Signaling Effects of Monetary Policy

Leonardo Melosi

London Business School

24 May 2012
Motivation

- Disperse information about aggregate fundamentals
  Morris and Shin (2003), Sims (2003), and Woodford (2002)

- Publicly observable policy actions transfer information to market participants
  - Example: central bank setting the policy rate
  - The policy rate conveys information about the central bank’s view on macroeconomic developments
  \[\Rightarrow \text{Signaling effects of monetary policy}\]

- Consider an interest cut in the face of a contractionary shock
  - Effect of \textit{stimulating} the economy
  - But also \textit{contractionary} effects if it convinces unaware market participants about the disturbance
What I do

- Develop a DSGE model in which
  1. price setters have dispersed information
  2. the interest rate set by the central bank is perfectly observable

- I use the model to answer the following questions:
  1. Do we find empirical support for signaling effects of policy?
  2. What are the implications for the transmission of shocks?

- Estimation using the SPF as a measure of public expectations

Main Findings:

1. Signaling effects of monetary policy supported by the data
2. Signaling effects
   - monetary shocks: dampen the effect on inflation
   - demand shocks: enhance Fed’s ability to stabilize inflation
   - technology shocks: are quite neutral
Related Literature

Signaling Effects of Monetary Policy

- **Optimal monetary policy**: Walsh (2010)
- **Empirical evidence**: Coibion and Gorodnichenko (2011)

Dispersed Information Models

- **Persistent effects of nominal shocks**: Woodford (2002), Angeletos and La’O (2009a), and Melosi (2010)
- **Interactions with price rigidities**: Nimark (2008) and Angeletos and La’O (2009b)
- **Change in inflation persistence**: Melosi and Surico (2011)
- **Endogenous information structure**: Sims (2002 and 2006), Maćkowiak and Wiederholt (2009 and 2010)
The Model
The Model Environment

- Three types of agents: households, firms, and the fiscal and monetary authority

- Maintained assumptions:
  1. Firms produce differentiated goods and are monopolistically competitive
  2. Firms face a Calvo lottery (⇒ forward-looking behaviors)
  3. Firms have dispersed information; they observe:
      - Exogenous private signals: their productivity and a signal on the demand conditions
      - Endogenous public signal: the interest rate set by the monetary authority

⇒ Higher-order uncertainty
The Time Protocol

- Every period $t$ is divided into three stages:

**Stage 1:** Shocks are realized, the central bank observes the aggregate shocks and sets the interest rate.

**Stage 2:** Firms observe their private signals, the outcome of the Calvo lottery, and the interest rate and set their prices.

**Stage 3:** Markets open. Households observe shocks and take their decisions. Firms hire labor to produce the demanded quantity at the price set at the **Stage 2**. Government supplies bonds and levies taxes. Markets close.
Imperfect Information Model (IIM)

- The consumption Euler equation:
  \[
  \hat{g}_t - \hat{y}_t = E_t \hat{g}_{t+1} - E_t \hat{y}_{t+1} - E_t \hat{\pi}_{t+1} + \hat{R}_t
  \]

- The (Imperfect-Common-Knowledge) Phillips curve:
  \[
  \hat{\pi}_t = (1 - \theta) (1 - \beta \theta) \sum_{k=0}^{\infty} (1 - \theta)^k \hat{m}_c^{(k)}_t + \beta \theta \sum_{k=0}^{\infty} (1 - \theta)^k \hat{\pi}^{(k+1)}_{t+1|t}
  \]
  where \( \hat{m}_c^{(k)}_t = \hat{y}^{(k)}_t - \hat{a}^{(k-1)}_t \).

- The Taylor rule:
  \[
  \hat{R}_t = \phi_\pi \hat{\pi}_t + \phi_y (\hat{y}_t - \hat{y}^*_t) + \sigma_r \hat{\eta}_{r,t}
  \]
Exogenous Processes and Signals

- The preference shifter evolves according to
  \[ \hat{g}_t = \rho_g \hat{g}_{t-1} + \sigma_g \varepsilon_{g,t} \]

- The process for technology becomes
  \[ \hat{a}_t = \rho_a \hat{a}_{t-1} + \sigma_a \varepsilon_{a,t} \]

- The process leading the state of monetary policy
  \[ \hat{\eta}_{r,t} = \rho_r \hat{\eta}_{r,t-1} + \sigma_r \varepsilon_{r,t} \]

- The equations for the private signals are:
  \[ \hat{g}_{j,t} = \hat{g}_t + \tilde{\sigma}_g \varepsilon_{g,j,t} \]
  \[ \hat{a}_{j,t} = \hat{a}_t + \tilde{\sigma}_a \varepsilon_{a,j,t} \]

- The public endogenous signal:
  \[ \hat{R}_t = \phi_\pi \hat{\pi}_t + \phi_y \left( \hat{y}_t - \hat{y}^*_t \right) + \sigma_r \eta_{r,t} \]
Model Solution

- The model can be solved by characterizing the law of motion of the HOEs
- An analytical characterization is not available
- We guess the law of motion for the HOEs
- Conditional to this guess we solve the model
- Signal extraction delivers the implied law of motion for the HOEs
Perfect Information Model (PIM)

- The consumption Euler equation:

$$\hat{g}_t - \hat{y}_t = E_t \hat{g}_{t+1} - E_t \hat{y}_{t+1} - E_t \hat{\pi}_{t+1} + \hat{R}_t$$

- The New-Keynesian Phillips curve:

$$\hat{\pi}_t = \frac{(1 - \theta)(1 - \theta \beta)}{\theta} \hat{m}_c_t + \beta E_t \hat{\pi}_{t+1}$$

where $$\hat{m}_c_t = \hat{y}_t - a_t$$.

- The Taylor rule:

$$\hat{R}_t = \phi_\pi \hat{\pi}_t + \phi_y (\hat{y}_t - \hat{y}^*) + \sigma_r \eta_{r,t}$$
The Signal Channel of Monetary Transmission
The Signaling Channel

• The policy rate signals information about non-policy shocks (*signaling effects*)

• **Signaling effects are strong** if two conditions *jointly* hold:
  1. Information about non-policy shocks is quite disperse
  2. The policy rate is very informative about non-policy shocks

  ⇒ Firms rely a lot on the policy signal to infer non-policy shocks

• Firms use the policy rate to jointly infer:
  • the history of non-policy shocks
  • potential exogenous deviations from the rule

  ➞ The policy signal *confuses* firms about the exact nature of shocks
Signaling Effects

- Macroeconomic effects of the signal channel depend on:

1. **The quality of private information**
   - Better private information on non-policy shocks weakens the signaling effects

2. **The informative content of the public signal**
   - More information about monetary shocks weakens the signaling effects

3. **The expected inflationary consequences of shocks**
   - More accommodative monetary policy strengthens the signaling effects
Empirical Analysis
The Data and Bayesian Estimation

- The data set include five observables:
  1. GDP growth rate
  2. Inflation (GDP deflator)
  3. Federal funds interest rate
  4. One-quarter-ahead inflation expectations
  5. Four-quarter-ahead inflation expectations

- The last two observables are obtained from the *Survey of Professional Forecasters* (SPFs).

- The data set ranges from 1970:3 to 2007:4

- Combine the likelihood derived from the model and a prior

- Perform Bayesian inference
The Strength of the Signal Channel

- The strength of the signal channel depends on the extent to which the policy rate can influence firms’ expectations about non-policy shocks.

- Two important statistics:
  1. The precision of private information:
     \[
     \frac{\sigma_a}{\tilde{\sigma}_a} = 0.95; \quad \frac{\sigma_g}{\tilde{\sigma}_g} = 0.72
     \]
  2. Informative content of the policy rate:
     \[
     \begin{array}{c|c|c|c}
     \text{Posterior medians} & \varepsilon_{a,t} & \varepsilon_{r,t} & \varepsilon_{g,t} \\
     \hline
     \text{Prior} & 26.73\% & 35.13\% & 38.14\% \\
     \text{Posterior} & \text{(values)} & \text{(values)} & \text{(values)}
     \end{array}
     \]
Model Evaluation

To evaluate the empirical relevance of the signal channel, we address two questions:

1. How does the IIM fare at fitting the data?

2. Does the IIM fit the observed inflation expectations?
Question 1: MDD Comparison

- Bayesian tests rely on computing the marginal data density (MDD):

\[ P(Y|M) = \int \mathcal{L}(Y|\Theta, M) \cdot p(\Theta) \, d\Theta \]

- The MDD is the density to update prior probabilities over competing models

- Log-MDD:

| \( \ln P(Y|M_P) \) | IIM  | PIM  |
|---------------------|------|------|
| -252.3              | -266.3 |

- Prior probability in favor of IIM has to be smaller than \( 8.50E-7 \) to select the PIM
Question 2: Predictive Paths

- Two competing models:
  1. Imperfect information model (IIM)
  2. Perfect information model (PIM)

- Compute *predictive paths* implied by the two competing models

\[
\mathbb{E} \left( \pi_{t+1|t}^{(1)} | \tilde{Y}, \mathcal{M} \right) \quad \text{and} \quad \mathbb{E} \left( \pi_{t+4|t}^{(1)} | \tilde{Y}, \mathcal{M} \right)
\]

where \( \tilde{Y} \) is the data set *NOT including the Surveys*

- Compare the *predictive paths* with the data on the observed inflation expectations
Model Predictions and the SPFs

Inflation Expectations

One-Quarter-Ahead inflation Expectations:
Data vs. Model Prediction

Four-Quarters-Ahead inflation Expectations:
Data vs. Model Prediction

RMSE
Posterior
Propagation of Shocks in the IIM

Monetary Shocks

Preference Shocks

Technology Shocks
Overview of the Findings

- **Contractionary monetary shocks:**
  - monetary tightening signals a **positive demand shock**
  - **signaling effects dampen the response of inflation**

- **Positive preference shocks:**
  - monetary tightening signals a **contractionary monetary shock**
  - **signaling effects help the Fed to stabilize inflation**

- **Negative technology shocks:**
  - monetary tightening signals both a **positive preference shocks** and a **contractionary monetary shock**
  - conflicting effects on inflation expectations and inflation
  - **signaling effects are quite neutral**

- **Reason:** Policy rate mainly informative about monetary and preference shocks
IRFs to a Monetary Shock

IRF: MP Shock => GDP

IRF: MP Shock => Inflation

IRF: MP Shock => Interest Rate

IRF: MP Shock => One-Quarter-Ahead Inflation Expectations

IRF: MP Shock => Four-Quarters-Ahead Inflation Expectations
The law of motion of inflation reads:

\[ \hat{\pi}_t = \begin{bmatrix} v'_a, v'_m, v'_g \end{bmatrix} \cdot \begin{bmatrix} X^a_t \\ X^m_t \\ X^g_t \end{bmatrix} \]

Decompose the effects of a monetary shock:

\[ \frac{\partial \hat{\pi}_{t+h}}{\partial \varepsilon_{r,t}} = v'_a \cdot \frac{\partial X^a_{t+h}}{\partial \varepsilon_{r,t}} + v'_m \cdot \frac{\partial X^m_{t+h}}{\partial \varepsilon_{r,t}} + v'_g \cdot \frac{\partial X^g_{t+h}}{\partial \varepsilon_{r,t}} \]
IRFs to a MP Shock: Decompositions
Propagation of Monetary Shocks

Main Findings

- Firms interpret a rise in the policy rate as the central bank’s response to a positive demand shock
  - Medium-term inflation expectations respond positively
  - The signal channel raises the real effects of monetary shocks
IRFs to a Preference Shock
Propagation of Preference Shocks

• The signal channel has two effects:

  1. it may confuse firms leading them to believe that a **contractionary monetary shock** has occurred

  2. it may confuse firms leading them to believe that a **negative technology shock** has hit the economy
IRFs to a Preference shock: Decompositions
Propagation of Preference Shocks

- Response of inflation to a preference shock is damped by the signal channel

- **WHY?**

- A monetary tightening persuades firms that
  - a *contractionary monetary shock* is likely to have occurred
  - a *technology shock* must play a *little* role because:
    1. Precise private information about tech shocks
    2. Little information about tech shocks from the policy signal
IRFs to a Technology Shock

IRF: Tech Shock => GDP

IRF: Tech Shock => Inflation

IRF: Tech Shock => Interest Rate

IRF: Tech Shock => One-Quarter-Ahead Inflation Expectations

IRF: Tech Shock => Four-Quarters-Ahead Inflation Expectations
Propagation of Technology Shocks

- The signal channel has two effects:
  1. it may confuse firms leading them to believe that a *contractionary monetary shock* has occurred
  2. it may confuse firms leading them to believe that a *positive preference shock* has hit the economy
IRFs to a Tech shock: Decompositions
The Signal Channel and Technology Shocks

- The signal channel seems to have a neutral impact on the response of inflation to a technology shock.

- **WHY?**

- The monetary tightening signals firms that a *positive preference shock* or a *contractionary monetary shock* may have hit the economy.

- The effects of such a confusion on inflation expectations turn out to *cancel each other out*.
Concluding Remarks

- I develop a model in which
  - Information is dispersed across price setters
  - Since the policy rate is perfectly observed, monetary policy has signaling effects

- Estimation using SPF as a measure of public expectations

- The signal channel is found
  - to be empirically relevant
  - to raise the real effects of monetary disturbances
  - to curb the inflationary effects of demand shocks
  - to have little impact on the propagation of technology shocks
Appendix
Stage 3: Households’ Problem

- Households choose consumption $C_{j,t}$, labor $N_t$, and bond holdings $B_t$ under perfect information.
- The representative household maximizes:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^{t+s} g_{t+s} [\ln C_{t+s} - \chi_n N_{t+s}]$$

- The demand shock is a preference shifter that follows:

$$\ln g_t = \rho_g \ln g_{t-1} + \sigma_g \varepsilon_{g,t}, \quad \varepsilon_{g,t} \sim \mathcal{N}(0, 1)$$

- Composite consumption

$$C_t = \left( \int_0^1 C_{j,t}^\nu \, di \right)^{\frac{\nu}{\nu-1}}$$
Stage 3: Households’ Problem (cont’d)

- The flow budget constraint:

\[ P_t C_t + B_t = W_t N_t + R_{t-1} B_{t-1} + \Pi_t + T_t \]

- The price level

\[ P_t = \left( \int (P_{j,t})^{1-\nu} \, di \right)^{\frac{1}{1-\nu}} \]

- The representative household

  - chooses \( C_{j,t} \), labor \( N_t \), and bond holdings \( B_t \)
  - subject to the sequence of the flow budget constraints
  - \( R_t, W_t, \Pi_t, T_t \), and \( P_{j,t} \) are taken as given
Stage 3: The Fiscal Authority

- The fiscal authority has to finance maturing government bonds
- The flow budget constraint of the fiscal authority reads
  \[ R_{t-1}B_{t-1} - B_t = T_t \]
- Fiscal policy is Ricardian
Stage 2: Firms’ Technology

- Firms are endowed with a linear technology:

\[ Y_{j,t} = A_{j,t} N_{j,t} \]

where

\[ A_{j,t} = A_t e^{\tilde{\sigma}_a \epsilon_{j,t}} \]

with \( \epsilon_{j,t} \sim iid \mathcal{N}(0,1) \), and

\[ A_t = \gamma^t a_t \]

where \( \gamma > 1 \) is the linear trend of the aggregate technology

- \( a_t \) is the de-trended level of aggregate technology

\[ \ln a_t = \rho_a \ln a_{t-1} + \sigma_a \epsilon_{a,t} \quad \text{with} \quad \epsilon_{a,t} \sim iid \mathcal{N}(0,1) \]
Stage 2: Firms’ Information Set

- Firm’s information set at stage 2 of time $t$ is

$$\mathcal{I}_{j,t} \equiv \{ A_{j,\tau}, g_{j,\tau}, R_{\tau}, P_{j,\tau} : \tau \leq t \}$$

where $g_{j,t}$ denotes the private signal concerning the preference shifter $g_t$:

$$g_{j,t} = g_t e^{\tilde{\sigma} \varepsilon_{g_{j,t}}}, \quad \text{with } \varepsilon_{g_{j,t}} \overset{iid}{\sim} \mathcal{N}(0, 1)$$

- Firms are assumed to know the model equations and the parameters
Stage 2: Firms’ Price-Setting

- The optimizing firm $j$ sets its price $P_{j,t}^*$ so as to maximize

$$\mathbb{E}_{j,t} \left[ \sum_{s=0}^{\infty} (\beta \theta)^s \mathbb{E}_{t|t+s} \left( \pi_s^* P_{j,t}^* - MC_{j,t+s} \right) Y_{j,t+s} \right]$$

subject to

$$Y_{j,t} = \left( \frac{P_{j,t}}{P_t} \right)^{-\nu} Y_t$$

with $MC_{j,t} = W_t / A_{j,t}$ and taking $W_t$ and $P_t$ as given

- Firms will satisfy any demanded quantity that will arise at stage 3 at the price they have set at stage 2

- Non-optimizing firms index prices to the steady-state inflation
Stage 1: Monetary Policy

- The central bank sets the nominal interest rate according to the reaction function

\[ R_t = (r_*, \pi_*) \left( \frac{\pi_t}{\pi_*} \right)^{\phi_{\pi}} \left( \frac{Y_t}{Y_*} \right)^{\phi_y} \eta_{r,t} \]

- This process is assumed to follow an AR process:

\[ \ln \eta_{r,t} = \rho_r \ln \eta_{r,t-1} + \sigma_r \varepsilon_{r,t}, \quad \text{with } \varepsilon_{r,t} \overset{iid}{\sim} \mathcal{N}(0, 1). \]

- We refer to the innovation \( \varepsilon_{r,t} \) as a monetary policy shock
Higher-Order Expectations

Definitions

\[ \widehat{m}_t^{(k)} \equiv \int_{k} \mathbb{E}_{j,t} \ldots \int_{k} \mathbb{E}_{j,t} \widehat{m}_{c,j,t} \]

\[ \widehat{\pi}_{t+1|t}^{(k)} \equiv \int_{k} \mathbb{E}_{j,t} \ldots \int_{k} \mathbb{E}_{j,t} \widehat{\pi}_{t+1} \]
## Priors

<table>
<thead>
<tr>
<th>Name</th>
<th>Support</th>
<th>Density</th>
<th>Median</th>
<th>95% Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>[0, 1]</td>
<td>Beta</td>
<td>0.65</td>
<td>(0.28, 0.99)</td>
</tr>
<tr>
<td>$\phi_{\pi}$</td>
<td>$\mathbb{R}^+$</td>
<td>Gamma</td>
<td>2.0</td>
<td>(1.61, 2.40)</td>
</tr>
<tr>
<td>$\phi_y$</td>
<td>$\mathbb{R}^+$</td>
<td>Gamma</td>
<td>0.25</td>
<td>(0.00, 0.65)</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>[0, 1]</td>
<td>Beta</td>
<td>0.50</td>
<td>(0.15, 0.90)</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>[0, 1]</td>
<td>Beta</td>
<td>0.85</td>
<td>(0.30, 0.99)</td>
</tr>
<tr>
<td>$\rho_g$</td>
<td>[0, 1]</td>
<td>Beta</td>
<td>0.50</td>
<td>(0.15, 0.90)</td>
</tr>
</tbody>
</table>
# Priors (cont’d)

<table>
<thead>
<tr>
<th>Name</th>
<th>Support</th>
<th>Density</th>
<th>Median</th>
<th>95% Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_a)</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>0.70</td>
<td>(0.35, 1.70)</td>
</tr>
<tr>
<td>(\tilde{\sigma}_a)</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>1.40</td>
<td>(0.95, 2.20)</td>
</tr>
<tr>
<td>(\sigma_g)</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>1.00</td>
<td>(0.50, 2.40)</td>
</tr>
<tr>
<td>(\tilde{\sigma}_g)</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>1.00</td>
<td>(0.67, 1.55)</td>
</tr>
<tr>
<td>(\sigma_r)</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>0.10</td>
<td>(0.05, 0.85)</td>
</tr>
<tr>
<td>(\sigma_{m_1})</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>0.45</td>
<td>(0.22, 1.10)</td>
</tr>
<tr>
<td>(\sigma_{m_2})</td>
<td>(\mathbb{R}^+)</td>
<td>InvGamma</td>
<td>0.45</td>
<td>(0.22, 1.10)</td>
</tr>
<tr>
<td>(\ln \gamma)</td>
<td>(\mathbb{R})</td>
<td>Normal</td>
<td>0.00</td>
<td>(−0.20, 0.20)</td>
</tr>
<tr>
<td>(\ln \pi^*_)</td>
<td>(\mathbb{R})</td>
<td>Normal</td>
<td>0.00</td>
<td>(−0.20, 0.20)</td>
</tr>
</tbody>
</table>
# Posteriors

<table>
<thead>
<tr>
<th>Name</th>
<th>IIM</th>
<th>PIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>95% Interval</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>( \theta )</td>
<td>0.46</td>
<td>0.39</td>
</tr>
<tr>
<td>( \phi_\pi )</td>
<td>1.07</td>
<td>1.03</td>
</tr>
<tr>
<td>( \phi_y )</td>
<td>0.25</td>
<td>0.17</td>
</tr>
<tr>
<td>( \rho_r )</td>
<td>0.71</td>
<td>0.66</td>
</tr>
<tr>
<td>( \rho_a )</td>
<td>0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>( \rho_g )</td>
<td>0.77</td>
<td>0.74</td>
</tr>
</tbody>
</table>
## Posteriors (cont’d)

<table>
<thead>
<tr>
<th>Name</th>
<th>IIM</th>
<th></th>
<th>PIM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>95% Interval</td>
<td>Median</td>
<td>95% Interval</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>1.10</td>
<td>0.94 - 1.26</td>
<td>1.03</td>
<td>0.92 - 1.16</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>1.14</td>
<td>0.90 - 1.40</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>$\sigma_g$</td>
<td>1.21</td>
<td>1.05 - 1.31</td>
<td>0.81</td>
<td>0.67 - 0.95</td>
</tr>
<tr>
<td>$\sigma_g$</td>
<td>1.57</td>
<td>0.94 - 2.52</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>0.61</td>
<td>0.50 - 0.70</td>
<td>0.57</td>
<td>0.50 - 0.65</td>
</tr>
<tr>
<td>$\sigma_{m_1}$</td>
<td>0.16</td>
<td>0.15 - 0.19</td>
<td>0.19</td>
<td>0.17 - 0.22</td>
</tr>
<tr>
<td>$\sigma_{m_2}$</td>
<td>0.16</td>
<td>0.14 - 0.18</td>
<td>0.18</td>
<td>0.16 - 0.21</td>
</tr>
<tr>
<td>$100\ln \gamma$</td>
<td>0.32</td>
<td>0.28 - 0.35</td>
<td>0.31</td>
<td>0.26 - 0.34</td>
</tr>
<tr>
<td>$100\ln \pi_*$</td>
<td>0.80</td>
<td>0.62 - 0.99</td>
<td>0.81</td>
<td>0.59 - 1.01</td>
</tr>
</tbody>
</table>
## Variance Decomposition

**Table:** Prior Variance Decomposition

<table>
<thead>
<tr>
<th>Observable Variables</th>
<th>ε&lt;sub&gt;a&lt;/sub&gt;</th>
<th>ε&lt;sub&gt;r&lt;/sub&gt;</th>
<th>ε&lt;sub&gt;g&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP Growth</td>
<td>0.56</td>
<td>0.05</td>
<td>0.39</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.61</td>
<td>0.01</td>
<td>0.39</td>
</tr>
<tr>
<td>FedFunds</td>
<td>0.46</td>
<td>0.04</td>
<td>0.50</td>
</tr>
<tr>
<td>1Q-ahead Inflation Expectations</td>
<td>0.65</td>
<td>0.01</td>
<td>0.07</td>
</tr>
<tr>
<td>4Q-ahead Inflation Expectations</td>
<td>0.70</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
## Variance Decomposition

**Table:** Posterior Variance Decomposition

<table>
<thead>
<tr>
<th>Observable Variables</th>
<th>Shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\mathbf{\varepsilon_a}$</td>
</tr>
<tr>
<td>GDP Growth</td>
<td>0.44</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.73</td>
</tr>
<tr>
<td>FedFunds</td>
<td>0.63</td>
</tr>
<tr>
<td>1Q-ahead Inflation Expectations</td>
<td>0.93</td>
</tr>
<tr>
<td>4Q-ahead Inflation Expectations</td>
<td>0.96</td>
</tr>
</tbody>
</table>
### Table: RMSE for Models’ One-Step-Ahead Predictions

<table>
<thead>
<tr>
<th>Observable Variables</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IIM</td>
</tr>
<tr>
<td>GDP Growth</td>
<td>11.05</td>
</tr>
<tr>
<td>Inflation</td>
<td>3.58</td>
</tr>
<tr>
<td>FedFunds</td>
<td>3.21</td>
</tr>
<tr>
<td>1Q-ahead Inflation Expectations</td>
<td>2.06</td>
</tr>
<tr>
<td>4Q-ahead Inflation Expectations</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Note: The table provides the root mean squared errors (RMSEs) for the model’s one-step ahead prediction about observables.
Table: Forecasting Performance of the Smoothed Estimates

<table>
<thead>
<tr>
<th></th>
<th>1Q-ahead SPF</th>
<th>4Q-ahead SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IIM</td>
<td>PIM</td>
</tr>
<tr>
<td>1970:3-1986:4</td>
<td>1.18</td>
<td>1.49</td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.90</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Note: The table provides the root mean squared errors (RMSEs) for the smoothed estimates of the inflation expectations.
## Posteriors

NO SPFs

<table>
<thead>
<tr>
<th>Name</th>
<th>IIM</th>
<th>95% Interval</th>
<th>PIM</th>
<th>95% Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Lower</td>
<td>Upper</td>
<td>Median</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.43</td>
<td>0.35</td>
<td>0.51</td>
<td>0.60</td>
</tr>
<tr>
<td>$\phi_\pi$</td>
<td>1.76</td>
<td>1.54</td>
<td>1.97</td>
<td>1.27</td>
</tr>
<tr>
<td>$\phi_y$</td>
<td>0.30</td>
<td>0.22</td>
<td>0.40</td>
<td>0.75</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>0.52</td>
<td>0.45</td>
<td>0.58</td>
<td>0.48</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.99</td>
<td>0.98</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>$\rho_g$</td>
<td>0.90</td>
<td>0.85</td>
<td>0.93</td>
<td>0.85</td>
</tr>
</tbody>
</table>
## Posteriors (cont’d)

### NO SPFs

<table>
<thead>
<tr>
<th>Name</th>
<th>IIM</th>
<th>PIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>95% Interval</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.91</td>
<td>0.76 - 1.03</td>
</tr>
<tr>
<td>$\tilde{\sigma}_a$</td>
<td>1.78</td>
<td>1.01 - 2.67</td>
</tr>
<tr>
<td>$\sigma_g$</td>
<td>0.72</td>
<td>0.58 - 0.93</td>
</tr>
<tr>
<td>$\tilde{\sigma}_g$</td>
<td>0.71</td>
<td>0.61 - 0.82</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>1.80</td>
<td>1.16 - 2.24</td>
</tr>
<tr>
<td>$\sigma_{m1}$</td>
<td>0.55</td>
<td>0.24 - 1.03</td>
</tr>
<tr>
<td>$\sigma_{m2}$</td>
<td>0.56</td>
<td>0.22 - 1.10</td>
</tr>
<tr>
<td>100ln $\gamma$</td>
<td>0.35</td>
<td>0.26 - 0.43</td>
</tr>
<tr>
<td>100ln $\pi_*$</td>
<td>0.98</td>
<td>0.98 - 0.98</td>
</tr>
</tbody>
</table>