"Monetary Policy Risks in the Bond Markets and Macroeconomy"

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Economic Uncertainty and Monetary Policy

- Much work links the *levels of economic dynamics* with monetary policy
  - Macro variables and the short term interest rate (New Keynesian models)
  - Yield levels and monetary regimes (eg. Gallmeyer et al. (2009))

- We explore the link between *economic uncertainty and monetary policy*

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- We explore the link between *economic uncertainty and monetary policy*
- We develop an economically-founded term structure model to infer the relationship of policy and macro-volatility
- Focus on the quantitative contribution of *monetary policy towards risk premia movements*, including the macro-uncertainty channel

Our Paper

- A novel asset pricing framework
  - Flexible dynamics of short rates and macroeconomy
  - Pricing restrictions of recursive-utility based models
- Macroeconomic dynamics
  - Persistent movements in expected growth and inflation
  - **Monetary policy affects inflation uncertainty**
- Time-varying monetary policy rule
  - Regime-dependent response of short rates to expected growth and expected inflation

Historical Works

This paper connects to many strands of literature...

- *Macro and MP Regime Shifts*
  (Hamilton (1988), Sims and Zha (2006), Among Many Others)

- *Time Variation in Asset Risk Premia*
  (Ang and Bekaert (2002), Bansal and Zhou (2003), Ang and Piazzesi (2003), Bansal and Yaron (2004), Hasseltoft (2011), Bansal and Shaliastovich (2013))

- *Links b/w Term Structure and Monetary Policy*
  (Gallmeyer et al. (2009), Ang et al. (2011), **Campbell et al. (2013)**, **Chernov and Bikbov (2013)**, Song (2014), Backus et al. (2015))

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$\Longrightarrow$ Our model accounts for links between macro volatility and policy
$\Longrightarrow$ Monetary risks are accounted for in the joint solution of Euler equation, quantities, and financial prices

Model

Ingredients

- Representative Investor with Epstein and Zin (EZ) Preferences
- Novel SDF specification that allows for flexible modeling of consumption, inflation, and interest rate dynamics
- Regime-shifting Taylor Rule for one-period nominal interest rates
- Explore Financial Market implications with resulting Nonlinear Term Structure Model

Modeling Challenges

- We know from:

$$\begin{aligned} \text{Lucas (1978)}: &\quad \text{Preferences} + \pi_t \text{ Process} \Longrightarrow y_t^1 \\ \text{Gallmeyer et al. (2009)}: &\quad \text{Preferences} + \text{Rule for } y_t^1 \Longrightarrow \pi_t \text{ Process} \end{aligned}$$

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- Ideally, we would like to have a more flexible form of the SDF that can allow us to have an exogenous expression of preferences, a short rate rule, and inflation, yet maintain tractability
- In this framework, we utilize an SDF that prices the risks of cash flow, real rate, and "volatility" news

Nominal Economy

- The EZ agent maximizes lifetime utility (U_t) under endowment uncertainty:

$$U_t = \underset{\dots}{\text{Max}} \left[(1-\delta) C_t^{\frac{1-\gamma}{\theta}} + \delta \left(E_t \left[U_{t+1}^{1-\gamma} \right] \right)^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}}$$

- Equilibrium solution to log *nominal* SDF can be written as:

$$m_{t+1} \quad = \quad \theta \log \delta - \frac{\theta}{\psi} \Delta c_{t+1} + (\theta - 1) r_{c,t+1} - \pi_{t+1}$$

where $\triangle c$ is log consumption growth, r_c is return on aggregate wealth portfolio, and π is inflation

Dynamic-CAPM SDF

- The Euler restriction gives us that:

$$E_t\left[m_{t+1} + i_{t+1}\right] = 1$$

and the log-linearized wealth constraint:

$$r_{c,t+1} = \log \frac{W_{t+1}}{W_t - C_t} \approx \kappa_0 + wc_{t+1} - \frac{1}{\kappa_1} wc_t + \triangle c_{t+1}$$

- Using forward recursions of these two equations and the EZ pricing kernel we can derive the SDF as a function of innovations to future news

Dynamic-CAPM SDF (II)

- Following Bansal et al. (2013) and Campbell et al. (2013), we formulate the SDF as a function of cash flow, real interest rate, and vol news:

$$m_{t+1} = -i_t - V_t - \gamma N_{CF,t+1} + N_{R,t+1} + N_{V,t+1}$$

$$\begin{aligned} V_t &= \log E_t\left(\exp\left(m_{t+1} - E_t(m_{t+1})\right)\right) \\ N_{CF,t+1} &= (E_{t+1} - E_t)\sum_{j=0} \kappa_1^j \triangle c_{t+j+1} \\ N_{R,t+1} &= (E_{t+1} - E_t)\sum_{j=0} \kappa_1^j (i_{t+j} - \pi_{t+j+1}) \\ N_{V,t+1} &= (E_{t+1} - E_t)\sum_{j=0} \kappa_1^j V_{t+j} \end{aligned}$$

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- We exogenously specify consumption, inflation, and interest rate dynamics; **volatility news is solved endogenously**

Economic Dynamics

- Denote the regime of monetary policy as s_t, which is governed by an N-state Markov switching process. Transition from state j to state i will be given by probability π_{ij}.

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- The consumption / inflation processes are given by:

$$\begin{aligned} \triangle c_{t+1} &= \mu_c + x_{ct} + \sigma_c^* \epsilon_{c,t+1} \\ \pi_{t+1} &= \mu_\pi + x_{\pi t} + \sigma_\pi^* \epsilon_{\pi,t+1} \end{aligned}$$

where we model the expected components of endowments with stochastic volatility

Economic Dynamics (II)

- The joint, demeaned VAR process $X_t = [x_{ct}, x_{\pi t}]'$ will be given by:

$$X_{t+1} = \Pi X_t + \Sigma_t \epsilon_{t+1}$$

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where Σ_t is given by:

$$\Sigma_t = \begin{pmatrix} \sigma_{c0} & 0 \\ 0 & \sigma_{\pi,t} \end{pmatrix} = \begin{pmatrix} \sigma_{c0} & 0 \\ 0 & \sqrt{\delta^{\pi}(s_t) + \tilde{\sigma}^2_{\pi,t}} \end{pmatrix}$$

and the transient, continuous portions of volatility are given by:

$$\tilde{\sigma}^2_{\pi t} = \tilde{\sigma}^2_{\pi,0} + \varphi_{\pi} \tilde{\sigma}^2_{\pi,t-1} + \omega_{\pi} \eta_{\sigma\pi,t}$$

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- Notice that the inflation variance is a linear combination of (1) a monetary policy portion and (2) a smooth variance component

Economic Dynamics (III)

- We have specified consumption and inflation dynamics; the last thing to specify is the rule for the short rate:

$$\begin{aligned} i_t &= i_0 + \alpha_c(s_t) \underbrace{(x_{ct} + \mu_c)}_{\text{Expected Growth}} + \alpha_\pi(s_t) \underbrace{(x_{\pi t} + \mu_\pi)}_{\text{Expected Inflation}} \\ &= \alpha_0(s_t) + \alpha(s_t)' X_t \end{aligned}$$

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&= \alpha_0(s_t) + \alpha(s_t)' X_t
\end{aligned}
$$

- Regime, s_t, links movements in Taylor rule coefficients to those in inflation volatilities

Model Solution

- Recall that the log-SDF is given by :

$$m_{t+1} = -i_t - V_t - \gamma N_{CF,t+1} + (N_{I,t+1} - N_{\pi,t+1}) + N_{V,t+1}$$

- We take into account the risks associated with monetary regime switches and continuous state movements when computing each type of news ▸ Details

Model Solution (II)

- To receive V_t we guess and verify by conjecturing a nonlinear form:

$$V_t(s_t) = V_0(s_t) + V_1(s_t)' X_t + V_{2\pi}(s_t)\tilde{\sigma}^2_{\pi,t}$$

- Solve using 1 period Euler relation:

$$\begin{aligned} 1 &= E_t\left[\exp(m_{t+1} + i_t)\right] \\ \Longrightarrow \exp\left(V_t\right) &= E_t\left[\exp(m_{t+1} + i_t + V_t)\right] \\ &= E_t\left[\exp(-\gamma N_{CF,t+1} + N_{I,t+1} - N_{\pi,t+1} + N_{V,t+1})\right] \end{aligned}$$

- For every set of parameters, we can solve for a V_t process that satisfies no-arbitrage restriction

Nominal Term Structure

- With solution to V_t we can re-express the SDF as:

$$\begin{aligned} m_{t+1} &= S_0 + S'_{1,X} X_t + S_{1,\sigma\pi} \tilde{\sigma}^2_{\pi t} \\ &+ S'_{2,\epsilon} \Sigma_t \epsilon_{t+1} + S_{2,\eta\pi} \omega_\pi \eta_{\pi,t+1} \end{aligned}$$

where we have regime-dependent loadings and time-varying quantities of risks

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- We can now show that log bond prices and hence yields, y_t^n, take a nonlinear structure in states

$$y_t^n(s_t) = -\frac{1}{n} p_t^n = \mathcal{A}^n(s_t) + \mathcal{B}_X^{n'}(s_t) X_t + \mathcal{B}_{\sigma\pi}^n(s_t) \tilde{\sigma}^2_{\pi t}$$

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- Risk premia in this economy will take a similar form as well:

$$rp_t^n = E_t\left[\frac{P_{t+1}^{n-1}}{P_t^n}\right] - y_t^1 = r_0(s_t) + r_{\sigma\pi}(s_t)\tilde{\sigma}_{\pi t}^2$$

Estimation

Empirical Implementation

- 2 monetary regimes
- Filtered Time Series: $\{x_{ct}, x_{\pi t}, \tilde{\sigma}^2_{\pi t}, s_t\}$ using Bayesian MCMC methods
- Estimation is from 1969 onwards at a quarterly basis using bond yields $\{$3M, 1Y - 5Y$\}$ from Fed & CRSP
- Nondurables and Services Consumption and GDP Deflator Inflation from the BEA
- Expectations data from Survey of Professional Forecasters

State Space

- Our state space for estimation is given by (indicates measurement error):

(Measurement)

$$y_{t+1}^{1:N} = \mathcal{A}^{1:N}(s_{t+1}) + \mathcal{B}_X^{1:N}(s_{t+1})X_{t+1} + \mathcal{B}_{\sigma\pi}^{1:N}(s_{t+1})\tilde{\sigma}^2_{\pi,t+1} + u_{t+1,y}$$

$$\triangle c_{t+1} = \mu_c + e_1' X_t + \sigma_c^* \epsilon_{c,t+1}$$

$$\pi_{t+1} = \mu_\pi + e_2' X_t + \sigma_\pi^* \epsilon_{\pi,t+1}$$

$$X_{SPF,t+1} = X_{t+1} + u_{t+1,X}$$

$$\Longleftrightarrow \qquad Y_{t+1}^{DATA} = f_Y\left(\mathbb{Z}_t, \mathbb{Z}_{t+1}\right) + \Sigma_{u,Y} u_{t+1,Y}$$

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(Transition)

$$X_{t+1} = \Pi X_t + \Sigma_t(\tilde{\sigma}^2_{\pi t}, s_t)\epsilon_{t+1}$$

$$\tilde{\sigma}^2_{\pi t} = \tilde{\sigma}^2_{\pi,0} + \varphi_\pi \tilde{\sigma}^2_{\pi,t-1} + \omega_\pi \eta_{\sigma\pi,t}$$

$$s_t \sim \text{ Discrete Markov Process with } T(\mathbb{P}_s)$$

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- The set of parameters (θ) is given by:

$$\{\Pi, \delta^{\alpha\pi}, \tilde{\sigma}_{c0}^2, \tilde{\sigma}_{\pi 0}^2, \varphi_\pi, \omega_\pi, \sigma_c^*, \sigma_\pi^*, i_0, \kappa_1, \gamma, \mu_c, \mu_\pi, \alpha_c^{1:2}, \alpha_\pi^{1:2}, \mathbb{P}_s\}$$

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- Keep in mind, each $\theta \longrightarrow \{\mathcal{A}, \mathcal{B}_X, \mathcal{B}_{\sigma\pi}\}$, so state space coefficients are all model-based

Estimation Technique

- We draw parameters using a Bayesian MCMC algorithm, using **Particle-Filter** evaluation of the likelihood function

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- To evaluate the likelihood, we need to take into account state uncertainty. We use a particle filter approach. That is to say for J "particles" of the exogenous states we use:

$$P\left(Y^{DATA}|\theta\right) \approx \frac{1}{J}\sum_{j=1}^{J} P\left(Y^{DATA}|States^{j},\theta\right)$$

$States^{j}$ can be drawn individually, for given θ, and we evaluate each set's probabilities using particle weights

Estimation Technique (II)

- To draw parameters we can use Random-Walk Metropolis-Hastings algorithm where we draw:

$$\theta^* = \theta^{j-1} + \Sigma_{draw}\varepsilon$$

$$\text{Accept w/Prob } \alpha = \frac{P\left(\theta^* | Y^{DATA}\right)}{P\left(\theta^{j-1} | Y^{DATA}\right)}$$

- After getting sufficient number of draws, remove burn-in and report results across draws of θ

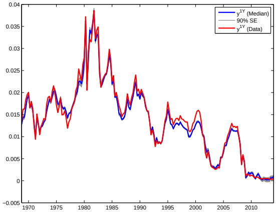
Results

- Model Fit
- Parameter Estimates
- Counterfactuals, among which:
  - Within-Regime Characteristics
  - Risk Premia Movements
  - Role of MP Shifts

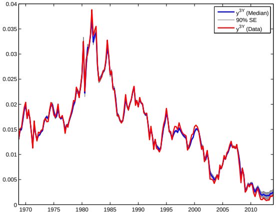
Model Fit (In-Sample Yields)

Data, Posterior Median (Solid), 90% Credible Sets (shaded)

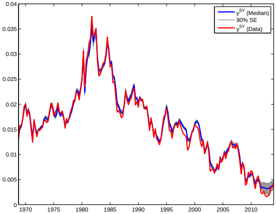
(i) In-Sample y_t^{1Y}



(ii) In-Sample y_t^{3Y}



(iii) In-Sample y_t^{5Y}

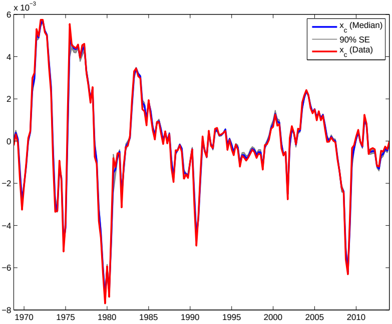


$\Longrightarrow$ We fit bond yields with low measurement error

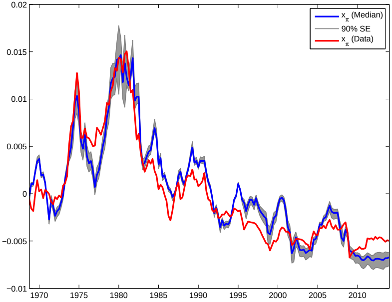
Latent States (Filtered Expectations)

Data, Posterior Median (Solid), 90% Credible Sets (shaded)

(i) Filtered x_{ct}



(ii) Filtered $x_{\pi t}$

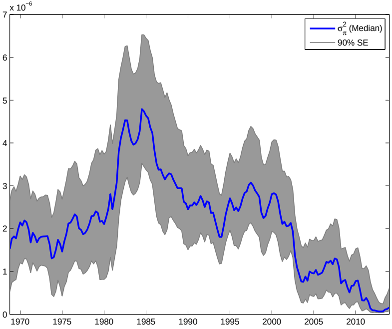


$\Longrightarrow$ Model measures of macroeconomic expectations are close to the data

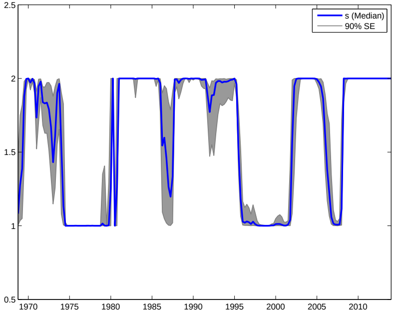
Latent States (Filtered Expectations)

Data, Posterior Median (Solid), 90% Credible Sets (shaded)

(i) Filtered $\tilde{\sigma}^2_{\pi t}$



(ii) Filtered s_t



$\Longrightarrow$ Non-policy related inflation volatility jumps in levels in the 1980's and declines to very low value recently

$\Longrightarrow$ Regimes are consistent with anecdotal evidence and other literature Details

Parameter Values

Posterior medians are provided. Values in parentheses are (10%, 90%) credible sets.

	Π	Π	
x_{ct}	.991	-.011	
	(.972, .998)	(-.032, -.004)	
$x_{\pi t}$	0.00	.955	
		(.920, .978)	
	$\frac{\tilde{\sigma}^2_{i,0}}{1-\varphi_i} \times 10^5$	φ_i	$\omega_i \times 10^6$
$\tilde{\sigma}^2_{ct}$	.025	–	–
	(.013, .068)		
$\tilde{\sigma}^2_{\pi t}$	.021	.976	.190
	(.009,.043)	(.962, .992)	(.186, .194)

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$\Longrightarrow$ The inflation non-neutrality is key to receive upward sloping yield levels and risk premia levels!

Parameter Values (II)

Posterior medians are provided. Values in parentheses are (10%, 90%) credible sets.

	$\delta_\pi(i) \times 10^5$	$\alpha_c(i)$	$\alpha_\pi(i)$	π_{ii}		
Regime $i = 1$	0.00	.091	.791	.975		
		(.023, .274)	(.622, 1.01)	(.945, .994)		
Regime $i = 2$	.0083	.315	1.90	.929		
	(.0063, .0099)	(.174, .524)	(1.66, 1.99)	(.893, .971)		
	γ	i_0	μ_c	μ_π	σ^*_c	σ^*_π
Other Pars	24.38	.013	.0045	.0091	.0038	.0039
	(22.81, 26.09)				(.0029, .0050)	(.0029, .00

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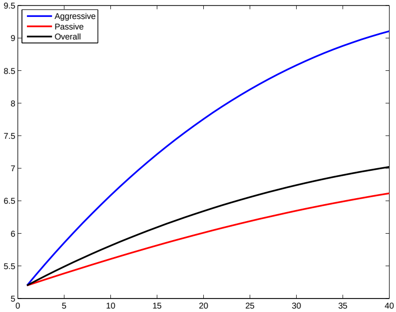
$\Longrightarrow$ We can interpret regime 1 as an "Aggressive Policy" state while regime 2 exhibits a "Passive Policy."

$\Longrightarrow$ Aggressive regimes generate more macroeconomic volatility (about one quarter of total inflation vol in levels!)

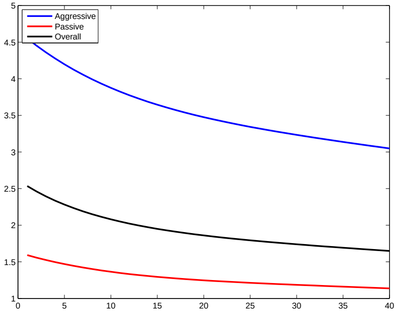
Within-Regime Characteristics

We take median parameters and fix policy variables at each regime's values.

(i) Yield Levels



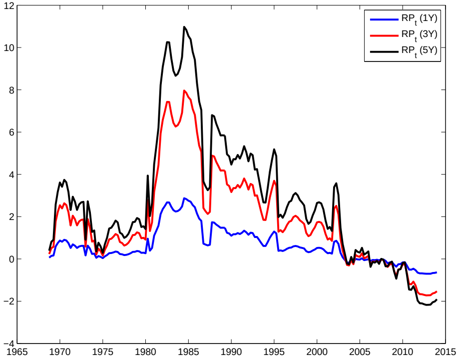
(ii) Volatilities



$\Longrightarrow$ Aggressive regimes are associated with higher levels and volatilities.

Risk Premia Movements

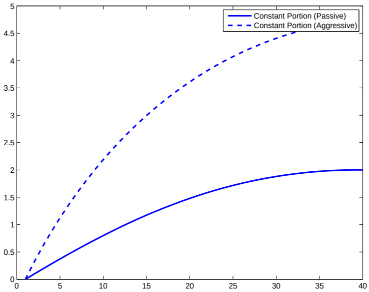
Figure: Model-Implied, In-Sample Risk Premia



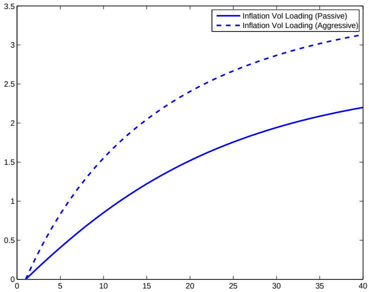
$\Longrightarrow$ Upward sloping RP term structure, model breaks Expectation Hypothesis
$\Longrightarrow$ Estimates also capture recent negative risk premia period

Risk Premia Movements (II)

Figure: Risk Premia Loadings



(i) Constant Coef



(ii) Loading on $\tilde{\sigma}^2_{\pi}$

$\Longrightarrow$ Aggressive regimes identify with higher risk premia levels and volatilities

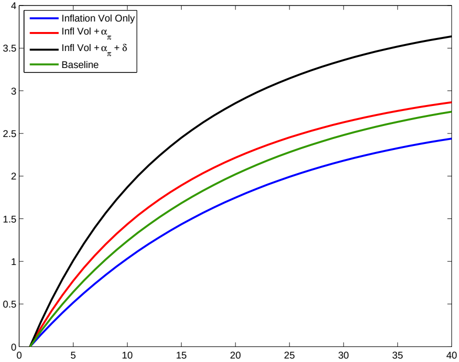
$\Longrightarrow$ Recent negative risk-premia period, identified through low $\tilde{\sigma}^2_{\pi t}$

Experiments

- What is the marginal contribution of non-policy volatility? Of policy volatility? Of time-varying coefficients?
- We test this by examing risk premia moments with four specifications:
  (a) Keep constant all regime shifting constants (Infl Vol Only)
  (b) Allow variation in $\alpha_\pi(s_t)$ (Infl vol + α_π)
  (c) Allow variation in $\delta^\pi(s_t)$ (Infl vol + $\alpha_\pi + \delta$)
  (d) Allow all variations (Baseline)

Experiments (II)

Figure: Risk Premia Volatilities (II)



$\Longrightarrow$ Vol effects are sizeable. $\{\alpha_\pi, \delta^\pi\}$ both raise overall RP Vol by $\sim 20\%$ each.

$\Longrightarrow$ Variation in growth sensitivity, α_c decreases it

Differing Signs of Volatility Movements

- We can rewrite the risk premia as:

$$rp_t^n = Cons(s_t) + \underbrace{r_{\sigma c}(s_t)}_{<0}\tilde{\sigma}_{c0}^2 + \underbrace{r_{\sigma\pi}(s_t)}_{>0}\tilde{\sigma}_{\pi t}^2$$

  where the second portion denotes the piece from growth-related volatility
- Variation in α_c largely affects $r_{\sigma c}$ while α_π variation affects $r_{\sigma\pi}$
- Growth sensitivity variation decreases risk premia volatility
- Signs of risk premia loadings are consistent with empirical results

Conclusion

- We propose a theory-based, flexible asset pricing model that disentangles slow-moving components of stochastic volatility from monetary policy aggresiveness
- Through an estimation of a two-regime monetary setup, we show the importance of the monetary channel in stochastic volatility and asset risk premia
    - Aggressive monetary policies increase macro-volatility
    - Aggressive regimes are associated with higher yield levels, more volatility, and greater risk premia variability
    - The policy portion of fundamental inflation vol increases risk premia volatility in conjunction with movements in the inflation sensitivity of the Taylor rule.

$\Longrightarrow$ Thank you for attending! Comments and questions are very much welcome.

Appendix

Details on Model Solution

We can show that Cash Flow (N_{CF}), Inflation News (N_π) , and Interest Rate News (N_I) are given by:

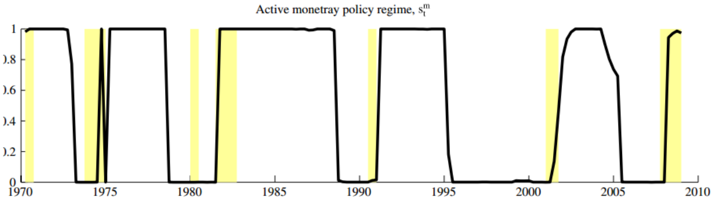
$$\begin{aligned}
N_{CF,t+1}(s_t, s_{t+1}) &= (E_{t+1} - E_t) \sum_{j=0}^{\infty} \kappa_1^j \Delta c_{t+j+1} \\
&= F_{CF,0}(s_t, s_{t+1}) + F_{CF,\epsilon}(\dots)' \Sigma_t \epsilon_{t+1} + \sigma_c^* \epsilon_{c,t+1} \\
N_{\pi,t+1}(s_t, s_{t+1}) &= (E_{t+1} - E_t) \sum_{j=0}^{\infty} \kappa_1^j \pi_{t+j+1} \\
&= F_{\pi,0}(s_t, s_{t+1}) + F_{\pi,\epsilon}(\dots)' \Sigma_t \epsilon_{t+1} + \sigma_\pi^* \epsilon_{\pi,t+1} \\
N_{I,t+1}(s_t, s_{t+1}) &= (E_{t+1} - E_t) \sum_{j=0}^{\infty} \kappa_1^j i_{t+j} \\
&= F_{I,0}(s_t, s_{t+1}) + F_{I,X}(\dots)' X_t + F_{I,\epsilon}(\dots)' \Sigma_t \epsilon_{t+1}
\end{aligned}$$

where $F_{\dots}$ are functions of model primitives (parameters of state governance, regime transition matrix, etc.)

Back

Use of Output Gap

Chernov and Bikbov (2013) uses output gap in a New Keynesian setting to identify regimes.



Estimation of active regime in their work is very similar. Picks up in 1980's, and mid 2000's. Also increases in ZLB period. Back