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Measuring Monetary Policy Uncertainty

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On Monetary Policy Uncertainty at Zero Interest Rate

Shangwen Huang and Shu Wu

University of Kansas

July 2015
Zero interest rate in U.S.

3-Month Treasury Bill: Secondary Market Rate (TB3MS)
Source: Board of Governors of the Federal Reserve System

Shaded areas indicate US recessions.
Economic Policy Uncertainty Index

Baker, Bloom and Davis (2011)
Objective

- A simple econometric model of monetary policy uncertainty in the presence of zero interest rate.
A simple econometric model of monetary policy uncertainty in the presence of zero interest rate.

Incorporate such measure of policy uncertainty into an empirical asset pricing/term structure model. (in progress)
A State Space Model

- State variables: shadow rate $s_t$ and volatility $x_t$

**Transition equation**

\[
s_t = \beta_0 + \beta'_1 Z_t + e^{\frac{x_t}{2}} \varepsilon_t \\
x_t = \phi_0 + \phi_1 x_{t-1} + u_t
\]
A State Space Model

- State variables: shadow rate $s_t$ and volatility $x_t$

**Transition equation**

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\begin{align*}
s_t &= \beta_0 + \beta_1 Z_t + e^{\frac{x_t}{2}} \varepsilon_t \\
x_t &= \phi_0 + \phi_1 x_{t-1} + u_t
\end{align*}
\]

- Observed variables: interest rate $r_t$ and economic uncertainty index $v_t$

**Measurement equation**

\[
\begin{align*}
v_t &= \alpha_0 + \alpha_1 v_{t-1} + \alpha_2 x_t + e_t \\
r_t &= \max\{s_t, 0\}
\end{align*}
\]
Likelihood Function

\[
p(y_t | \theta, y_{1:t-1}) = \int p(y_t | x_t, \theta) p(x_t | x_{t-1}) p(x_{t-1} | y_{1:t-1}, \theta) dx_{t-1} dx_t \quad (1)
\]

\[
p(y_2 \ldots y_T | \theta) = \prod_{t=1}^{T-1} p(y_{t+1} | \theta, y_{1:t}) \quad (2)
\]
Particle filter(SIR)

- Draw N particles $x_t \{1 : N\} \sim p(x_t|x_t^{i}_{t-1})$
- Calculate each particle’s weight $w_t^i = p(y_t|x_t^i)$
- Normalize weights: $\tilde{w}_t^i = \frac{w_t^i}{\sum_{i=1}^{N} w_t^i}$
- Redraw N particles by their weights $\tilde{w}_t^i$
- Each particle has the same weight $1/N$
Particle filter (SIR)

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- Redraw N particles by their weights $\tilde{w}_t^i$
- Each particle has the same weight $1/N$
- Likelihood function:
  - $p(y_t|\theta, y_{1:t-1}) \approx \frac{1}{N} \sum_{i=1}^{N} \tilde{w}_t^i$
A Practical Problem

- Estimate parameters through maximizing log-likelihood
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- Problem: likelihood is not smooth
  - 2-dimensional -log-likelihood by using stratified sampling procedure (Malik and Pitt 2011)
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- Estimate parameters through maximizing log-likelihood
- Problem: likelihood is not smooth
  - 2-dimensional -log-likelihood by using stratified sampling procedure (Malik and Pitt 2011)
Data and the Baseline Model

- \( s_t = \beta_0 + \beta_1 \inf_t + \beta_2 \text{unem}_t + \beta_3 D_t \ast \inf_t + \beta_4 D_t \ast \text{unem}_t + \epsilon_t \)
- \( x_t = \phi_0 + \phi_1 x_{t-1} + u_t, \quad u_t \sim N(0, \sigma^2) \)
- \( r_t = \max\{s_t, 0\} \)
- \( v_t = \alpha_0 + \alpha_1 v_{t-1} + \alpha_2 x_t + e_t, \quad e_t \sim N(0, \gamma^2) \)
# Parameter Estimates

<table>
<thead>
<tr>
<th>parameters</th>
<th>estimator</th>
<th>std error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>13.3237</td>
<td>0.1350</td>
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<tr>
<td>$\beta_1$</td>
<td>0.1580</td>
<td>0.0320</td>
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<tr>
<td>$\beta_2$</td>
<td>-2.0629</td>
<td>0.0233</td>
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<td>$\beta_3$</td>
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<td>0.0562</td>
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<td>$\beta_4$</td>
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<td>$\phi_0$</td>
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<td>0.0253</td>
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<tr>
<td>$\phi_1$</td>
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<td>$\sigma$</td>
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<td>0.6063</td>
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<td>$\alpha_1$</td>
<td>0.8645</td>
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<td>$\alpha_2$</td>
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<td>$\gamma$</td>
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<td>log-likelihood</td>
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Shadow Interest Rate

Shangwen Huang and Shu Wu

On Monetary Policy Uncertainty at Zero Interest Rate
Policy Uncertainty: filtered $x\{1 : T\}$
Effect of Zero Lower Bound

Shangwen Huang and Shu Wu

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Effect of Zero Lower Bound

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Forecasting Aggregate Stock Market Return

- S&P 500 Index excess return: \( r_t = \log((D_t + P_t)/P_{t-1}) \times 12 - r_{f,t} \)
Forecasting Aggregate Stock Market Return

- S&P 500 Index excess return: \( r_t = \log((D_t + P_t)/P_{t-1}) \times 12 - r_{f,t} \)
- Campbell-Shiller log-linear present value formula

\[
pd_t = E_t \sum \rho^{j-1}\Delta d_{t+j} - E_t \sum \rho^{j-1}\Delta r_{t+j} - E_t \sum \rho^{j-1}\Delta r_{f,t+j}
\]
Forecasting Aggregate Stock Market Return

- S&P 500 Index excess return: \( r_t = \log((D_t + P_t)/P_{t-1}) \times 12 - r_{f,t} \)
- Campbell-Shiller log-linear present value formula
  \[
  p_d_t = E_t \sum \rho^{j-1} \Delta d_{t+j} - E_t \sum \rho^{j-1} \Delta r_{t+j} - E_t \sum \rho^{j-1} \Delta r_{f,t+j}
  \]
- Forecasting regression
  \[
  \sum_{j=1}^{k} \rho^{j-1} r_{t+j} = a^{(k)} + b^{(k)} p_d_t + c^{(k)} x p u_t + \epsilon_{t+k}
  \]
Return-forecasting regressions

$k = 1$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-stat</th>
<th>p-value</th>
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<tbody>
<tr>
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<td>0.7892</td>
<td>2.5865</td>
<td>0.0105</td>
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<tr>
<td>$pd_t$</td>
<td>-0.4534</td>
<td>0.1932</td>
<td>-2.3471</td>
<td>0.0200</td>
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<tr>
<td>$xpu_t$</td>
<td>-0.02035</td>
<td>0.0209</td>
<td>-0.9736</td>
<td>0.3315</td>
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Return-forecasting regressions

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For $k = 3$

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<td>-4.7237</td>
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<tr>
<td>$xpu_t$</td>
<td>-0.0865</td>
<td>0.0405</td>
<td>-2.1354</td>
<td>0.0341</td>
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Return-forecasting regressions

$k = 6$

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<tr>
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<th>t-stat</th>
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<tbody>
<tr>
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<td>$pd_t$</td>
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<td>$xpu_t$</td>
<td>-0.1198</td>
<td>0.0548</td>
<td>-2.1880</td>
<td>0.0299</td>
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### Return-forecasting regressions

- **$k = 6$**

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</table>

- **$k = 12$**

<table>
<thead>
<tr>
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<th>t-stat</th>
<th>p-value</th>
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<td>$xpu_t$</td>
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<td>0.0775</td>
<td>-1.4079</td>
<td>0.1609</td>
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</table>
Cross-section Pricing

- 30 Industries portfolio from Ken French library.

\[ R_{i,t} - RF_t = \alpha_{xi} + \beta_{xi} x_t + \epsilon_{xi,t} \]

\[ R_{i,t} - RF_t = \alpha_{mi} + \beta_{mi} (R_{mt} - RF_t) + \epsilon_{mi,t} \]

\[ R_i - RF = \alpha + \lambda_m \hat{\beta}_{mi} + \lambda_x \hat{\beta}_{xi} + \eta \]
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- 30 Industries portfolio from Ken French library.

\[ R_{i,t} - RF_t = \alpha_i + \beta_i x_t + \epsilon_{i,t} \]

\[ R_{i,t} - RF_t = \alpha_{mi} + \beta_{mi} (R_{mt} - RF_t) + \epsilon_{mi,t} \]

\[ R_i - RF = \alpha + \lambda_m \hat{\beta}_{mi} + \lambda_x \hat{\beta}_{xi} + \eta \]

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\alpha}$</td>
<td>0.7523</td>
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<td>27.5825</td>
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<tr>
<td>$\bar{\lambda}_m$</td>
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<td>0.4826</td>
<td>4.0063</td>
<td>0.0001</td>
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<tr>
<td>$\bar{\lambda}_x$</td>
<td>-0.1120</td>
<td>0.2621</td>
<td>-4.8637</td>
<td>0.0000</td>
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</table>

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On Monetary Policy Uncertainty at Zero Interest Rate
Macroeconomic Effects

Response to Cholesky One S.D. Innovations ± 2 S.E.

- Response of LOG(P_GAPA) to LOG(P_GAPA)
- Response of LOG(P_GAPA) to CPI_GROWTH
- Response of LOG(P_GAPA) to UNCERTAINTY
- Response of CPI_GROWTH to LOG(P_GAPA)
- Response of CPI_GROWTH to CPI_GROWTH
- Response of CPI_GROWTH to UNCERTAINTY
- Response of UNCERTAINTY to LOG(P_GAPA)
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On Monetary Policy Uncertainty at Zero Interest Rate
Summary

- Non-linear, non-Gaussian state-space model of the short-term rate via particle filter.

Ignoring the zero lower bound leads to an overestimate of the shadow rate and an underestimate of the policy uncertainty. Monetary policy uncertainty seems to be a priced risk factor.
Non-linear, non-Gaussian state-space model of the short-term rate via particle filter.

Estimates of the shadow policy rate and policy uncertainty.
Summary

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- Estimates of the shadow policy rate and policy uncertainty.
- Ignoring the zero lower bound leads to an overestimate of the shadow rate and an underestimate of the policy uncertainty.
- Monetary policy uncertainty seems to be a priced risk factor.
- Negative macroeconomic effects of policy uncertainty shocks.