Constant-gain learning for HHs and Firms:**
  \[
  \nu_{t+1} = (1 - \gamma)\nu_t + \gamma \nu_{est}^{t} \\
  \tilde{\nu}_{t+1} = (1 - \tilde{\gamma})\tilde{\nu}_t + \tilde{\gamma} \tilde{\nu}_{est}^{t}
  \]

  The parameters $\gamma$ and $\tilde{\gamma}$ are the constant (learning) gains.

- $\nu_{est}^{t}$ and $\tilde{\nu}_{est}^{t}$ are the estimated value functions from period-$t$ decision.

- The **continuation values** depend upon (a coarse description of states) aggregate information acquired at time $t$
  \[
  \nu_{est}^{t} = y_t - \zeta_t + \sigma \pi_t \\
  \tilde{\nu}_{est}^{t} = (1 - \alpha)^{-1} \pi_t
  \]
Monetary Policy

- **Systematic response to cyclical components**
  \[ \tilde{i}_t = i_t^* + \phi_\pi \tilde{\tau}_t + \phi_y \tilde{y}_t \]

- **Response to trends (time-varying intercept):**
  \[ \bar{i}_t = \phi_y \bar{y}_t + \phi_\pi \bar{\tau}_t \]

with \( \phi_y \geq 0, \phi_\pi \geq 0 \).

- **Testable implications:** \( \phi_y = \bar{\phi}_y \) and \( \phi_\pi = \bar{\phi}_\pi \).
  \[ i_t = \bar{i}_t + \phi_\pi \bar{\tau}_t + \phi_y \bar{y}_t + i_t^* \]
  or
  \[ i_t = \phi_\pi \bar{\tau}_t + \phi_y \bar{y}_t + i_t^* \]
Aggregate Equilibrium Dynamics

- **Aggregate dynamics with learning:**

\[
\tilde{x}_t = \rho M E_t\{\tilde{x}_{t+1}\} + N u_t \\
\bar{x}_t = F \bar{x}_{t-1} + (1 - \rho)\gamma Q \tilde{x}_{t-1} \\
\tilde{x}_t = x_t - \bar{x}_t
\]

Assuming \(\gamma = \tilde{\gamma}\), then \(Q\) becomes:

\[
Q = \frac{1}{\Delta} \begin{pmatrix} 1 - \beta \rho & \sigma (1 - \beta \bar{\phi}_\pi) \\ \kappa & \kappa \sigma + (1 - \rho + \sigma \bar{\phi}_y) \beta \end{pmatrix}
\]

with \(\Delta = (1 - \beta \rho)(1 - \rho + \sigma \bar{\phi}_y) + \kappa \sigma (\bar{\phi}_\pi - \rho)\).
Monetary Policy and the Passthrough from Cycle to Trend

Effects of $\tilde{y}_t$ on $\tilde{y}_{t+1}$

Effects of $\tilde{\pi}_t$ on $\tilde{\pi}_{t+1}$
Estimation Using Aggregate Data
Data and Estimation

- Estimate the model over sample 1966:Q1–2007:Q4, with three observables:
  
  \[
  \begin{align*}
  \text{Output Growth}_t &= \mu^Q + y_t - y_{t-1} \\
  \text{Inflation}_t &= \pi^A + 4\pi_t \\
  \text{Interest Rate}_t &= \pi^A + r^A + 4i_t
  \end{align*}
  \]

- Period with notable low-frequency variation in these time series.

- We allow for three – AR(1) – shocks: Technology, Preferences, Monetary Policy.

- We estimate the vector of parameters of the model, \( \theta \), using Bayesian techniques.
## Key Parameters of the Estimated Models

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<thead>
<tr>
<th>Model Type</th>
<th>Estimated</th>
<th>Fixed</th>
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<td>( \phi_\pi, \phi_y )</td>
<td>( \rho = 1 )</td>
<td>( \gamma, \tilde{\gamma}, \bar{\phi}_\pi, \bar{\phi}_y )</td>
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<td>( \phi = \bar{\phi} )</td>
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### Selected Parameter Estimates: Posterior Distributions

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Model Fit

- Joint posterior dist. of $\rho$ and $\gamma$
Model Fit

- Joint posterior dist. of $\rho$ and $\gamma$

\[ \Delta_t = \log \frac{\hat{\rho}_{FH}(Y_{1:t})}{\hat{\rho}_{Forward}(Y_{1:t})} \]
Ranking Overall Fit Alternative Models

\[
\begin{align*}
\tilde{y}_t &= \rho E_t\{\tilde{y}_{t+1}\} - \sigma[\tilde{i}_t - \lambda E_t\{\tilde{y}_{t+1}\} - r^n_t] \\
\tilde{\pi}_t &= \beta \rho_f E_t\{\tilde{\pi}_{t+1}\} + \kappa \tilde{y}_t + u_t \\
\tilde{i}_t &= \phi_{\pi} \tilde{\pi}_t + \phi_y \tilde{y}_t + i^*_t
\end{align*}
\]

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<th>Std.</th>
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<td>FH–(\tilde{\gamma})</td>
<td>-728.27</td>
<td>1.19</td>
<td></td>
</tr>
<tr>
<td>Angeletos/Lian/Gabaix</td>
<td>-737.00</td>
<td>0.95</td>
<td></td>
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<tr>
<td>Hybrid NK</td>
<td>-734.24</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Forward</td>
<td>-758.20</td>
<td>1.22</td>
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</tbody>
</table>
Aggregate Implications: Trend vs. Cycle
Trend-Cycle Decomposition: Output
Trend-Cycle Decomposition: Inflation
Trend-Cycle Decomposition: Inflation Expectations (SPF)
Aggregate Implications: Sources of Business Cycle
Historical Counterfactuals: Monetary Policy

Trend and Cycle of Output and Inflation: Historical Counterfactuals

- $y_t - y_{t-12}$
- $\pi_t - \pi_{t-12}$

Graph showing the trend and cycle of output and inflation with years 1969 to 2004.
Historical Counterfactuals: Aggregate Demand
### Trend and Cycle of Output and Inflation: Historical Counterfactuals

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Supply</th>
<th>Inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>-3.0%</td>
<td>2.5%</td>
</tr>
<tr>
<td>1974</td>
<td>-2.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>1979</td>
<td>-1.0%</td>
<td>3.5%</td>
</tr>
<tr>
<td>1984</td>
<td>0.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>1989</td>
<td>1.0%</td>
<td>4.5%</td>
</tr>
<tr>
<td>1994</td>
<td>2.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>1999</td>
<td>3.0%</td>
<td>5.5%</td>
</tr>
<tr>
<td>2004</td>
<td>4.0%</td>
<td>6.0%</td>
</tr>
</tbody>
</table>

#### Description:
- **Output Deviation:** $y_t - ar{y}_t$
- **Inflation Deviation:** $\pi_t - \bar{\pi}_t$

Graphs showing the trend and cycle of output and inflation deviations from their respective targets over time.
Microeconomic Heterogeneity: Disagreement
Disagreement about Inflation Expectations (MRW, 2003)

Dispersion in 4-Quarter Ahead Inflation Expectations

Interquartile Range (Michigan Survey)
Disagreement about Inflation Expectations (MRW, 2003)

Dispersion in 4-Quarter Ahead Inflation Expectations

Percentage points


Interquartile Range (Michigan Survey)
Model Simulation
Dispersion in 4-Quarter Ahead Inflation Expectations

-1 0 1 2 3 4 5 6 7 8 9 10 11 12

Total Inflation
Trend Component
Cyclical Component


Percentage points

Disagreement about Inflation Expectations (MRW, 2003)
Disagreement about Inflation Expectations (MRW, 2003)

Dispersion in 4-Quarter Ahead Inflation Expectations

Cyclical Inflation
Conditional on Policy Shocks
Inflation Experiences (Malmendier-Nagel, QJE 2016)

4-Quarter Ahead Inflation Expectations
Deviation from the cross-sectional mean expectation

Source: Malmendier and Nagel (QJE 2016).
Inflation Expectations across Planning Horizons

4-Quarter Ahead Inflation Expectations

-8 -6 -4 -2 0 2 4 6 8 10 12 14

Percent


Realized

Shorter Horizon Agents

Longer Horizon Agents
Policy Expectations across Planning Horizons

4–Quarter Ahead Policy Rate Expectations

-6  -4  -2  0  2  4  6  8  10  12  14  16  18
-6  -4  -2  0  2  4  6  8  10  12  14  16  18
Percent

Realized

Shorter Horizon Agents

Longer Horizon Agents
The Role of Short-Planning Heterogeneity

- How important is the (cross sectional) heterogeneity to explain aggregate dynamics? How do finite-horizon planning “representative agent” models fit aggregate data?

<table>
<thead>
<tr>
<th>Model</th>
<th>Log MDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterogeneous Agents</td>
<td>-716.5</td>
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<tr>
<td>Rep. Agent:</td>
<td></td>
</tr>
<tr>
<td>$K = 0$</td>
<td>-720.9</td>
</tr>
<tr>
<td>$K = 1$</td>
<td>-715.9</td>
</tr>
<tr>
<td>$K = 2$</td>
<td>-726.2</td>
</tr>
<tr>
<td>$K = 3$</td>
<td>-734.7</td>
</tr>
</tbody>
</table>

- Does a flexible “distribution function” help in fitting aggregate dynamics?
  - Hard to identify only with aggregate data.
  - Important to use the cross sectional variation over time on individuals’ expectations.
Final Remarks

- The FH model outperforms RE versions of the (hybrid) New Keynesian (with intrinsic persistence elements) as well as other behavioral macro models.

- FH model can be used and extended in several directions:
  - To bring data on individuals’ expectations to evaluate the underlying assumptions.
  - To study the heterogeneous implications (on expectations) of alternative MP strategies.
  - To explore the effects of FH planning on firms’ investment decisions and capital accumulation.
Thank you
Impulse-Responses: Monetary Policy Tightening

Impulse Responses to a Monetary Policy Tightening

- $y_t$
- $\pi_t$
- $i_t$

$y_t - \bar{y}_t$
$\pi_t - \bar{\pi}_t$
$i_t - \bar{i}_t$
Impulse Responses to a Monetary Policy Tightening

- Impulse Responses to a Monetary Policy Tightening
- Shorter Horizon Agents
- Longer Horizon Agents

Graphs showing the impulse responses of various variables (y_t, π_t, i_t) to a monetary policy tightening.