Learning from Monetary Shocks and Asset Returns

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November 2015
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Motivation

Stylized Facts

- **Stock Market Response to Monetary Shock**
  - Bernanke Kuttner 2005: Stock returns increase 100 bps for a 25 bps negative monetary shock
  - Standard New Keynesian models cannot match this reaction quantitatively

- **Bond Market Response to Monetary Shock**
  - Gurkaynak, Sack, and Swanson 2005: Nominal short term forward rates increase 50 bps given a 100 bps tightening monetary shock, and the response turns to negative after about four years
  - Nakamura and Steinsson 2015: Real short term and long term yields also increase about one to one in response to tightening shocks.

- **Macro Variables Comovements**
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- **Macro Variables Comovements**
This Model - Assumptions

- Standard New Keynesian model + *Information asymmetric*
  - Monetary authority has more information about TFP growth than the private sector
  - Monetary authority sets interest rate according to a Taylor rule using his information

- Agents in the private sector do not know TFP growth
  - Cannot fully distinguish monetary shocks from changes in TFP growth rates
  - Learning from monetary shocks and updating their beliefs using Kalman Filter
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This Model - Mechanism

- Following an *expansionary* monetary policy shock
  - Higher TFP growth rate expectation for current period
    - Stock price, output, and labor to rise simultaneously
    - TFP growth expectation is mean reverting $\Rightarrow$ lower growth expectation in the future
    - Nominal and real bond yields drop, and inflation rises
    - Match stock and bond market reaction to monetary shocks quantitatively
    - Monetary shocks work like noise shocks and generate business cycle comovements among key macro variables
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Related Works

Stock/bond markets and monetary shocks:

- Bernanke Kuttner 2005
- Gurkaynak, Sack, and Swanson 2005
- Nakamura and Steinsson 2015
- Palomino and Li 2014
- Challe and Giannitsarou 2014

Monetary policy signaling effects:

- Romer and Romer 2000
- Campbell et al 2012
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The Economy

- **Representative household**
  - Cannot observe TFP growth rate
  - Form expectation using Kalman Filter

- Intermediate good producers set prices in a Calvo (1983) setting
  - Same information structure as representative household

- Central bank sets nominal rate following a Taylor (1993) policy rule
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Information Structure

- Production function \( Y_t = A_t N_t \)
- Two different information structures for different \( A_t \) process
- Common assumption: \( A_t \) is not observable to private sector at time \( t \)
- Agents in the private sector solve the model using \( E_t(A_t) \)
- \( Y_t \) and other variables are subject to one time adjustments after shock to \( A_t \) realized
Preference:

\[ U_t = \frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+\varphi} \kappa_t N_t^{1+\varphi} \]

where \( \kappa_t \) helps to preserve balanced growth when TFP has random walk component

- No capital in the model
- Model can be solved and log linearized in the standard way
Solution 1 - Transitory TFP only

Solution 1:

\[
\hat{y}_t = E_t(\hat{y}_{t+1}) - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - r^n_t) \quad \text{DIS}
\]

\[
\pi_t = \kappa \hat{y}_t + \beta E_t \pi_{t+1} \quad \text{NKPC}
\]

\[
y^n_t = \frac{1 + \varphi}{\varphi + \sigma} E_t(a_t) - \frac{\mu}{\varphi + \sigma}
\]

\[
r^n_t = \rho + \sigma \frac{1 + \varphi}{\varphi + \sigma} E_t(a_{t+1} - a_t)
\]

\[
\hat{y}_t = y_t - y^n_t
\]

\[
\kappa = (1 - \theta \beta)(1 - \theta)(\sigma + \varphi) / \theta
\]
Solution 2 - with Permanent TFP component

Solution 2:

\[ \hat{y}_t = \mathcal{E}_t(\hat{y}_{t+1}) - \frac{1}{\sigma} (i_t - \mathcal{E}_t \pi_{t+1} - r^n_t) \quad DIS \]

\[ \pi_t = \kappa \hat{y}_t + \beta \mathcal{E}_t \pi_{t+1} \quad NKPC \]

\[ y^n_t = \mathcal{E}_t(a_t) - \frac{\mu}{\sigma + \varphi} \]

\[ r^n_t = \rho + \sigma \mathcal{E}_t(a_{t+1} - a_t) \]

\[ \hat{y}_t = y_t - y^n_t \]

\[ \kappa = (1 - \theta \beta)(1 - \theta)(\sigma + \varphi)/\theta \]
Asset Pricing

- Asset Pricing Equations:

\[ M_{t,t+1} = \beta E_t \left( \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \right) \]

\[ R_{t+1,D} = \frac{1 + PD_{t+1}}{PD_t} \left( \frac{D_{t+1}}{D_t} \right) \]

\[ 1 = E_t \left( M_{t,t+1} R_{t+1,D} \right) \]

\[ D_t = \text{Firm real profit} \]
Bond Yield Equations ($n$ periods real bond):

$$
P_t^{(n)} = E_t \left( P_{t+1}^{(n-1)} M_{t+1} \right) = E_t \left( \prod_{i=1}^{n} M_{t+i} \right)
$$

$$
y_t^{(n)} = -\frac{1}{n} p_t^{(n)}
$$

$$
p_t^{(n)} = \log \left( P_t^{(n)} \right)
$$

$$
y_t^{(n)} = n - \text{period real yield}
$$

For nominal yield, just replace $m_{t+i}$ with $m_{t+i}^\$ = m_{t+i} - \pi_t$
Case I: Transitory Only TFP

- Log technology follows:

\[ a_t = (1 - \rho_a)\bar{a} + \rho_a a_{t-1} + \varepsilon_{a,t} \]

\[ y_t^n = \frac{1 + \varphi}{\sigma + \varphi} E_t(a_t) - \frac{\mu}{\sigma + \varphi} \]

\[ r_t^n = \rho + \sigma \frac{1 + \varphi}{\sigma + \varphi} E_t(a_{t+1} - a_t) \]

\[ = \rho + \sigma \frac{1 + \varphi}{\sigma + \varphi} (1 - \rho_a)(\bar{a} - a_{t|t}) \]
Case I: Taylor Rule

- **Assumption 1**: Fed knows the log TFP $a_t$ up to time $t$, but agent doesn’t
- **Assumption 2**: Fed sets nominal rate using this accurate information

Taylor Rule follows:

$$i_t = \rho i_{t-1} + (1 - \rho) (\bar{\iota} + \phi_{\pi} \pi_t + \phi_y (y_t - \tilde{y}_t^n) - \phi_y \varepsilon_{i,t})$$

$$\tilde{y}_t^n = \frac{1 + \varphi}{\sigma + \varphi} a_t - \frac{\mu}{\sigma + \varphi}$$

- Rearrange Taylor Rule:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) (\bar{\iota} + \phi_{\pi} \pi_t + \phi_y (\hat{y}_t + \frac{1 + \varphi}{\sigma + \varphi} E_t (a_t)) - \phi_y \nu_t)$$

$$\nu_t = \varepsilon_{i,t} + a_t$$
Case I: Learning

- **State Space Representation**

\[
\begin{align*}
\nu_t &= \varepsilon_{i,t} + a_t \\
\alpha_t &= (1 - \rho_a)\bar{a} + \rho_a a_{t-1} + \varepsilon_{a,t} \\
\alpha_{t|t} &= (1 - K)((1 - \rho_a)\bar{a} + \rho_a a_{t-1|t-1}) + K\nu_t
\end{align*}
\]

- **Summary of 3 Equation system,**

\[
\begin{align*}
\hat{y}_t &= E_t(\hat{y}_{t+1}) - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho - \sigma \frac{1 + \varphi}{\sigma + \varphi}(1 - \rho_a)(\bar{a} - a_{t|t})) & \text{DIS} \\
\pi_t &= \kappa\hat{y}_t + \beta E_t\pi_{t+1} & \text{NKPC} \\
i_t &= \rho_i i_{t-1} + (1 - \rho_i)(\bar{t} + \phi_\pi \pi_t + \phi_y(\hat{y}_t + \frac{1 + \varphi}{\sigma + \varphi}E_t(a_t)) - \phi_y \nu_t)
\end{align*}
\]
Monetary Rules and Learning

Case II: Permanent + Transitory TFP

- Log technology follows:

\[ a_t = \bar{a} + a_{t-1} + \varepsilon_{a,t} + \theta_t \]
\[ \theta_t = \rho \theta_{t-1} + \varepsilon_{\theta,t} \]

- **Assumption 1**: Fed knows the transitory component \( \theta_t \) at \( t \), but agent doesn’t

\[ r^n_t = \rho + \sigma E_t (a_{t+1} - a_t) = \rho + \sigma \bar{a} + \sigma \rho \theta E_t (\theta_t) \]

- **Assumption 2**: \( a_t \) and \( \varepsilon_{a,t} \) are not observable at the beginning of period \( t \)

- **Assumption 3**: \( a_{t-1} \) is known for both Fed and agent at \( t \)

- **Assumption 4**: Taylor rule is set one period ahead - to limit contemporary feedback effect

Note: the key assumption is assumption 1, all other assumptions can be relaxed
Case II: Taylor Rule

- Taylor Rule follows \( \bar{y}_n^t = \tilde{E}_t(a_t) - \frac{\mu}{\sigma + \varphi} = \bar{a} + a_{t-1} + \theta_t - \frac{\mu}{\sigma + \varphi} \):

\[
\begin{align*}
    i_t &= \rho_i i_{t-1} + (1 - \rho_i)(\bar{i} + \phi_{\pi} \pi_{t-1} + \phi_y (y_{t-1} - \tilde{E}_{t-1} \bar{y}_{t-1}^n) - \phi_y \varepsilon_{i,t}) - \text{Assumption 4} \\
    i_t &= \rho_i i_{t-1} + (1 - \rho_i)(\bar{i} + \phi_{\pi} \pi_{t-1} + \phi_y (y_{t-1} - \bar{a} - a_{t-2} - \theta_{t-1} + \frac{\mu}{\sigma + \varphi}) - \phi_y \varepsilon_{i,t}) \\
    &\quad - \text{Assumption 2&3}
\end{align*}
\]

then define \( \nu_t = \varepsilon_{i,t} + \theta_{t-1} \), and rewrite Taylor rule as,

\[
\begin{align*}
    i_t &= \rho_i i_{t-1} + (1 - \rho_i)(\bar{i} + \phi_{\pi} \pi_{t-1} + \phi_y (\hat{y}_{t-1} + E_{t-1} (a_{t-1}) - \bar{a} - a_{t-2}) - \phi_y \nu_t) \\
    i_t &= \rho_i i_{t-1} + (1 - \rho_i)(\bar{i} + \phi_{\pi} \pi_{t-1} + \phi_y (\hat{y}_{t-1} + E_{t-1} (\theta_{t-1}) - \phi_y \nu_t)
\end{align*}
\]
Case II: Learning

- State Space Representation ($\nu_t$ is observable and $\theta_t-1$ not observable):

$$
\begin{align*}
\nu_t &= \varepsilon_{i,t} + \theta_{t-1} \\
\theta_t &= \rho \theta_{t-1} + \varepsilon_{\theta,t} \\
\theta_{t|t} &= (1 - K)(\rho \theta_{t-1|t-1}) + K\nu_t
\end{align*}
$$

- Summary of 3 Equation system,

$$
\begin{align*}
\hat{y}_t &= E_t(\hat{y}_{t+1}) - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho - \sigma \bar{a} - \sigma \rho \theta E_t(\theta_t)) \quad DIS \\
\pi_t &= \kappa \hat{y}_t + \beta E_t\pi_{t+1} \quad NKPC \\
i_t &= \rho_i i_{t-1} + (1 - \rho_i)(\bar{i} + \phi_{\pi} \pi_{t-1} + \phi_y(\hat{y}_{t-1} + E_{t-1}(\theta_{t-1})) - \phi_y \nu_t)
\end{align*}
$$
## Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.98</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Risk aversion parameter</td>
<td>4</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Inverse of Frisch labor elasticity</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Elasticity of substitution of differentiated goods</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Price rigidity</td>
<td>0.65</td>
</tr>
<tr>
<td>$\bar{a}$</td>
<td>Mean TFP growth</td>
<td>0</td>
</tr>
<tr>
<td>$\sigma_\theta$</td>
<td>transitory TFP growth volatility</td>
<td>0.1</td>
</tr>
<tr>
<td>$\rho_\theta$</td>
<td>autocorrelation of transitory TFP growth shocks</td>
<td>0.975</td>
</tr>
<tr>
<td>$\sigma_\alpha$</td>
<td>permanent TFP volatility</td>
<td>0.2</td>
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<tr>
<td>Taylor Rule from Campbell, Pflueger, and Viceira 2015</td>
<td>01.Q1-11.Q4</td>
<td></td>
</tr>
<tr>
<td>$\rho_i$</td>
<td>Interest-rate smoothing coefficient</td>
<td>0.82</td>
</tr>
<tr>
<td>$\bar{\iota}$</td>
<td>Long run rate</td>
<td>0.02</td>
</tr>
<tr>
<td>$\phi_{\pi}$</td>
<td>Response to inflation</td>
<td>1.6</td>
</tr>
<tr>
<td>$\phi_y$</td>
<td>Response to output gap</td>
<td>0.82</td>
</tr>
<tr>
<td>$\sigma_i$</td>
<td>Volatility of policy shock</td>
<td>0.15</td>
</tr>
<tr>
<td>$K_{Gain}$</td>
<td>Kalman Gain</td>
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</tr>
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</table>
Stock Market Response to Monetary Shock

Bernanke Kuttner 2005 estimates that stock return increases 100 bps for a 25 bps expansionary monetary shock.

Standard NK models cannot match this reaction quantitatively.

In our model, expansionary monetary shocks increase agent’s TFP growth expectation today $\Rightarrow$ stock price increases.

We provide a channel through which stock markets response to monetary shocks directly, and can match this empirical fact quantitatively.
Stock Return Response to Monetary Shock - Case II

- Impulse response to one standard deviation monetary shock (-15 bps)
- $re_{- div}$ - log real return to dividend claims, $p_{- d}$ - log price dividend ratio, $m$ - log discount factor, $n$ - log labor, $y$ - log output, $x$ - output gap, $pi$ is inflation, $i$ - interest rate, and $z_E$ - expectation of TFP growth $\theta$. 
Bond Market Response to Monetary Shock

**Motivation**

**The Model**

**Quantitative Results**

**Summary**

**Bond Yield Responses to Monetary Shock - Case II**

1. **Bond Market Response to Monetary Shock**
   - Gurkaynak, Sack, and Swanson 2005 shows that nominal short term forward rates increase 50 bps given a 100 bps tightening monetary shock, and the response turns negative after about four years.
   
   In addition, using high frequency identification of monetary shock, Nakamura and Steinsson 2015 finds the real short term and long term yields also increase one to one in response to tightening shocks.
   
   In our model, expansionary monetary shocks increase agent’s TFP growth expectation today $\Rightarrow$ future growth expectation decrease as expected growth rate is mean reverting $\Rightarrow$ real yields decrease.
   
   Lower future growth expectation also increases inflation, but with a smaller magnitude than decreases in real yields $\Rightarrow$ nomina yields decrease.
   
   Note that IRF for nominal rates is hump-shaped, Fed increase nominal rates in response to higher output or output gap (output - natural output as function of true TFP growth), but agents’ TFP growth expectation increased and is bigger than true TFP growth $\Rightarrow$ Higher nominal rates lower TFP growth expectation $\Rightarrow$ Lower inflation and output $\Rightarrow$ IRF for nominal and real yields do not appear hump-shaped because model implied growth and inflation (depend on agents’ TFP growth expectation along the IRF horizons) are lower.
**Bond Market Response to Monetary Shock**

**Bond Yield Responses to Monetary Shock - Case II**

- Impulse response to one standard deviation monetary shock (-15 bps)
- $y_{-1}, y_{-4}, y_{-20}$ are the log real yields for 1, 4, and 20 quarters, $y_{-1n}, y_{-4n}, y_{-20n}$ are the log nominal yields for 1, 4, and 20 quarters.
Macro Variables Comovements

- Monetary shocks work as noise shocks $\Rightarrow$ change agent’s TFP growth expectation $\Rightarrow$ generate macro variables business cycle comovements.

- In the model, expansionary monetary shocks increase agent’s TFP growth expectation today $\Rightarrow$ higher labor, output, and stock prices.

- TFP growth expectation is mean reverting $\Rightarrow$ future expected growth is low $\Rightarrow$ inflation increases.
Response to TFP growth shocks $\varepsilon_{\theta,t}$

- Impulse response to one standard deviation TFP growth (+10 bps)
- $re_{\text{div}}$ - log real return to dividend claims, $p_{\text{d}}$ - log price dividend ratio, $m$ - log discount factor, $n$ - log labor, $y$ - log output, $x$ - output gap, $pi$ is inflation, $i$ - interest rate, and $z_{E}$ - expectation of TFP growth $\theta$. 

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**Motivation**

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**Quantitative Results**

**Summary**
Summary

- Provide a new channel through which stock market and bond market react to monetary shocks directly
- Monetary shocks as noise shocks and generate macro variables business cycle comovements.
- Preliminary results match empirical studies well
- Extend to Epstein-Zin preference
- Add capital and investment in the model