Identification of Macroeconomic Shocks with External Instruments

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   - ▷ Instruments
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The Identification Problem

Dynamic Causal Effects of Macroeconomic Shocks

What is the effect, over time, of a policy intervention that propagates through the economy?

- Longstanding defining challenge of macroeconometrics
- Economy typically modelled by a system of simultaneous equations
- Identification with **internal instruments:**

  ↓

  restrictions to the system identify the shocks, e.g. some variables and/or their lags enter some equations but not other

A Model for the Economy: Structural

SVAR

$$\underset{[n\times 1]}{y_t} = \mathcal{B}(L) \underset{[n\times 1]}{e_t}$$

$$= B_0 e_t + B_1 e_{t-1} + B_2 e_{t-2} + \dots$$

y_t **observable variables** – e.g. output, unemployment, prices, ...

e_t **structural shocks** – e.g. monetary policy, technology, ...

$B_0, B_1, \dots$ **structural transmission coefficients**, function of primitive model parameters

Structural IRFs

$$B_h = \frac{\partial y_{t+h}}{\partial e_t'}$$

Row-i column-j element of B_h is the effect of a unit increase in $e_{t,j}$ on variable $y_{t,i}$ h periods into the future

IRFs are interpreted **holding other shocks constant**

1. shocks are orthogonal
2. unforecastable, primitive, unanticipated economic forces

An Empirical Model for the Economy: Reduced-Form

VAR

$$\underset{[n\times 1]}{y_t} = \Psi(L) \underset{[n\times 1]}{u_t}$$

$$= u_t + \psi_1 u_{t-1} + \psi_2 u_{t-2} + \dots$$

y_t same **observable variables**

u_t **innovations**/forecast errors ➔ $u_t \equiv y_t - \text{Proj}(y_t | y_{t-1}, y_{t-2}, \dots)$

$\psi_1, \psi_2, \dots$ **coefficients of MA representation**, Wold decomposition

[e.g. Hamilton (1994), Lütkepohl (2005)]

Forecasting Model:

$$y_t = u_t + \psi_1 u_{t-1} + \psi_2 u_{t-2} + \dots \qquad u_t \sim WN(0, \Sigma_u)$$

$$\mathcal{O}_t = \text{span}\{y_t, y_{t-1}, \dots\} \quad \rightarrow \quad \textbf{Information Set Econometrician}$$

$$u_t = y_t - \text{Proj}(y_t | \mathcal{O}_{t-1})$$

Structural Model:

$$y_t = B_0 e_t + B_1 e_{t-1} + B_2 e_{t-2} + \dots \qquad e_t \sim WN(0, \mathbb{I}_n)$$

$$\mathcal{I}_t = \text{span}\{e_t, e_{t-1}, \dots\} \quad \rightarrow \quad \textbf{Information Set Agents}$$

$$B_0 e_t = y_t - \text{Proj}(y_t | \mathcal{I}_{t-1})$$

Reduced-Form Innovations to Structural Shocks

$$\mathcal{O}_{t-1} = \mathcal{I}_{t-1}$$

$$\Downarrow$$

$$y_t - \text{Proj}(y_t|\mathcal{O}_{t-1}) = y_t - \text{Proj}(y_t|\mathcal{I}_{t-1})$$

$$\Downarrow$$

$$u_t = B_0 e_t$$

$$\Downarrow$$

$$\Sigma_u = B_0 B_0'$$

Remark: Assumes invertibility of MA representation

Problems:

1. What if $\mathcal{O}_t \neq \mathcal{I}_t$?
2. Which B_0?

Information Sufficiency

$\mathcal{O}_t = \mathcal{I}_t \Rightarrow$ the structural shocks (e_t) can be recovered as a linear combination of the reduced-form VAR innovations (u_t) ➔ the information in the history of y_t is sufficient to estimate the shocks

If the econometrician's information set does not span that of the agents, the structural shocks are non-fundamental and cannot be obtained from a VAR

Test for informational sufficiency:

1. **Global:** there is no $x_t \notin y_t$ such that x_t Granger causes y_t
2. **Partial:** there is no $x_t \notin y_t$ such that x_t Granger causes $\hat{e}_t$

[Hansen and Sargent (1991), Lippi and Reichlin (1993, 1994), Giannone and Reichlin (2006), Forni and Gambetti (2014)]

Foresight

Policy changes may be anticipated:

- **by the agents**: agents can know at time t of a shock that will affect variables at $t+h$ – e.g. forward guidance, announced changes in fiscal plans

$$e_t \notin \text{span}\{y_t, y_{t-1}, \ldots\}$$

- **by the policymaker**: the central bank can have superior information – e.g. forecasts of inflation [Romer and Romer (2000)]

confound e_t with systematic component of policy

[see Ramey (2016) for a review]

$$e_t = B_0^{-1} u_t$$

B_0 such that $B_0 B_0' = \Sigma_u$

Statistical orthogonalization

1. Cholesky decomposition ➔ B_0 is the Cholesky factor of Σ_u, unique and lower triangular
2. Spectral decomposition ➔ $B_0 = V D^{1/2}$ where $V D V' = \Sigma_u$
3. $B_0^{-1} u_t$ are orthogonal ➔ $\mathbb{E}[B_0^{-1} u_t u_t' (B_0')^{-1}] = B_0^{-1} \Sigma_u B_0^{-1\prime} = \mathbb{I}_n$

Are $B_0^{-1} u_t$ the *macroeconomic* shocks?

1. What is the economic interpretation of $B_0^{-1} u_t$?
2. What is the economic information in IRFs to $B_0^{-1} u_t$?

Class of Orthonormal Representations

Consider any orthogonal matrix H (rotation)

$$H'H = HH' = \mathbb{I}_n$$

Define $\widetilde{B}_0 = B_0 H \;\rightarrow\; \widetilde{B}_0 \widetilde{B}_0' = \Sigma_u$

1. $\mathbb{E}[\, \underbrace{\widetilde{B}_0 u_t}_{\eta_u} u_t' (\widetilde{B}_0^{-1})' \,] = H' B_0^{-1} \Sigma_u (B_0')^{-1} H = H' \mathbb{I}_n H = \mathbb{I}_n$
2. η_u are orthogonal (rotated) innovations

Problem: H can be any... how should we choose one?

The Identification Problem

- Identifying the VAR means fixing H – i.e. choosing one particular representation of y_t in order to recover the structural shocks from the VAR innovations ➔ **Structural economic shocks** are linear combinations of VAR innovations u_t

- To choose H we need $n(n-1)/2$ restrictions
  1. n^2 parameters
  2. $n(n+1)/2$ restrictions implied by orthonormality

- Use **economic theory** to derive the restrictions – e.g. on effects that a given shock has on some subset of y_t

Short-Run

1. Recursive [e.g. Christiano, Eichenbaum and Evans (1996, 1999)]
2. Zero restrictions – Non-Recursive [e.g. Blanchard and Perotti (200x)]
3. Identification through heteroskedasticity [Rigobon (2003)]

Medium/Long-Run

1. Sign restrictions [Uhlig (2005)]
2. Long-run restrictions [Blanchard and Quah (1989)]
3. Maximum variance [e.g. Beaudry and Portier (2006)]

Instruments for the Shocks

1. Narrative [e.g. Romer and Romer (2004, 2010)]
2. Agents' Expectations [e.g. Ramey (2009), Gertler and Karadi (2015)]
3. Shocks from DSGE, ...

Identification With External Instruments

Intuition

Isolate exogenous variation in the innovation of the policy variable (i.e. residuals of the policy equation) using information **not included** in the system (e.g. VAR)

Works through the use of **external instruments** that proxy for the unobserved policy shock

If a valid instrument is found, the contemporaneous transmission coefficients are consistently estimated using moments of observables

External Instrument for the Shock

$$u_t = \underset{[n\times n]}{B_0}\ e_t$$

$$\begin{pmatrix} u_t^p \\ u_t^o \end{pmatrix} = \left(\begin{array}{c:c} \underset{[n\times 1]}{b_1} & \underset{[n\times(n-1)]}{b_2} \end{array}\right) \begin{pmatrix} e_t^p \\ e_t^o \end{pmatrix}$$

IDENTIFYING ASSUMPTIONS

Find $z_t \notin y_t$ such that:

1. $\mathbb{E}[\ z_t e_t^{p\prime}\ ] = \alpha$ ➔ **relevance**
2. $\mathbb{E}[\ z_t \epsilon_t^{o\prime}\ ] = 0$ ➔ **exogeneity**

Contemporaneous Transmission Coefficients

$$u_t = \left(\underset{[n\times 1]}{b_1} \;\vdots\; \underset{[n\times(n-1)]}{b_2} \right) e_t$$

$$\begin{pmatrix} u_t^p \\ u_t^o \end{pmatrix} = \left(\begin{array}{c:c} \underset{[1\times 1]}{b_{11}} & b_{21} \\ \hdashline \underset{[(n-1)\times 1]}{b_{12}} & b_{22} \end{array} \right) \begin{pmatrix} e_t^p \\ e_t^o \end{pmatrix}$$

Let $\dim(z_t) = \dim(e_t^p)$

$$\begin{pmatrix} \mathbb{E}(u_t^p z_t') \\ \mathbb{E}(u_t^o z_t') \end{pmatrix} = B_0 \begin{pmatrix} \mathbb{E}(e_t^p z_t') \\ \mathbb{E}(e_t^o z_t') \end{pmatrix} = \left(\begin{array}{c:c} b_1 & b_2 \end{array} \right) \begin{pmatrix} \alpha' \\ 0 \end{pmatrix} = \begin{pmatrix} b_{11}\alpha' \\ b_{12}\alpha' \end{pmatrix}$$

$$\mathbb{E}(u_t^p z_t')^{-1}\mathbb{E}(u_t^o z_t') = b_{11}^{-1} b_{12}$$

[Montiel-Olea, Stock and Watson (2012), Mertens and Ravn (2013), Stock and Watson

Contemporaneous Transmission Coefficients

$$\mathbb{E}(u_t^p z_t')^{-1}\mathbb{E}(u_t^o z_t') = b_{11}^{-1} b_{12}$$

- b_1 is consistently estimated up to scale convention
- Equivalent to regressing u_t^o on u_t^p using z_t as external instrument
- Method:
  1. Get an estimate of u_t – e.g. VAR(p) residuals
  2. Regress $\hat{u}_t$ on z_t
  3. Calculate $b_{11}^{-1} b_{12}$ as ratio of regression coefficients
  4. Choose normalization – e.g. $b_{11} = 1$

1-Instrument & 1-Shock
Identification of Monetary Policy Shocks

Miranda-Agrippino and Ricco (2017a, 2017b)

Monetary Policy Shocks

Monetary policy shocks (e_t^p) are defined as the unexpected part of the equation for the monetary policy variable (i_t) – e.g. policy rate

$$i_t = f(\widehat{\Omega}_{t|t}^{CB}) + e_t^p$$

where

- $f(\cdot)$: is the reaction function of the monetary authority
- $\widehat{\Omega}_{t|t}^{CB}$: is the central bank's information set

$f(\widehat{\Omega}_{t|t}^{CB})$ is the systematic component of policy

Identification of the Effects of Monetary Policy

Most of the variation in the policy instrument (i_t) is accounted for by the way the monetary authority systematically reacts to the state of the economy – $f(\widehat{\Omega}^{CB}_{t|t})$ –, and not by random disturbances

The same policy instrument (i_t) is used to both induce changes in the economy and to react to them

The identification of the effects of a shock to monetary policy requires finding an exogenous "shifter" in the policy equation

[Sims (1998)]

Potential Instruments: HF Market Prices

- The price of an interest rate futures contract is a function of agents' expectations about future interest rates

↓

Futures prices measure expected path of policy

- Reactions following central banks' announcements measure the component of policy unexpected by market participants

↓

Monetary surprises measure monetary policy shocks

Interest Rate Futures

Contract that pays (a function of) the interest rate at time $t+h$

$$p_t^{(h)} = \mathbb{E}_t\left(i_{t+h}\right) + \zeta_t^{(h)}$$

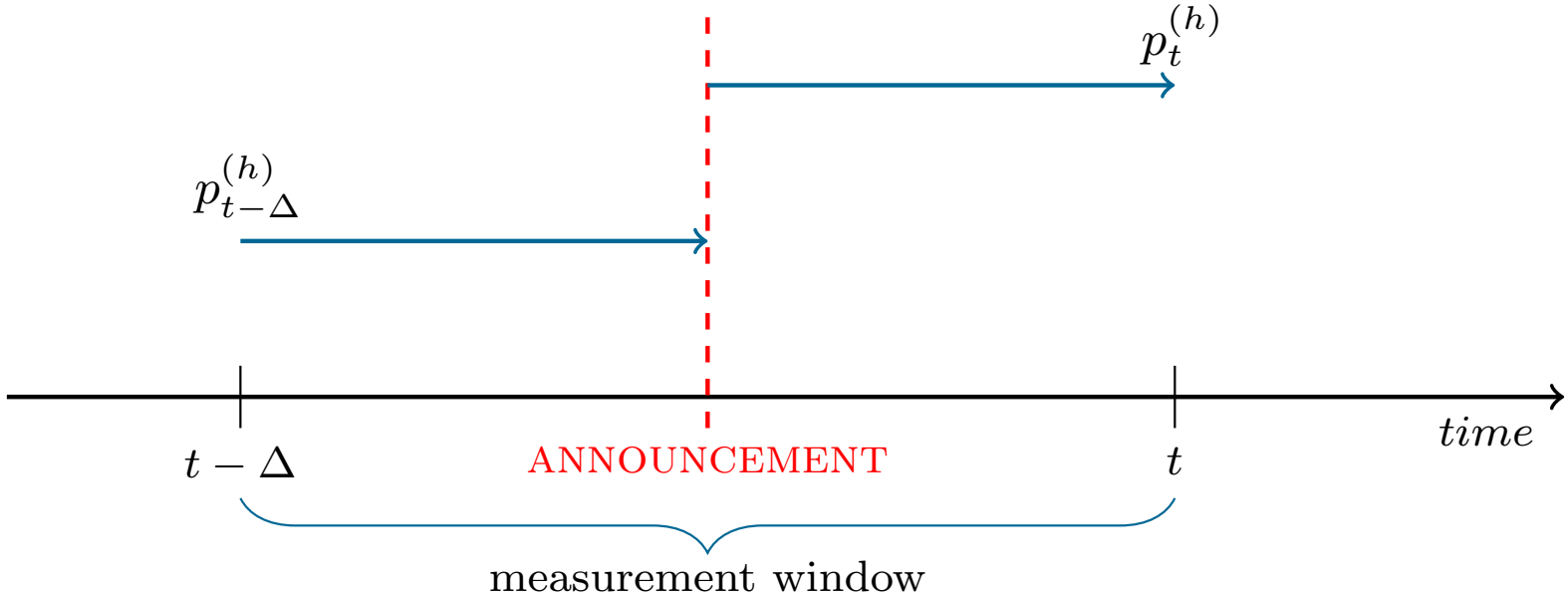
$p_t^{(h)}$ ➔ price of futures contract expiring at $t+h$

$\mathbb{E}_t\left(i_{t+h}\right)$ ➔ $t+h$ interest rate expected at time t

$\zeta_t^{(h)}$ ➔ risk compensation/premium

[Rudebusch (1998), Kuttner (2001), Sack (2004)]

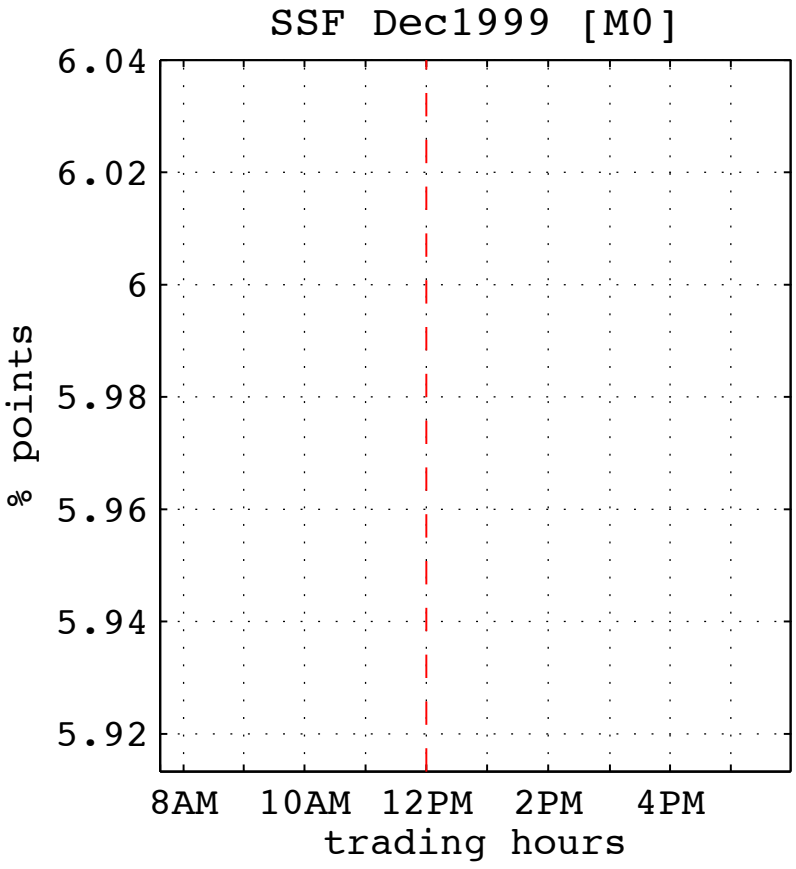
Monetary Surprises



$$mps_t^{(h)} \equiv p_t^{(h)} - p_{t-\Delta}^{(h)} = \underbrace{\left[\mathbb{E}_t\left(i_{t+h}\right) - \mathbb{E}_{t-\Delta}\left(i_{t+h}\right)\right]}_{\text{expectation revision}} + \underbrace{\left[\zeta_t^{(h)} - \zeta_{t-\Delta}^{(h)}\right]}_{\text{premium revision}}$$

[Gürkaynak, Sack, Swanson (2005)]

A Typical Announcement Day



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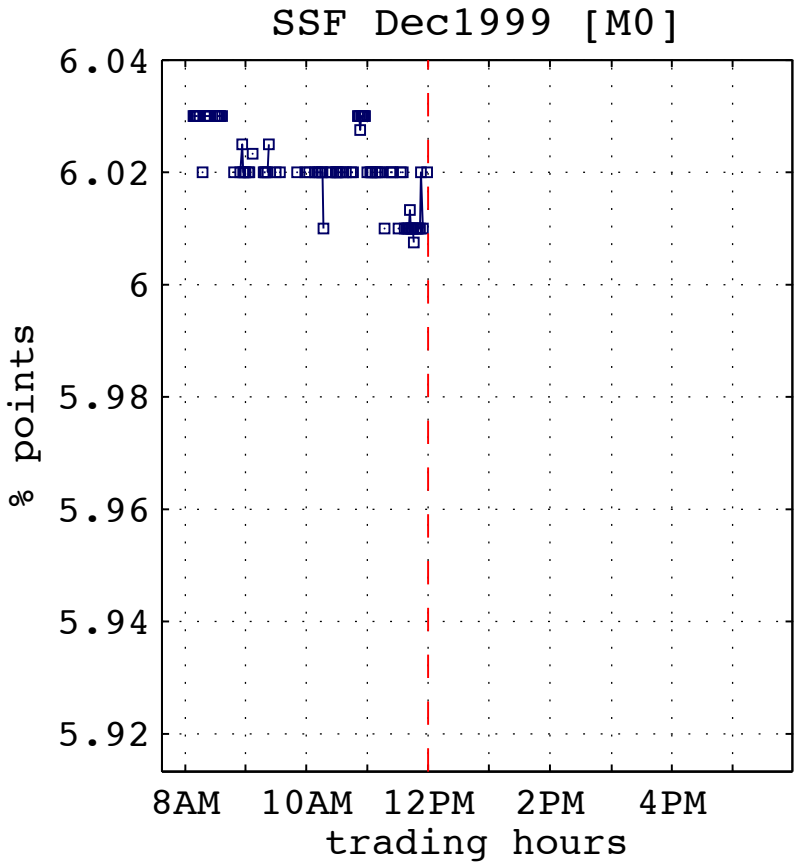

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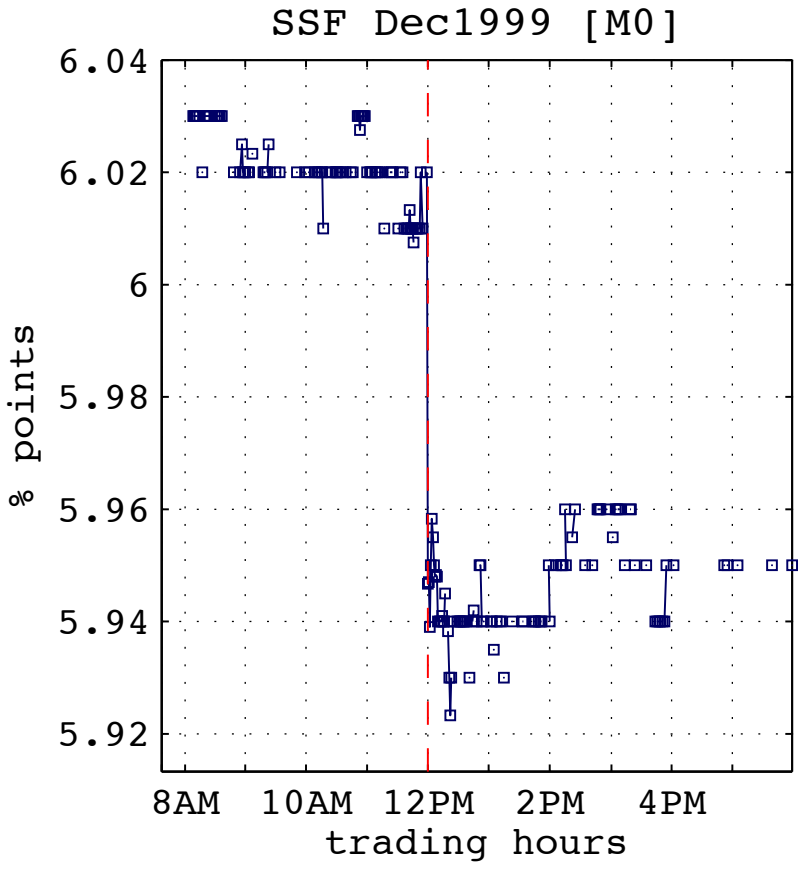

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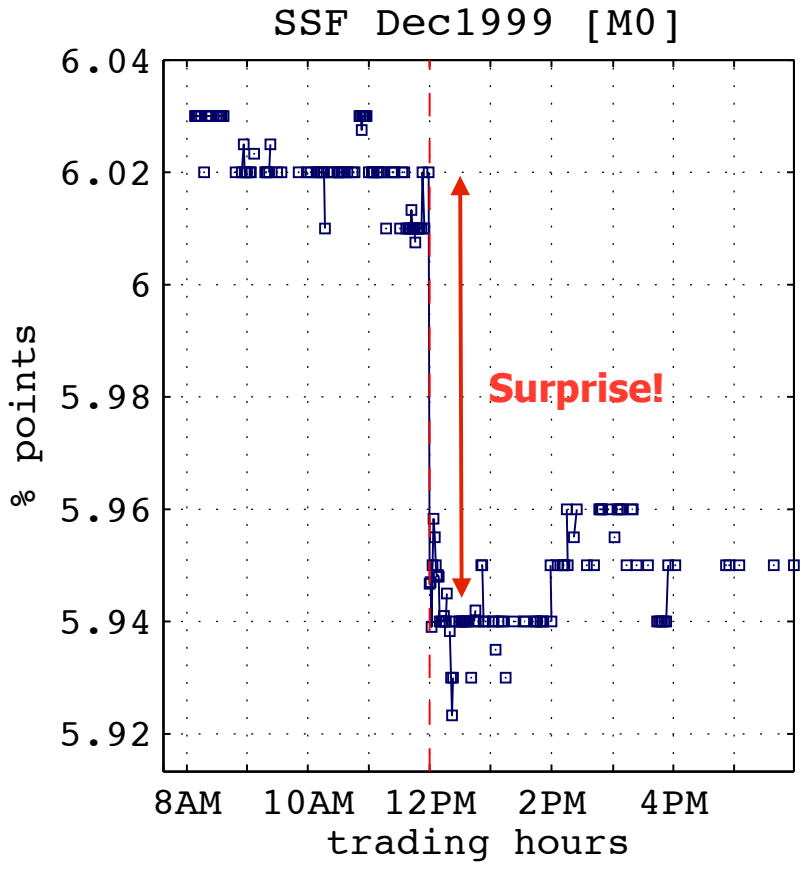


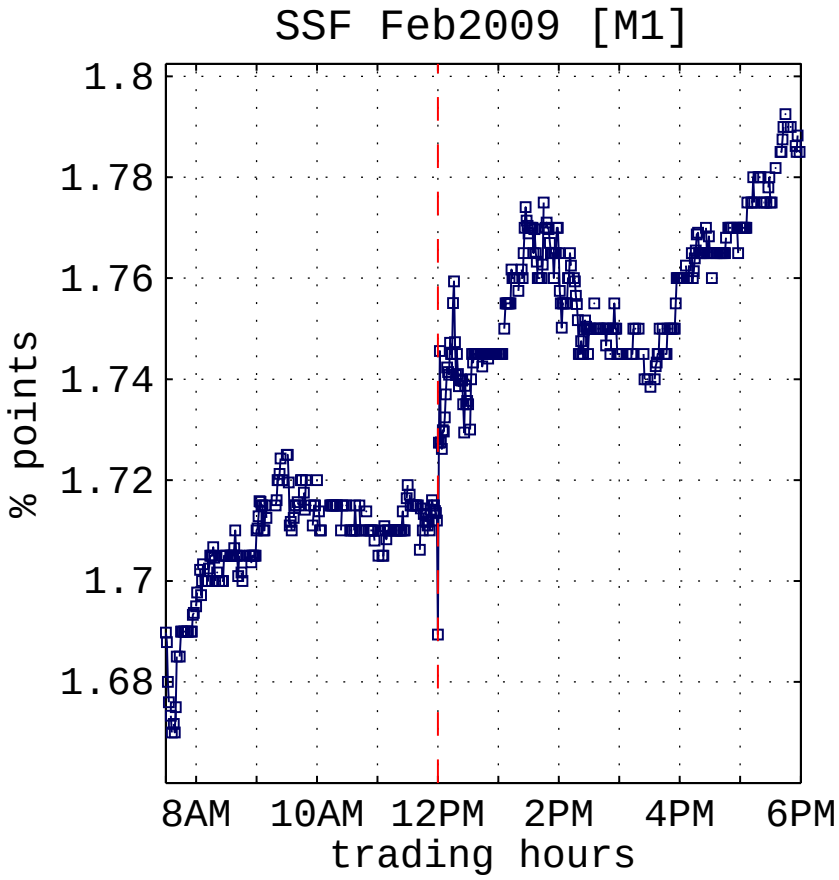
MPS → MP Shocks: Implicit Assumptions

1. The announcement is the only event in Δ
2. Markets know the CB reaction function (and the economy's DGP)
3. Markets incorporate all information as soon as it is released
4. The risk premium $\zeta_t^{(h)}$ is unaffected by the MP shock

$$p_t^{(h)} - p_{t-\Delta}^{(h)} = \underbrace{\left[\mathbb{E}_t\left(i_{t+h}\right) - \mathbb{E}_{t-\Delta}\left(i_{t+h}\right)\right]}_{\text{expectation revision}} + \underbrace{\left[\zeta_t^{(h)} - \zeta_{t-\Delta}^{(h)}\right]}_{=0}$$
$$= e_t^{mp} + \text{measurement error}$$

[Gürkaynak, Sack, Swanson (2005), Gertler and Karadi (2015), and many more]

UK: Q1-2009



event type: Rate Decision
date: 05/02/2009 12:00
new rate: 1 (old: 1.5)
forecast: 1

conflicts:
none

UK: Q1-2009

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News release

5 February 2009

Bank of England Reduces Bank Rate by 0.5 Percentage Points to 1.0%

The Bank of England's Monetary Policy Committee today voted to reduce the official Bank Rate paid on commercial bank reserves by 0.5 percentage points to 1.0%.

The global economy is in the throes of a severe and synchronised downturn. Output in the advanced economies fell sharply in the fourth quarter of 2008, and growth in the emerging market economies appears to have slowed markedly. Business and household sentiment in many countries has deteriorated. The weakness of the global banking and financial system means that the supply of credit remains constrained.

In the United Kingdom, output dropped sharply in the fourth quarter of 2008 and business surveys point to a similar rate of decline in the early part of this year. Credit conditions faced by companies and households have tightened further. The underlying picture for consumer spending appears weak. Businesses have

Information Content of Market Surprises

- Market surprises are **autocorrelated**
- Market surprises are **predictable**
  1. By past information
  2. By Central Bank's private forecasts
- Good instruments for monetary policy shocks only under FIRE
- With information frictions market surprises incorporate CB information ➔ **not exogenous!**

[Miranda-Agrippino and Ricco (2017)]

US Surprises and Past Information

Table II: Predictability of Monetary Surprises: Past Information

	$MP1_t$		$FF4_t$		$ED2_t$		$ED3_t$		$ED4_t$	
$f_{1,t-1}$	-0.014	[-1.51]	-0.011	[-1.67]*	-0.021	[-3.05]***	-0.023	[-3.25]***	-0.021	[-3.21]***
$f_{2,t-1}$	0.003	[0.63]	0.002	[0.74]	0.004	[1.07]	0.004	[1.18]	0.004	[1.07]
$f_{3,t-1}$	-0.01	[-1.50]	0.002	[0.37]	0.003	[0.63]	0.003	[0.58]	0.004	[0.72]
$f_{4,t-1}$	0.015	[1.43]	0.015	[2.05]**	0.015	[2.07]**	0.015	[2.02]**	0.013	[1.91]*
$f_{5,t-1}$	0.003	[0.34]	0.001	[0.21]	-0.001	[-0.14]	0.001	[0.15]	0.004	[0.57]
$f_{6,t-1}$	-0.013	[-2.02]**	-0.012	[-2.19]**	-0.011	[-1.89]*	-0.012	[-1.90]*	-0.013	[-2.18]**
$f_{7,t-1}$	-0.014	[-1.32]	-0.007	[-0.98]	-0.009	[-1.21]	-0.01	[-1.33]	-0.009	[-1.35]
$f_{8,t-1}$	-0.004	[-0.70]	-0.002	[-0.49]	-0.001	[-0.16]	-0.001	[-0.27]	0.000	[0.07]
$f_{9,t-1}$	0.002	[0.26]	-0.003	[-0.68]	-0.008	[-1.63]	-0.006	[-1.32]	-0.006	[-1.26]
$f_{10,t-1}$	0.000	[0.01]	0.005	[0.84]	0.003	[0.71]	0.003	[0.64]	0.004	[0.74]
$f^*_{1,t-1}$	0.022	[2.36]**	0.015	[2.30]**	0.020	[2.78]***	0.022	[3.17]***	0.021	[3.12]***
$f^*_{2,t-1}$	-0.011	[-1.73]*	-0.004	[-0.75]	-0.005	[-0.88]	-0.005	[-0.84]	-0.005	[-0.92]
$f^*_{3,t-1}$	0.006	[1.51]	0.006	[1.47]	0.011	[2.34]**	0.013	[2.62]***	0.014	[3.14]***
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$f_{10,t-1}$	0.000	[0.01]	0.005	[0.84]	0.003	[0.71]	0.003	[0.64]	0.004	[0.74]
$f^*_{1,t-1}$	0.022	[2.36]**	0.015	[2.30]**	0.020	[2.78]***	0.022	[3.17]***	0.021	[3.12]***
$f^*_{2,t-1}$	-0.011	[-1.73]*	-0.004	[-0.75]	-0.005	[-0.88]	-0.005	[-0.84]	-0.005	[-0.92]
$f^*_{3,t-1}$	0.006	[1.51]	0.006	[1.47]	0.011	[2.34]**	0.013	[2.62]***	0.014	[3.14]***
$f^*_{4,t-1}$	0.014	[1.73]*	0.006	[0.95]	0.004	[0.70]	0.004	[0.65]	0.003	[0.49]
$f^*_{5,t-1}$	-0.006	[-0.79]	-0.002	[-0.37]	-0.003	[-0.57]	-0.003	[-0.57]	-0.003	[-0.62]

US Surprises and CB Forecasts

Table I: Predictability of Monetary Surprises: Central Bank Forecasts

	$MP1_t$		$FF4_t$		$ED2_t$		$ED3_t$		$ED4_t$	
$\Delta y^{GB}_{t\|t}$	0.013	[1.48]	0.012	[2.02]**	0.012	[1.75]*	0.013	[1.86]*	0.013	[1.96]*
$\Delta y^{GB}_{t+1\|t}$	0.040	[2.90]***	0.028	[2.31]**	0.034	[2.75]***	0.030	[2.33]**	0.021	[1.81]*
$\Delta y^{GB}_{t+2\|t}$	-0.035	[-1.81]*	-0.023	[-1.84]*	-0.017	[-1.35]	-0.004	[-0.40]	0.007	[0.68]
$\Delta \pi^{GB}_{t\|t}$	-0.004	[-0.30]	0.004	[0.37]	0.009	[0.58]	0.01	[0.64]	0.010	[0.67]
$\Delta \pi^{GB}_{t+1\|t}$	-0.010	[-0.47]	-0.003	[-0.17]	-0.017	[-0.96]	-0.017	[-0.94]	-0.011	[-0.62]
$\Delta \pi^{GB}_{t+2\|t}$	0.044	[1.39]	0.036	[1.67]*	0.045	[2.09]**	0.047	[2.10]**	0.042	[1.85]*
$\Delta u^{GB}_{t\|t}$	0.109	[1.49]	0.094	[2.23]**	0.155	[2.37]**	0.141	[2.13]**	0.147	[2.10]**
$\Delta u^{GB}_{t+1\|t}$	-0.311	[-2.02]**	-0.305	[-2.83]***	-0.316	[-2.80]***	-0.270	[-2.52]**	-0.250	[-2.38]**
$\Delta u^{GB}_{t+2\|t}$	0.156	[1.30]	0.156	[1.76]*	0.119	[1.54]	0.084	[1.13]	0.068	[0.96]

US Surprises and CB Forecasts

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$\Delta y^{GB}_{t+1\|t}$	0.040	[2.90]***	0.028	[2.31]**	0.034	[2.75]***	0.030	[2.33]**	0.021	[1.81]*
$\Delta y^{GB}_{t+2\|t}$	0.035	[1.81]*	0.023	[1.84]*	0.017	[1.35]	0.004	[0.40]	0.007	[0.68]
$\Delta \pi^{GB}_{t\|t}$	-0.004	[-0.30]	0.004	[0.37]	0.009	[0.58]	0.01	[0.64]	0.010	[0.67]
$\Delta \pi^{GB}_{t+1\|t}$	-0.010	[-0.47]	-0.003	[-0.17]	-0.017	[-0.96]	-0.017	[-0.94]	-0.011	[-0.62]
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US Surprises and CB Forecasts

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$\Delta y^{GB}_{t+1\|t}$	0.040	[2.90]***	0.028	[2.31]**	0.034	[2.75]***	0.030	[2.33]**	0.021	[1.81]*
$\Delta y^{GB}_{t+2\|t}$	-0.035	[-1.81]*	-0.023	[-1.84]*	-0.017	[-1.35]	-0.004	[-0.40]	0.007	[0.68]
$\Delta \pi^{GB}_{t\|t}$	-0.004	[-0.30]	0.004	[0.37]	0.009	[0.58]	0.01	[0.64]	0.010	[0.67]
$\Delta \pi^{GB}_{t+1\|t}$	-0.010	[-0.47]	-0.003	[-0.17]	-0.017	[-0.96]	-0.017	[-0.94]	-0.011	[-0.62]
$\Delta \pi^{GB}_{t+2\|t}$	0.044	[1.39]	0.036	[1.67]*	0.045	[2.09]**	0.047	[2.10]**	0.042	[1.85]*
$\Delta u^{GB}_{t\|t}$	0.109	[1.49]	0.094	[2.23]**	0.155	[2.37]**	0.141	[2.13]**	0.147	[2.10]**
$\Delta u^{GB}_{t+1\|t}$	-0.311	[-2.02]**	-0.305	[-2.83]***	-0.316	[-2.80]***	-0.270	[-2.52]**	-0.250	[-2.38]**
$\Delta u^{GB}_{t+2\|t}$	0.156	[1.30]	0.156	[1.76]*	0.119	[1.54]	0.084	[1.13]	0.068	[0.96]

Surprises Correction

$$mps_t = \mu + \alpha i_{t-1} + \underbrace{\sum_{j=-1}^{3} \gamma_j \, \widehat{x}^{CB}_{q+j|t}}_{\text{level forecasts}} + \underbrace{\sum_{j=-1}^{2} \delta_j \left[\widehat{x}^{CB}_{q+j|t} - \widehat{x}^{CB}_{q+j|t-1} \right]}_{\text{forecast revisions}} + mps^{\star}_t$$

- CB forecasts for output, inflation and unemployment
- Lagged level policy rate i_t

Orthogonal Surprises – US

Table V: Orthogonal Surprises and Past Information

	$MP1_t^\star$		$FF4_t^\star$		$ED2_t^\star$		$ED3_t^\star$		$ED4_t^\star$	
$f_{1,t-1}$	0.005	[0.65]	0.003	[0.44]	0.004	[0.65]	0.002	[0.36]	0.001	[0.22]
$f_{2,t-1}$	0.003	[0.56]	0.002	[0.66]	0.004	[1.29]	0.005	[1.25]	0.004	[1.18]
$f_{3,t-1}$	0.004	[0.74]	0.008	[1.64]	0.009	[1.88]*	0.009	[1.70]*	0.007	[1.45]
$f_{4,t-1}$	0.010	[1.09]	0.011	[1.66]*	0.008	[1.21]	0.008	[1.24]	0.007	[1.05]
$f_{5,t-1}$	0.001	[0.12]	-0.002	[-0.31]	0.000	[-0.04]	0.001	[0.19]	0.003	[0.38]
$f_{6,t-1}$	-0.008	[-1.39]	-0.007	[-1.35]	-0.005	[-0.86]	-0.005	[-0.89]	-0.006	[-1.12]
$f_{7,t-1}$	-0.009	[-0.94]	-0.007	[-1.09]	-0.007	[-1.06]	-0.009	[-1.37]	-0.01	[-1.45]
$f_{8,t-1}$	-0.005	[-0.91]	-0.001	[-0.37]	0.002	[0.45]	0.002	[0.49]	0.004	[0.91]
$f_{9,t-1}$	0.000	[-0.02]	-0.004	[-0.93]	-0.007	[-1.51]	-0.005	[-1.12]	-0.004	[-0.89]
$f_{10,t-1}$	-0.006	[-1.02]	-0.001	[-0.12]	0.000	[-0.07]	-0.001	[-0.16]	0.001	[0.16]
$f_{1,t-1}^*$	-0.001	[-0.14]	-0.001	[-0.12]	-0.004	[-0.68]	-0.002	[-0.36]	-0.001	[-0.11]
$f_{2,t-1}^*$	0.000	[-0.06]	0.001	[0.15]	-0.001	[-0.13]	-0.001	[-0.18]	-0.002	[-0.31]
$f_{3,t-1}^*$	0.001	[0.39]	0.002	[0.76]	0.005	[1.40]	0.006	[1.58]	0.007	[1.92]*
$f_{4,t-1}^*$	0.009	[1.23]	0.004	[0.83]	0.002	[0.30]	0.002	[0.44]	0.003	[0.50]
$f_{5,t-1}^*$	0.001	[0.24]	0.005	[1.11]	0.005	[1.01]	0.006	[1.28]	0.006	[1.18]
$F-stat$	0.74	(0.592)	0.92	(0.470)	0.92	(0.471)	1.29	(0.267)	1.47	(0.201)

Orthogonal Surprises – US

Table V: Orthogonal Surprises and Past Information

	$MP1_t^\star$		$FF4_t^\star$		$ED2_t^\star$		$ED3_t^\star$		$ED4_t^\star$	
$f_{1,t-1}$	0.005	[0.65]	0.003	[0.44]	0.004	[0.65]	0.002	[0.36]	0.001	[0.22]
$f_{2,t-1}$	0.003	[0.56]	0.002	[0.66]	0.004	[1.29]	0.005	[1.25]	0.004	[1.18]
$f_{3,t-1}$	0.004	[0.74]	0.008	[1.64]	0.009	[1.88]*	0.009	[1.70]*	0.007	[1.45]
$f_{4,t-1}$	0.010	[1.09]	0.011	[1.66]*	0.008	[1.21]	0.008	[1.24]	0.007	[1.05]
$f_{5,t-1}$	0.001	[0.12]	-0.002	[-0.31]	0.000	[-0.04]	0.001	[0.19]	0.003	[0.38]
$f_{6,t-1}$	-0.008	[-1.39]	-0.007	[-1.35]	-0.005	[-0.86]	-0.005	[-0.89]	-0.006	[-1.12]
$f_{7,t-1}$	-0.009	[-0.94]	-0.007	[-1.09]	-0.007	[-1.06]	-0.009	[-1.37]	-0.01	[-1.45]
$f_{8,t-1}$	-0.005	[-0.91]	-0.001	[-0.37]	0.002	[0.45]	0.002	[0.49]	0.004	[0.91]
$f_{9,t-1}$	0.000	[-0.02]	-0.004	[-0.93]	-0.007	[-1.51]	-0.005	[-1.12]	-0.004	[-0.89]
$f_{10,t-1}$	-0.006	[-1.02]	-0.001	[-0.12]	0.000	[-0.07]	-0.001	[-0.16]	0.001	[0.16]
$f^*_{1,t-1}$	-0.001	[-0.14]	-0.001	[-0.12]	-0.004	[-0.68]	-0.002	[-0.36]	-0.001	[-0.11]
$f^*_{2,t-1}$	0.000	[-0.06]	0.001	[0.15]	-0.001	[-0.13]	-0.001	[-0.18]	-0.002	[-0.31]
$f^*_{3,t-1}$	0.001	[0.39]	0.002	[0.76]	0.005	[1.40]	0.006	[1.58]	0.007	[1.92]*
$f^*_{4,t-1}$	0.009	[1.23]	0.004	[0.83]	0.002	[0.30]	0.002	[0.44]	0.003	[0.50]
$f^*_{5,t-1}$	0.001	[0.24]	0.005	[1.11]	0.005	[1.01]	0.006	[1.28]	0.006	[1.18]
$F-stat$	0.74	(0.592)	0.92	(0.470)	0.92	(0.471)	1.29	(0.267)	1.47	(0.201)

Orthogonal Surprises – US

Table V: Orthogonal Surprises and Past Information

	$MP1_t^\star$		$FF4_t^\star$		$ED2_t^\star$		$ED3_t^\star$		$ED4_t^\star$	
$f_{1,t-1}$	0.005	[0.65]	0.003	[0.44]	0.004	[0.65]	0.002	[0.36]	0.001	[0.22]
$f_{2,t-1}$	0.003	[0.56]	0.002	[0.66]	0.004	[1.29]	0.005	[1.25]	0.004	[1.18]
$f_{3,t-1}$	0.004	[0.74]	0.008	[1.64]	0.009	[1.88]*	0.009	[1.70]*	0.007	[1.45]
$f_{4,t-1}$	0.010	[1.09]	0.011	[1.66]*	0.008	[1.21]	0.008	[1.24]	0.007	[1.05]
$f_{5,t-1}$	0.001	[0.12]	-0.002	[-0.31]	0.000	[-0.04]	0.001	[0.19]	0.003	[0.38]
$f_{6,t-1}$	-0.008	[-1.39]	-0.007	[-1.35]	-0.005	[-0.86]	-0.005	[-0.89]	-0.006	[-1.12]
$f_{7,t-1}$	-0.009	[-0.94]	-0.007	[-1.09]	-0.007	[-1.06]	-0.009	[-1.37]	-0.01	[-1.45]
$f_{8,t-1}$	-0.005	[-0.91]	-0.001	[-0.37]	0.002	[0.45]	0.002	[0.49]	0.004	[0.91]
$f_{9,t-1}$	0.000	[-0.02]	-0.004	[-0.93]	-0.007	[-1.51]	-0.005	[-1.12]	-0.004	[-0.89]
$f_{10,t-1}$	-0.006	[-1.02]	-0.001	[-0.12]	0.000	[-0.07]	-0.001	[-0.16]	0.001	[0.16]
$f^*_{1,t-1}$	-0.001	[-0.14]	-0.001	[-0.12]	-0.004	[-0.68]	-0.002	[-0.36]	-0.001	[-0.11]
$f^*_{2,t-1}$	0.000	[-0.06]	0.001	[0.15]	-0.001	[-0.13]	-0.001	[-0.18]	-0.002	[-0.31]
$f^*_{3,t-1}$	0.001	[0.39]	0.002	[0.76]	0.005	[1.40]	0.006	[1.58]	0.007	[1.92]*
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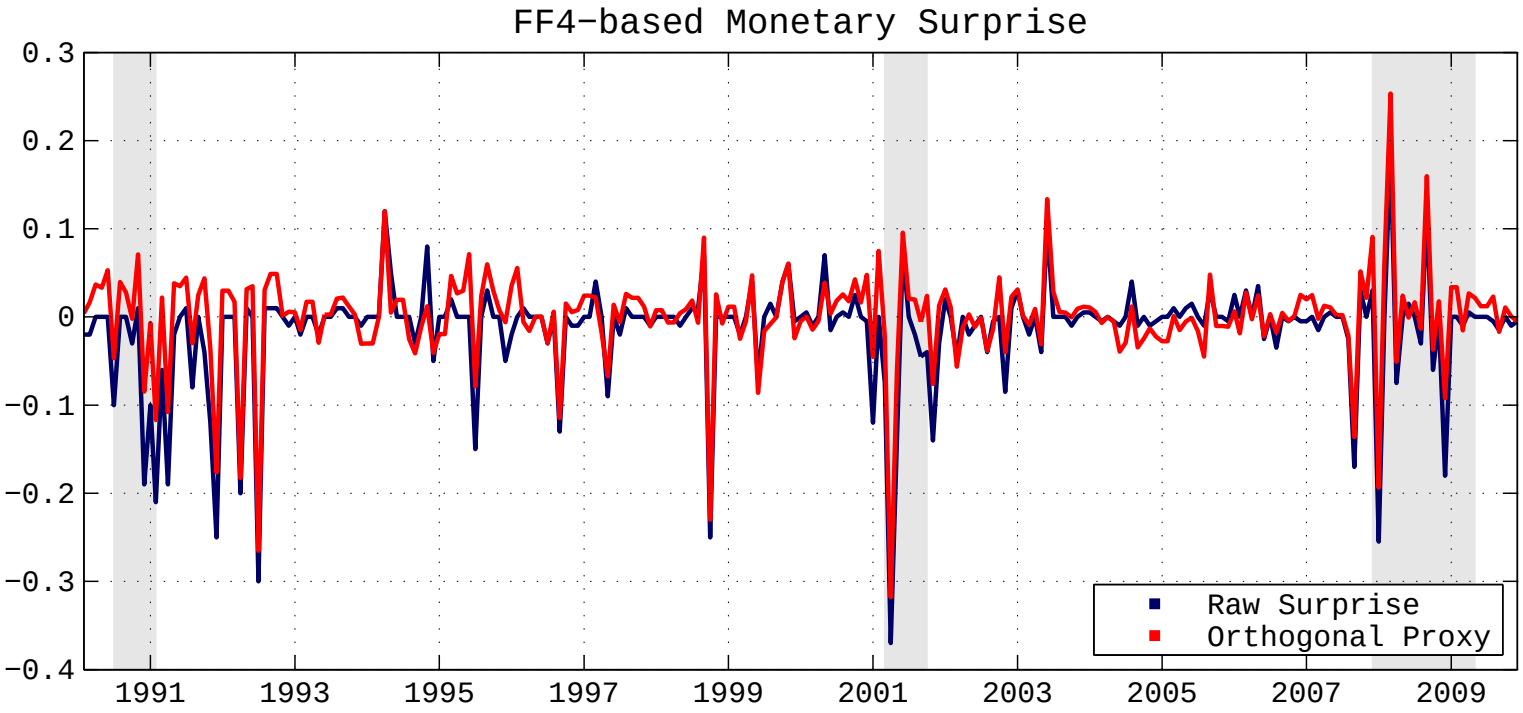
$f^*_{5,t-1}$	0.001	[0.24]	0.005	[1.11]	0.005	[1.01]	0.006	[1.28]	0.006	[1.18]
$F-stat$	0.74	(0.592)	0.92	(0.470)	0.92	(0.471)	1.29	(0.267)	1.47	(0.201)

Orthogonal Surprises – US



VAR setup – US

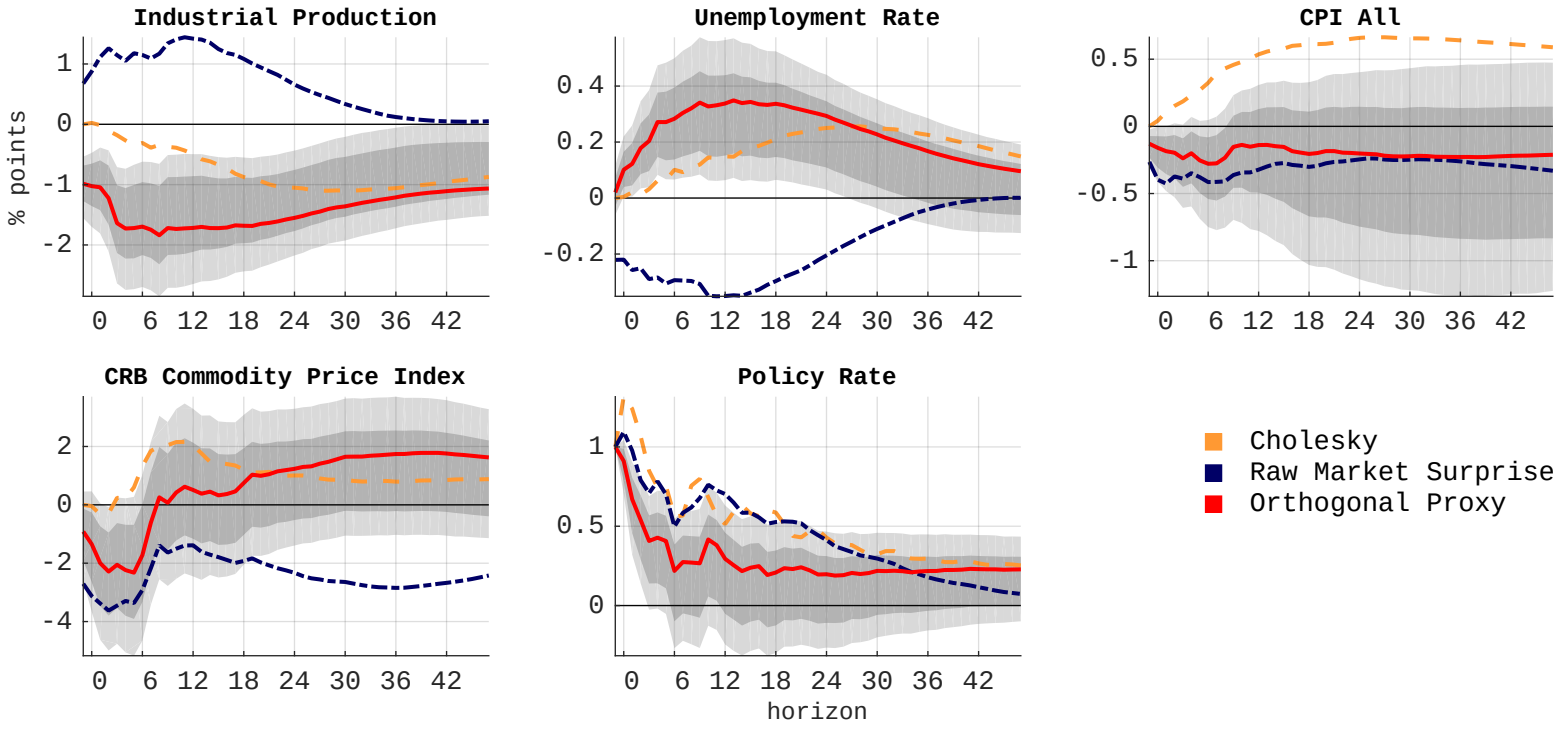
Estimation

- Monetary policy variable: 1-Year rate
- VAR(12) in (log) levels
- Estimation sample 1969:1 - 2014:12

Identification

- External instrument: orthogonal FF4* – 1990:1 - 2009:12
- Recursive Cholesky scheme with the effective FFR ordered last
- External instrument: Gertler and Karadi (2015)'s FF4

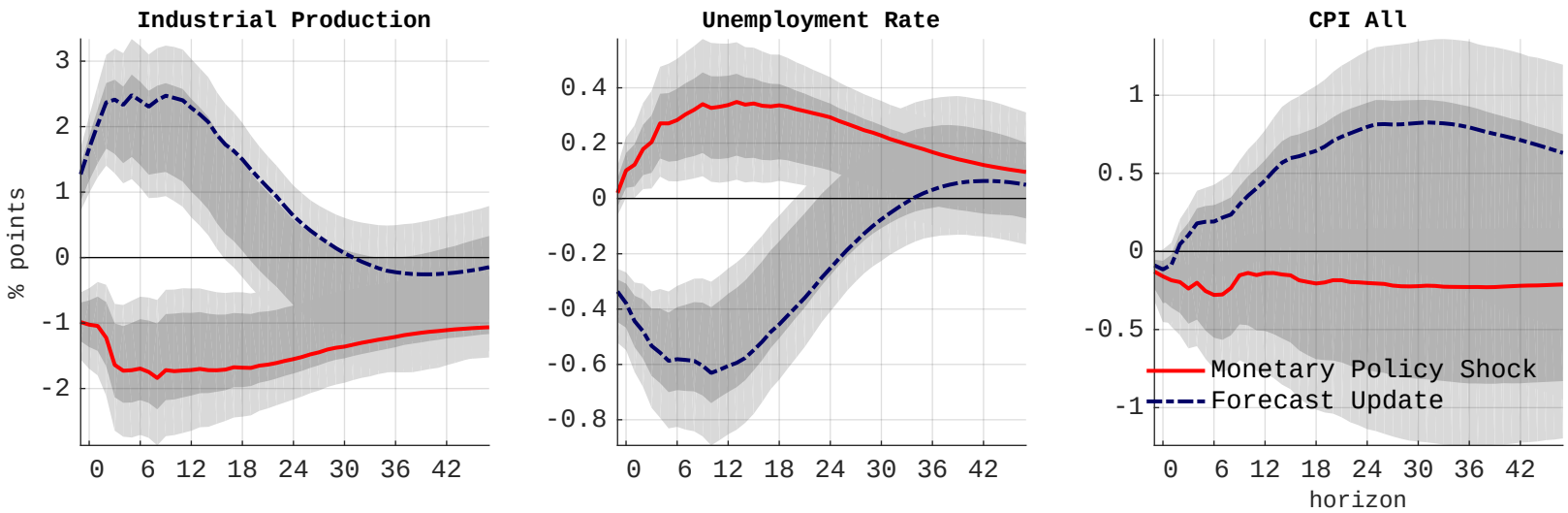
Responses to a Monetary Policy Shock – US



- Recursive ➔ price puzzle
- Market Surprises ➔ real activity puzzles ➔ **induced by CB info**

Information vs MP Shocks

- **MP Shock Instrument:** residuals of projection of market surprises on CB info – $mps_t^{\star}$
- **CB Information Instrument:** fitted part of mps_t



2-Instrument & 2-Shocks
Interaction of Monetary and Fiscal Policy

Miranda-Agrippino and Tamoni (2017)

With one shock and one instruments B_0 is identified up to a normalization

If more shocks are to be identified, more assumptions are needed

$$\text{Let } e_t = \begin{pmatrix} e_t^p \\ e_t^o \end{pmatrix} = \begin{pmatrix} e_t^f \\ e_t^m \\ e_t^o \end{pmatrix}$$

Shocks of interest

1. e_t^f ➔ **Fiscal Policy**
2. e_t^m ➔ **Monetary Policy**

[Mertens and Ravn (2013), Mertens and Montiel-Olea (2017)]

INSTRUMENTS' VALIDITY

1. $\mathbb{E}[\ z_t e_t^{p\prime}\ ] = A$ ➔ **relevance**
2. $\mathbb{E}[\ z_t \epsilon_t^{o\prime}\ ] = 0$ ➔ **exogeneity**

A is a nonsingular (2×2) matrix ➔ instruments can be correlated

Consider the parameterization of $B_0^{-1} u_t = e_t$

$$C \begin{pmatrix} u_t^g \\ u_t^i \end{pmatrix} = D u_t^o + \begin{pmatrix} e_t^f \\ e_t^m \end{pmatrix}$$

Validity identifies CC' and $C^{-1}D$ but not C and D separately

[Mertens and Ravn (2013), Mertens and Montiel-Olea (2017)]

Recursive Restrictions

1. $C_{2,1} = 0$ ➔ m ordered first

$$\begin{aligned} u_t^g &= \widetilde{d}_1 u_t^o + \widetilde{c}_{11} e_t^f + \widetilde{c}_{12} e_t^m \\ u_t^i &= \widetilde{d}_2 u_t^o \qquad\qquad + \widetilde{c}_{22} e_t^m \end{aligned}$$

   - ▷ Identifies a fiscal shock which has no direct impact on policy rates
   - ▷ Also identifies a monetary shock which can affect all variables

2. $C_{1,2} = 0$ ➔ f ordered first

$$\begin{aligned} u_t^g &= \widetilde{d}_1 u_t^o + \widetilde{c}_{11} e_t^f \\ u_t^i &= \widetilde{d}_2 u_t^o + \widetilde{c}_{21} e_t^f + \widetilde{c}_{22} e_t^m \end{aligned}$$

   - ▷ Identifies a monetary shock which has no direct impact on spending
   - ▷ Also identifies a fiscal shock which can affect all variables

External Instruments for Identification: FP

- Revisions of expectations about future Federal Spending
  1. Survey of Professional Forecasts (SPF) – Current Quarter
     [Ramey (2011), Perotti (2011)]
  2. Congressional Budget Office (CBO) – 5-Year Fiscal Plan
     [Auerbach (2003)]

External Instruments for Identification: MP

- Revisions of expectations about future Monetary Policy
  1. Target Factor – Current Policy Rate
  2. Path Factor – Communication/Guidance
     [Gürkaynak, Sack & Swanson (2005)]
- Control for CB information (also on fiscal stance)
  [Miranda-Agrippino (2016), Miranda-Agrippino & Ricco (2017)]

Empirical Model

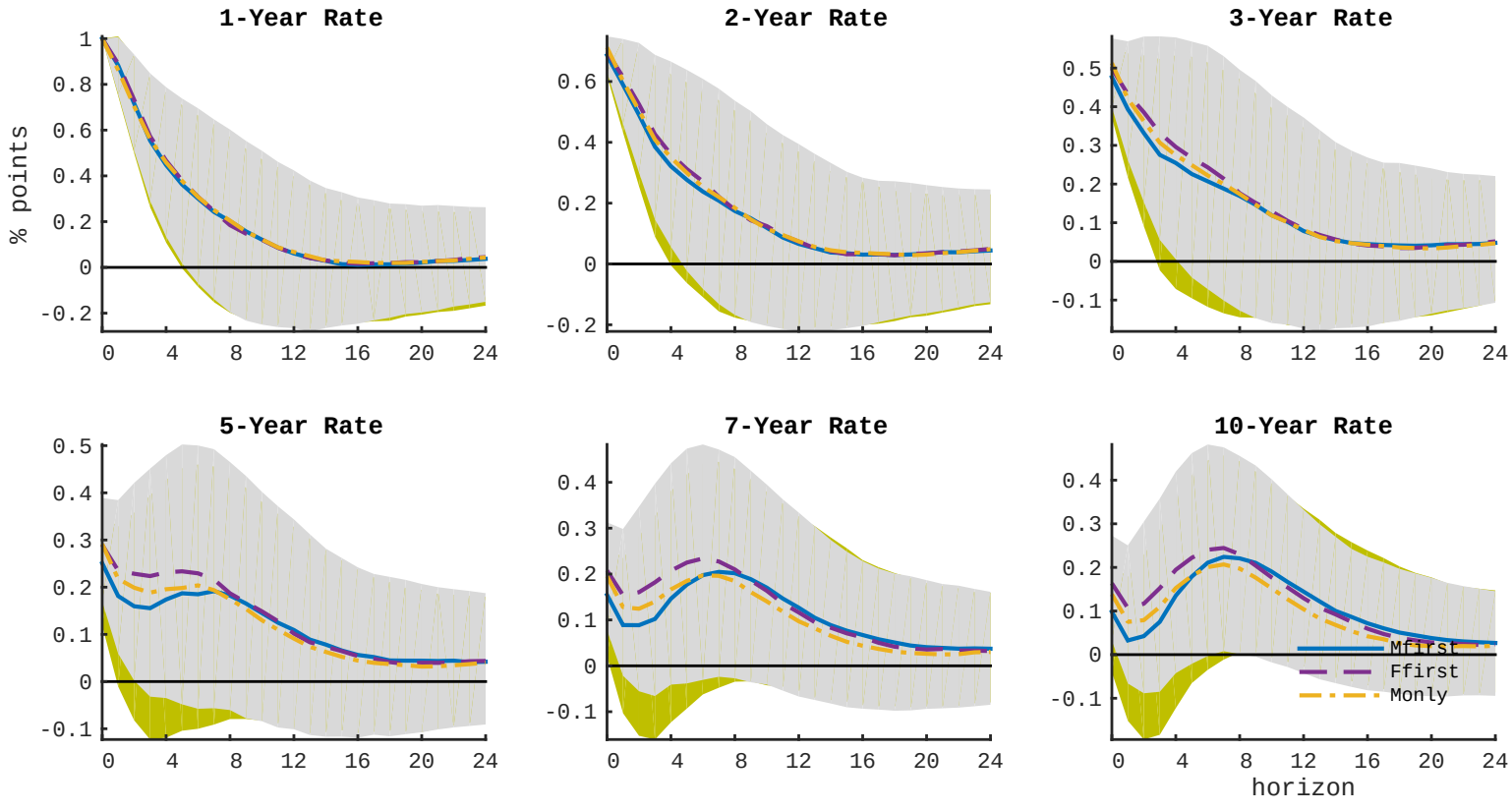
STRUCTURAL STATE SPACE

$$y_t = [\mathbf{0} \quad \Lambda] X_t + \eta_t$$

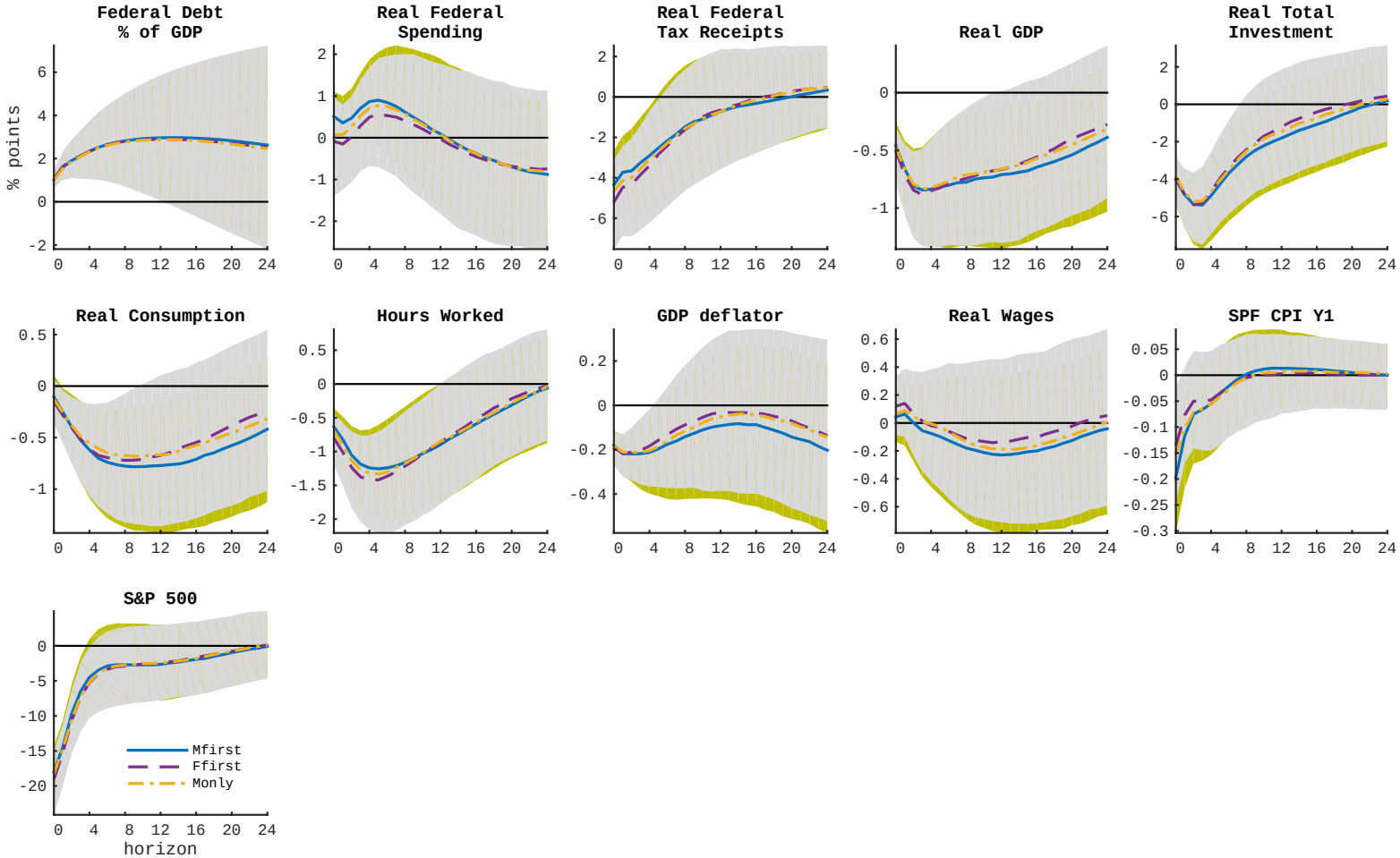
$$A_0 X_t = A_1 X_{t-1} + \ldots + A_p X_{t-p} + e_t$$

- $\underset{[m\times 1]}{y_t} = \left[y_t^{(1)}, y_t^{(2)}, y_t^{(3)}, y_t^{(5)}, y_t^{(7)}, y_t^{(10)}\right]^{\intercal}$
- $\underset{[n\times 1]}{X_t} \equiv [x_t^{\intercal}, PC_t^{\intercal}]^{\intercal}$
- $\underset{[3\times 1]}{PC_t} \equiv \left[y_t^{(1)}, PC_{2,t}, PC_{3,t}\right]^{\intercal}$

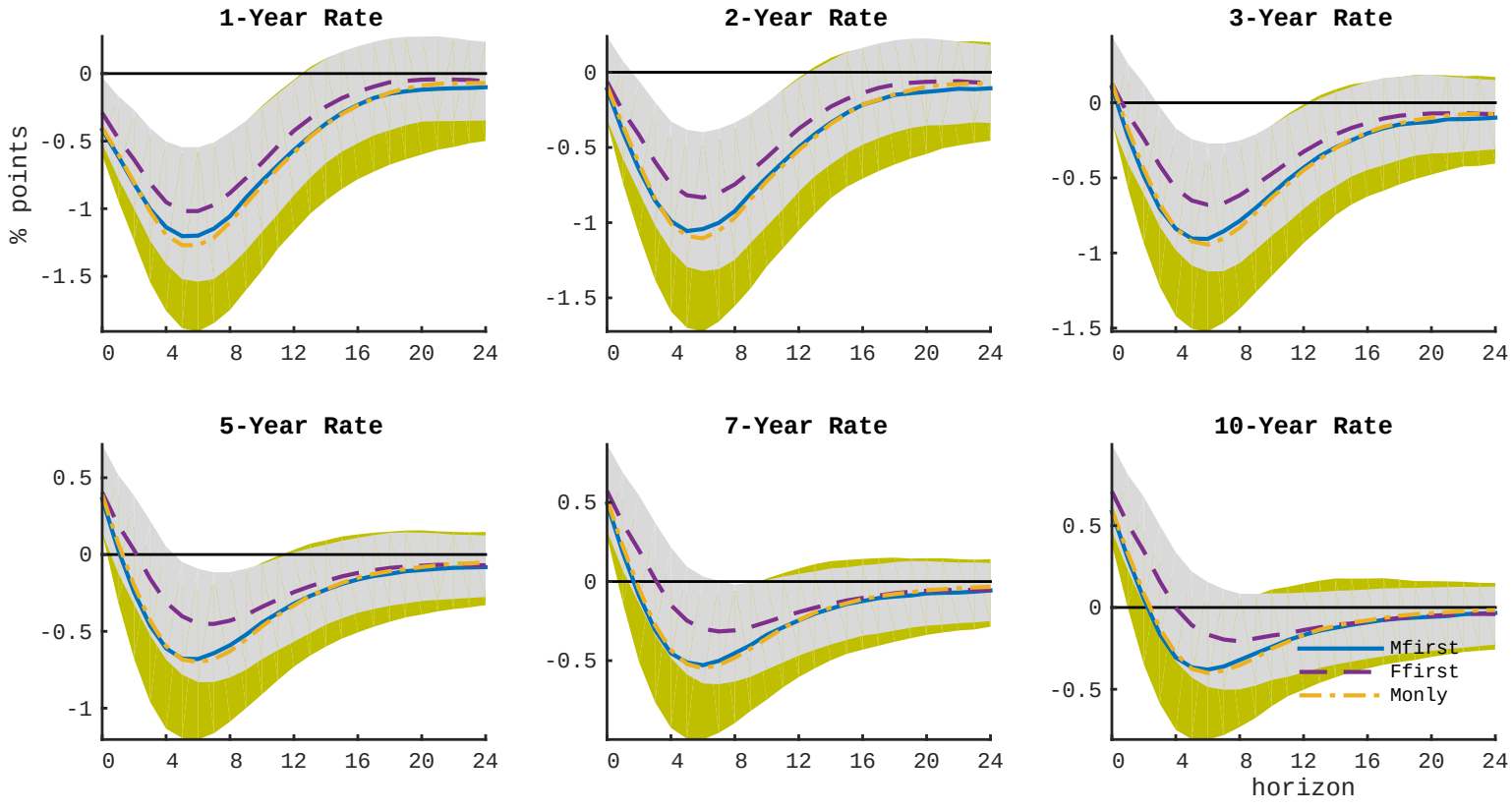
Contractionary MP Shock: Yields



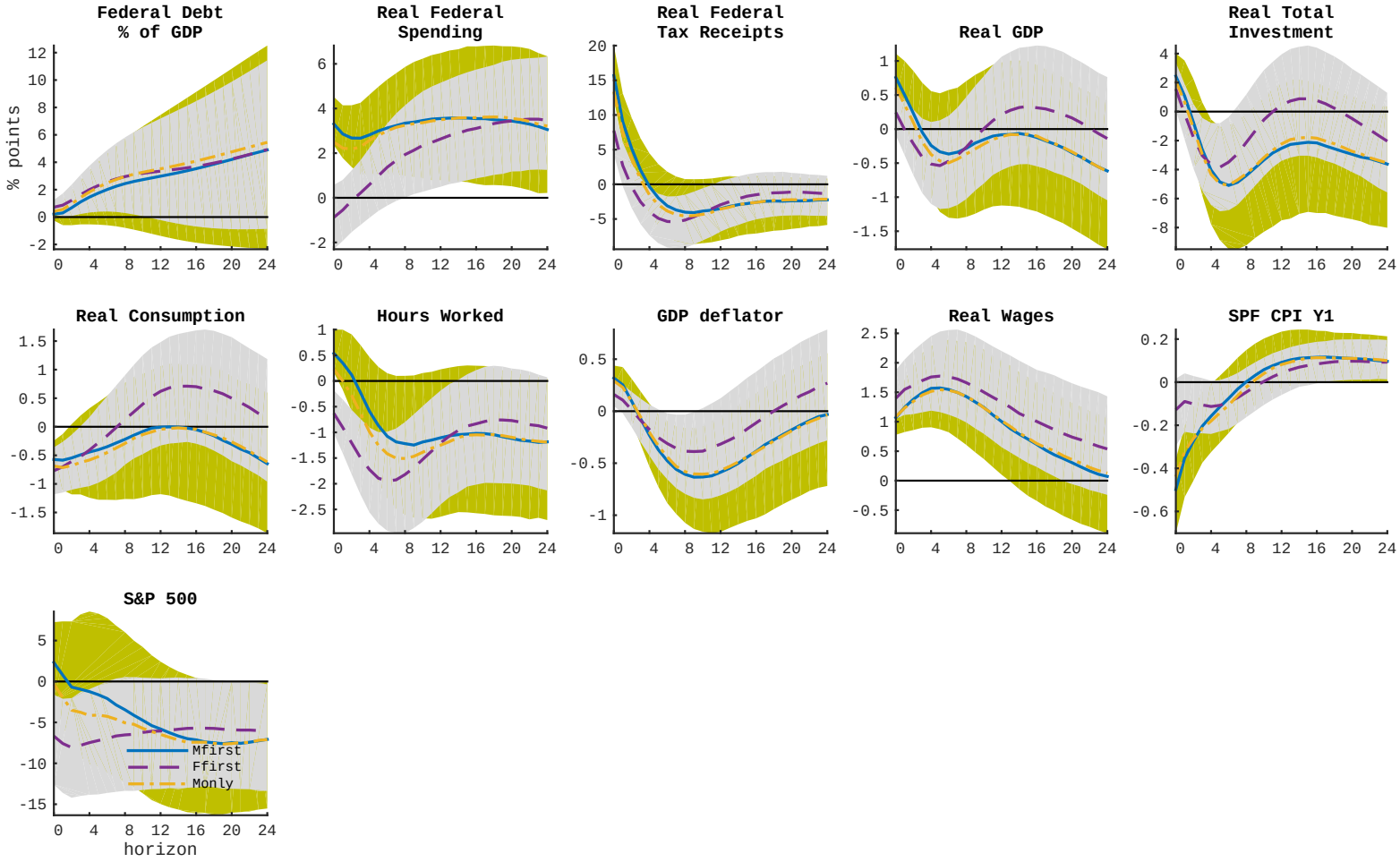
Contractionary MP Shock: Macro



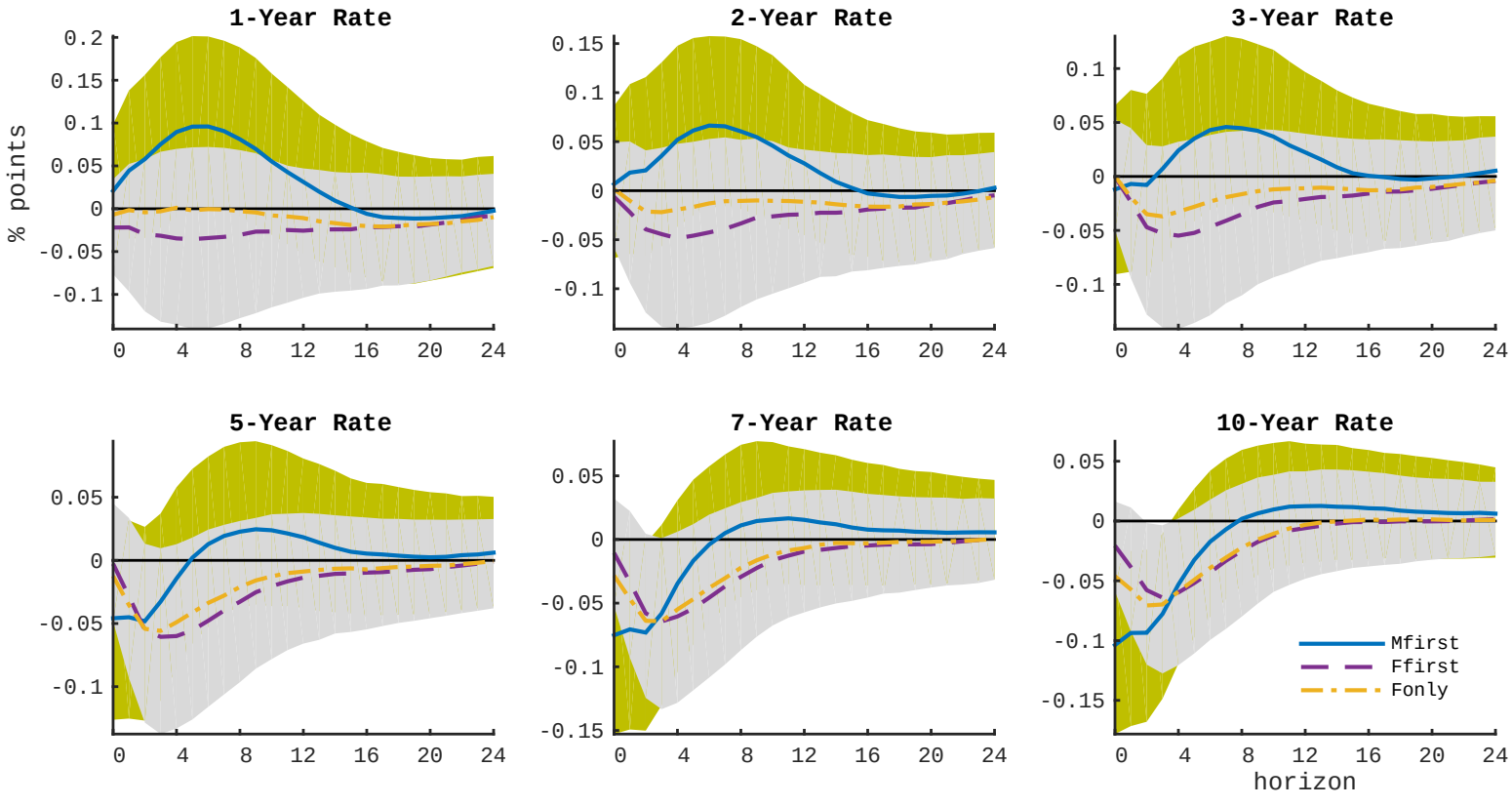
Higher Future Rates: Yields



Higher Future Rates: Macro



One-Period Fiscal Expansion: Yields



One-Period Fiscal Expansion: Macro