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Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound

Jing Cynthia Wu
Chicago Booth and NBER

Fan Dora Xia
Merrill Lynch

Paper presented at the 16th Jacques Polak Annual Research Conference
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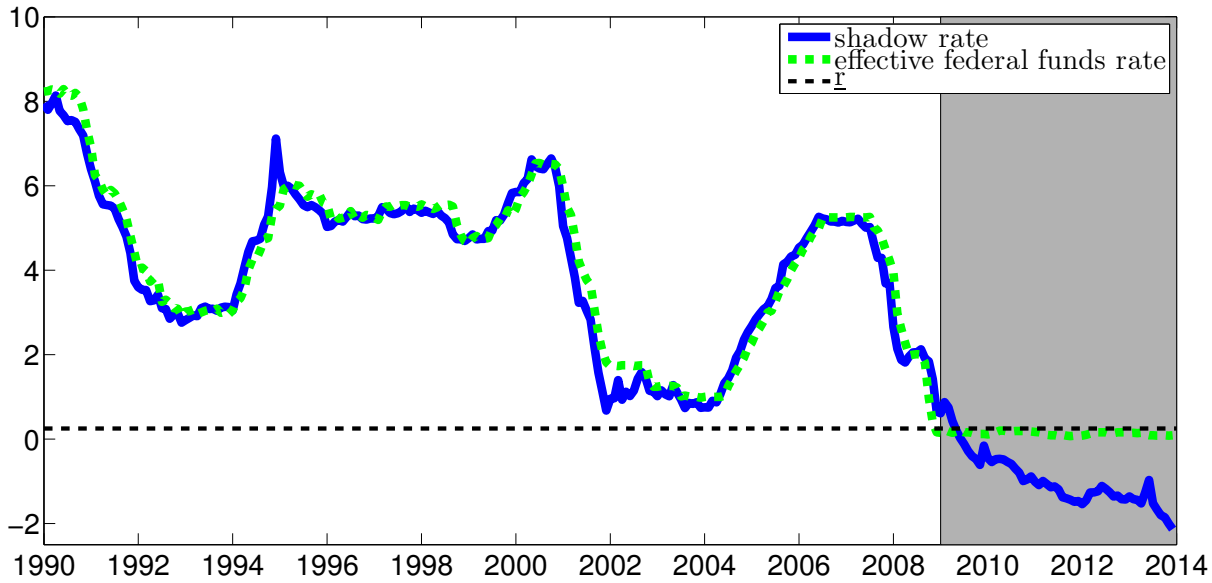
Key question

What is the macroeconomic impact of monetary policy at the ZLB?

Conventional approach before ZLB

- VAR with the fed funds rate

But since December 2008, the fed funds rate has been near zero



Challenges of zero lower bound

Challenges

- What framework to study unconventional monetary policy?
  - The fed funds rate has been replaced by large-scale asset purchases and forward guidance as primary policy tools.
- How to describe the yield curve?
  - Gaussian ATSM allows negative interest rates.

Shadow rate term structure model: Black (1995)

- Non-negative short rate: $r_t = max(\underline{r}, s_t)$
- Analytical solution does not exist in general

Contributions

This paper

- an analytical approximation for SRTSM

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- shadow rate has similar dynamic correlations with macro variables as the fed funds rate did previously

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- an analytical approximation for SRTSM
- shadow rate has similar dynamic correlations with macro variables as the fed funds rate did previously
- our shadow rate updated monthly by Atlanta Fed
  www.frbatlanta.org/cqer/researchcq/shadow_rate.cfm

Outline

Bond pricing

Risk-neutral factor dynamics:

$$X_{t+1} = \mu^{\mathbb{Q}} + \rho^{\mathbb{Q}} X_t + \Sigma \varepsilon_{t+1}^{\mathbb{Q}}, \quad \varepsilon_{t+1}^{\mathbb{Q}} \overset{\mathbb{Q}}{\sim} N(0, I).$$

▸ Pricing kernel

Pricing equation

$$P_t^n = \mathbb{E}_t^{\mathbb{Q}}[\exp(-r_t - r_{t+1} - \ldots - r_{t+n-1})]$$

Yield

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

Forward rate

$$f_{n,n+1,t} = (n+1)y_{n+1,t} - ny_{nt}$$

SRTSM and GATSM

SRTSM

$$\begin{aligned} r_t &= max(\underline{r}, s_t) \\ s_t &= \delta_0 + \delta_1' X_t \end{aligned}$$

Forward rate

$$f_{n,n+1,t}^{SRTSM} = \underline{r} + \sigma_n^{\mathbb{Q}} g\left(\frac{a_n + b_n' X_t - \underline{r}}{\sigma_n^{\mathbb{Q}}}\right)$$

where $g(z) = z\Phi(z) + \phi(z)$

▸ a_n, b_n

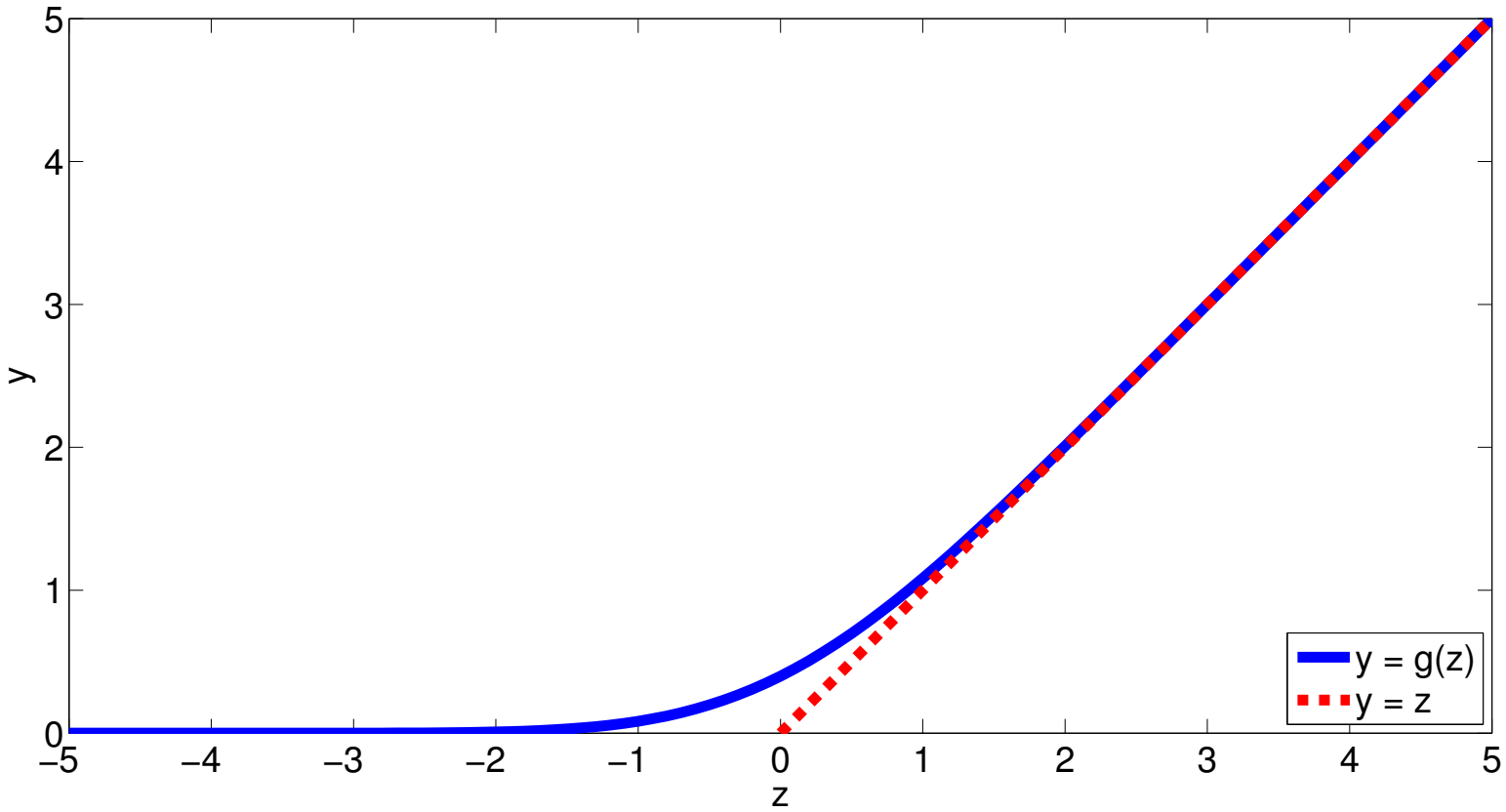
GATSM

$$r_t = \delta_0 + \delta_1' X_t$$

Forward rate

$$f_{n,n+1,t}^{GATSM} = a_n + b_n' X_t.$$

Property of $g(.)$



$$f^{SRTSM}_{n,n+1,t} \begin{cases} \approx \underline{r}, \text{ at the ZLB} \\ \approx a_n + b_n' X_t = f^{GATSM}_{n,n+1,t}, \text{ when interest rates are high} \end{cases}$$

Model fit

- GSW Data: monthly 1990-2013; maturities: 3m, 6m, 1y, 2y, 5y, 7y, 10y
- Estimation: Kalman filters ▸ details
- Average absolute approximation error between 1990M1 and 2013M1 ▸ more

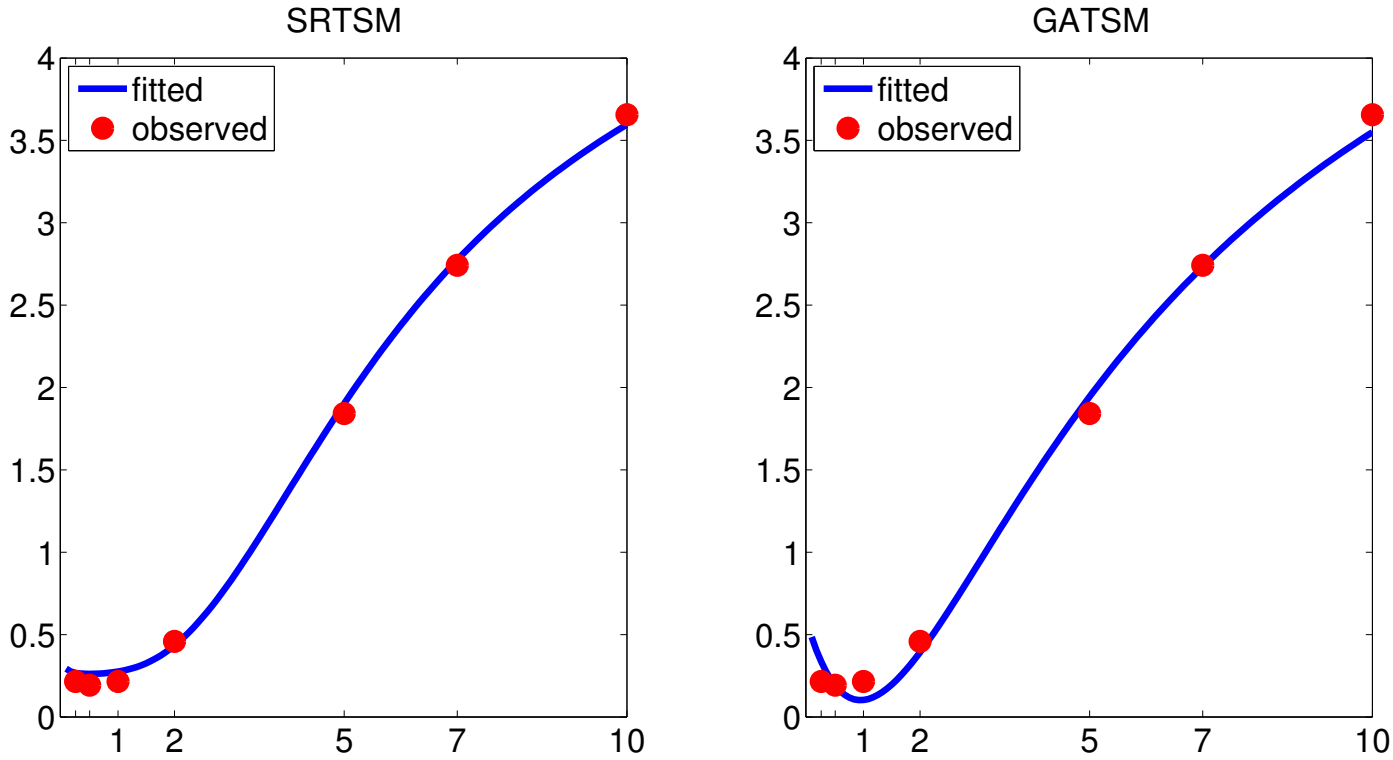
	3M	6M	1Y	2Y	5Y	7Y	10Y
forward rate error	0.01	0.02	0.04	0.13	0.69	1.14	2.29
forward rate level	346	357	384	435	551	600	636
yield error	0.00	0.01	0.01	0.04	0.24	0.42	0.78

Model fit

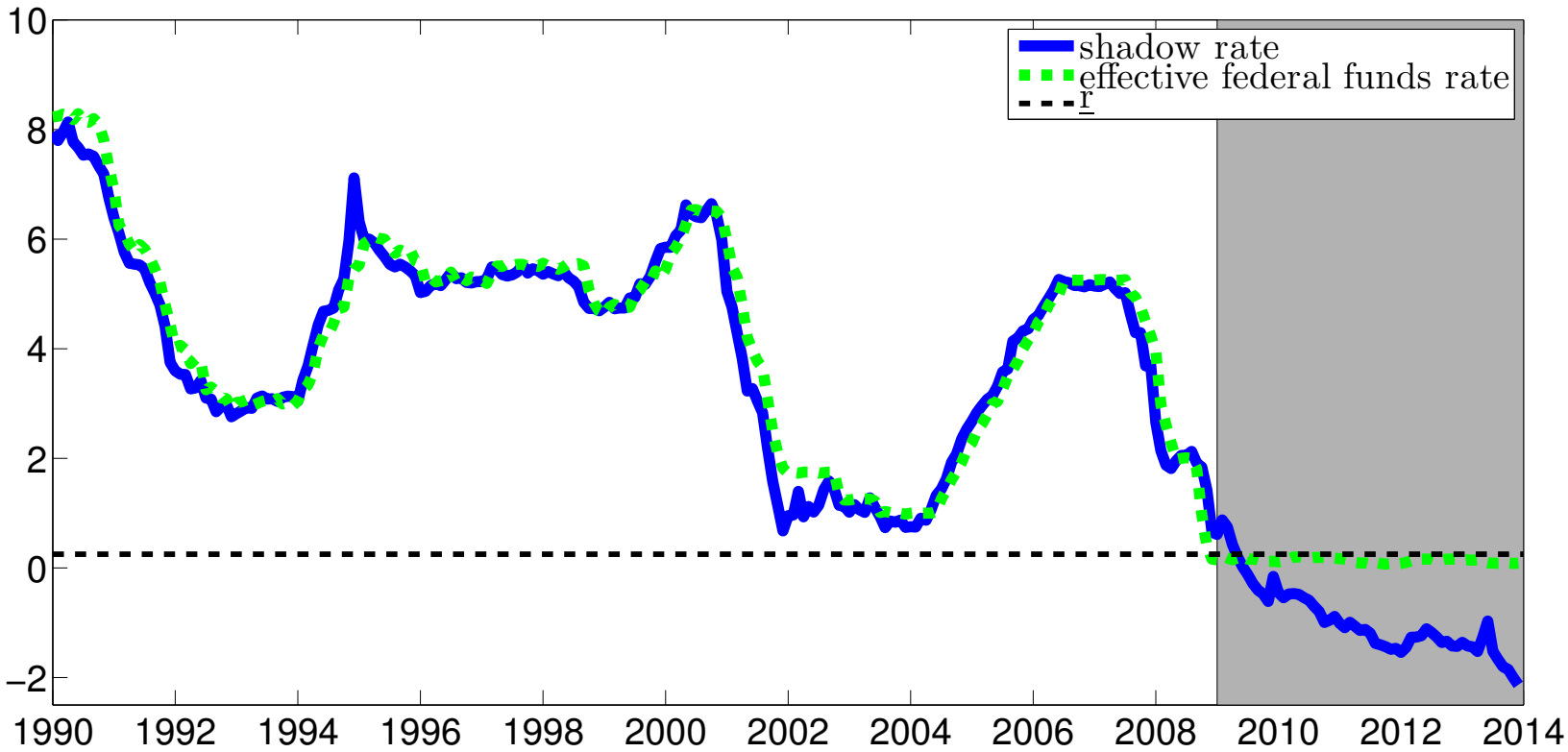
Log likelihood values ▸ specification

- SRTSM: 856; GATSM: 755

Figure: Average forward curve in 2012

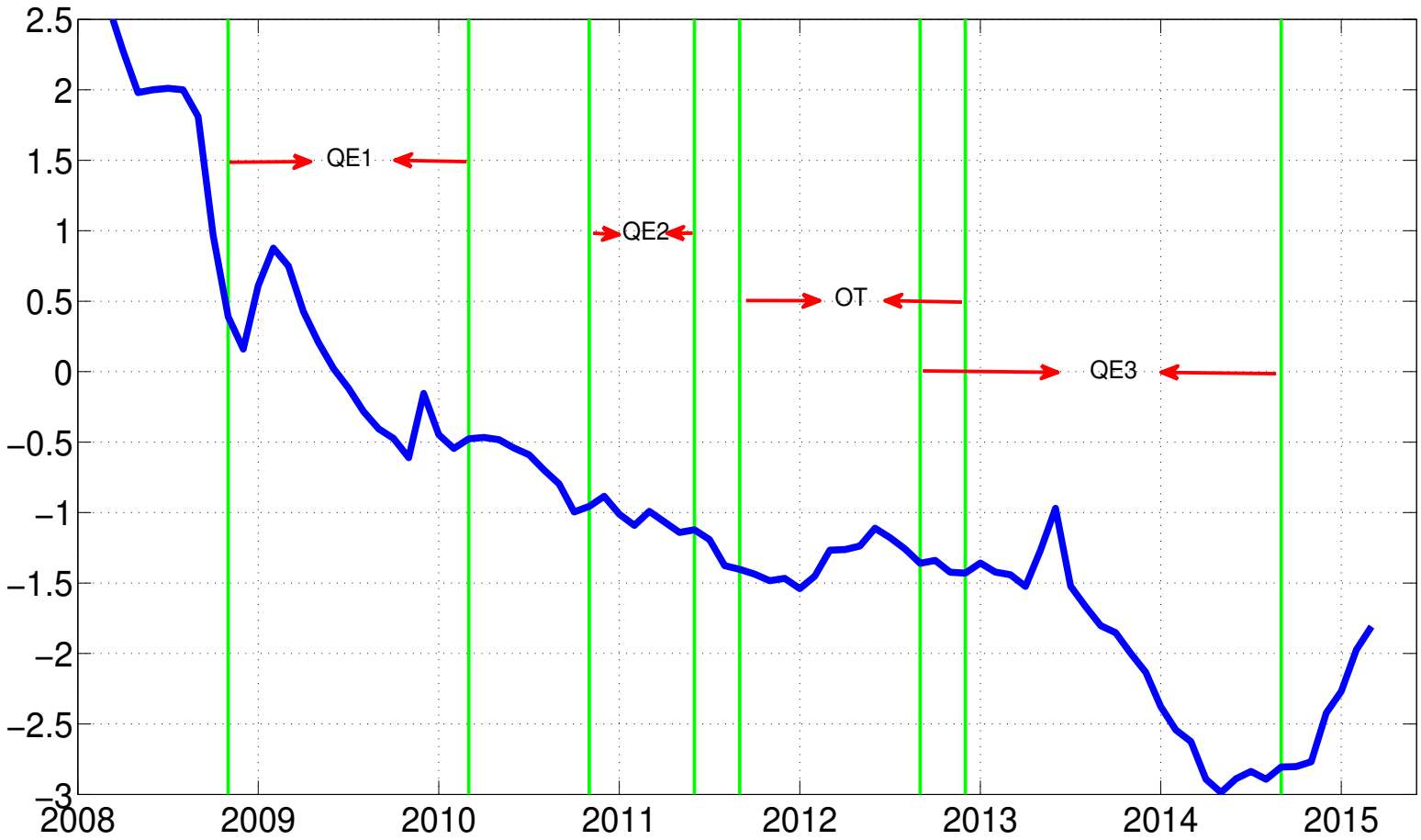


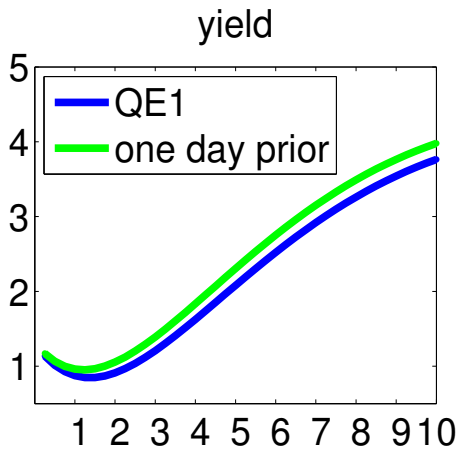
Shadow rate

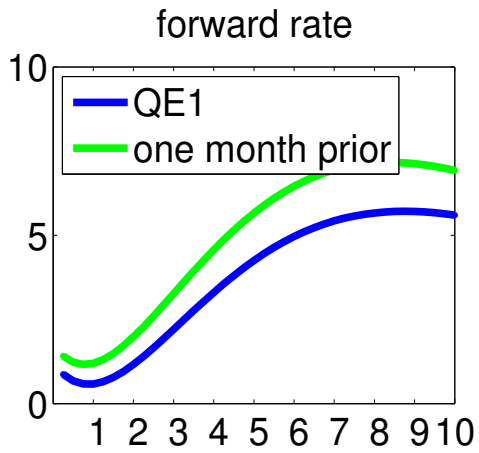


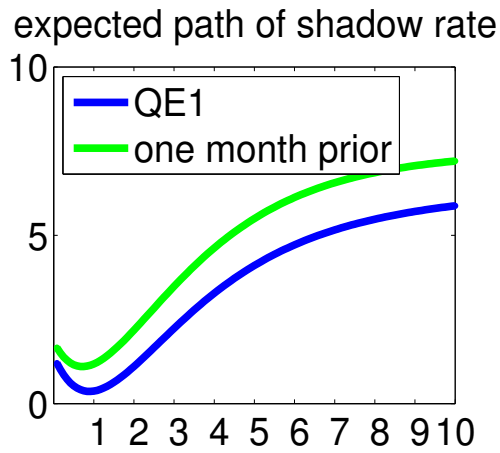
Summary for unconventional monetary policy?

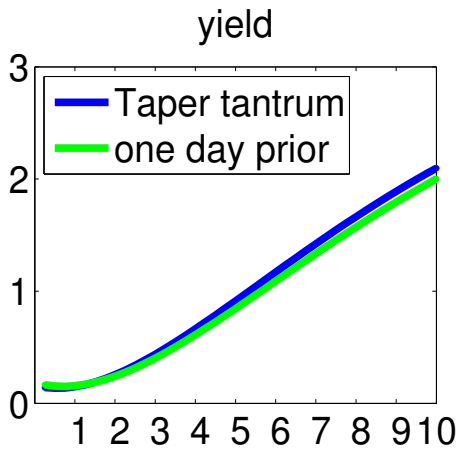
Shadow rate and LSAPs

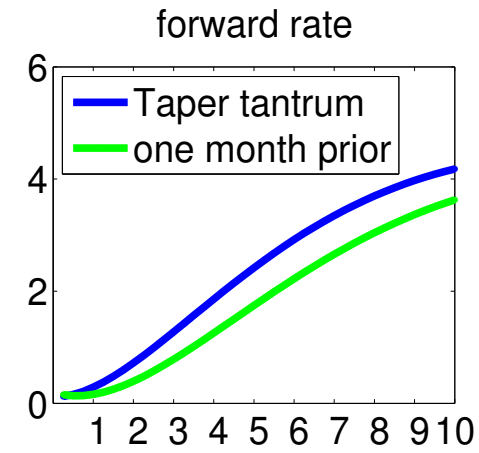


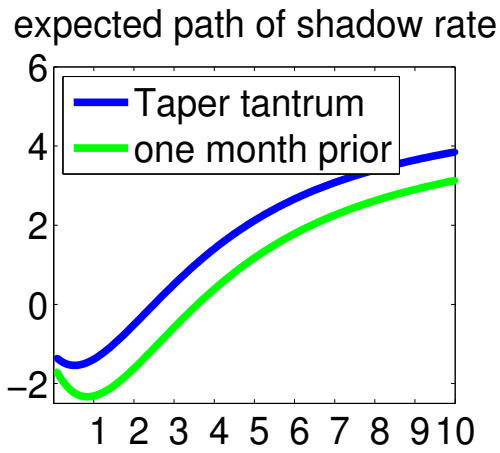

yield
QE1
one day prior
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10


forward rate
QE1
one month prior
10
5
0
1 2 3 4 5 6 7 8 9 10

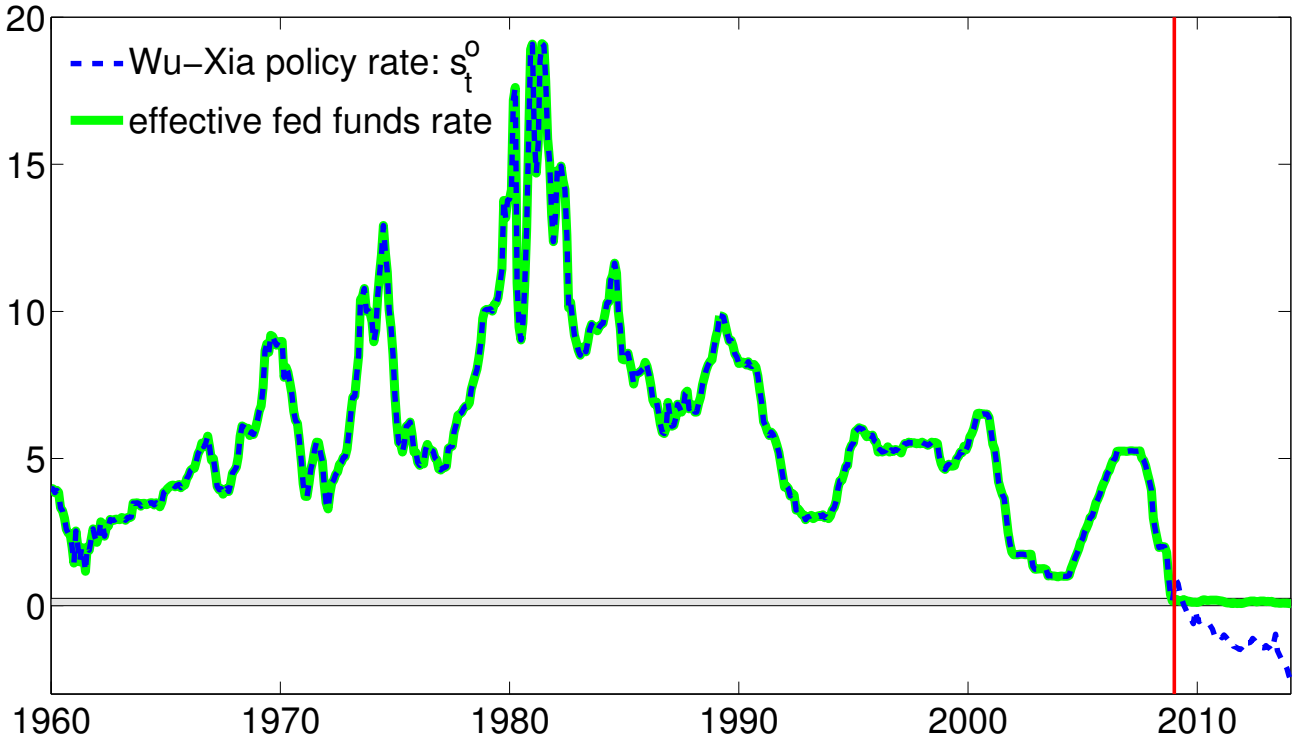

expected path of shadow rate
QE1
one month prior
10
5
0
1 2 3 4 5 6 7 8 9 10


yield
Taper tantrum
one day prior
3
2
1
0
1 2 3 4 5 6 7 8 9 10


forward rate
Taper tantrum
one month prior
6
4
2
0
1 2 3 4 5 6 7 8 9 10


expected path of shadow rate
Taper tantrum
one month prior
6
4
2
0
−2
1 2 3 4 5 6 7 8 9 10

Monetary policy



$$s_t^o = \begin{cases} \text{effective federal funds rate} & \text{before 2009} \\ \text{shadow rate} & \text{since 2009} \end{cases}$$

Can we use shadow rate as similar summary of Fed actions as fed funds rate provided historically?

Factor augmented vector autoregression

Replace the fed funds rate with s_t^o in Bernanke, Boivin, and Eliasz (2005)

$$Y_t^m = a_m + b_x x_t^m + b_s s_t^o + \eta_t^m, \quad \eta_t^m \sim N(0, \Omega)$$

- Y_t^m: 97 economic variables from 1960 to 2013
- x_t^m: 3 underlying macro factors

Factor dynamics:

$$\begin{bmatrix} x_t^m \\ s_t^o \end{bmatrix} = \begin{bmatrix} \mu^x \\ \mu^s \end{bmatrix} + \begin{bmatrix} \rho^{xx} & \rho^{xs} \\ \rho^{sx} & \rho^{ss} \end{bmatrix} \begin{bmatrix} X_{t-1}^m \\ S_{t-1}^o \end{bmatrix} + \Sigma^m \begin{bmatrix} \varepsilon_t^m \\ \varepsilon_t^{\mathrm{MP}} \end{bmatrix}, \quad \begin{bmatrix} \varepsilon_t^m \\ \varepsilon_t^{\mathrm{MP}} \end{bmatrix} \sim N(0, I)$$

- monthly VAR(13)
- Σ^m: Cholesky decomposition

Measures of monetary policy

Can we use shadow rate as similar summary of Fed actions as fed funds rate provided historically?

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Hypothesis I

$$H_0 : \rho^{xs}(t < \text{Great Recession}) = \rho^{xs}(t > \text{Great Recession})$$

- $p = 0.29$ for s_t^o

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- $p = 0.0007$ for EFFR

Measures of monetary policy

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Hypothesis II

$$H_0 : \rho^{sx}(t < \text{Great Recession}) = \rho^{sx}(t > \text{Great Recession})$$

- $p = 1$ for s_t^o
- $p = 1$ for EFFR

Measures of monetary policy

Can we use shadow rate as similar summary of Fed actions as fed funds rate provided historically?

Hypothesis I

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- $p = 0.0007$ for EFFR

Hypothesis II

$$H_0 : \rho^{sx}(t < \text{Great Recession}) = \rho^{sx}(t > \text{Great Recession})$$

- $p = 1$ for s_t^o
- $p = 1$ for EFFR

Implication: researchers can use shadow rate to update earlier studies that had been based on the historical fed funds rate.

Robustness

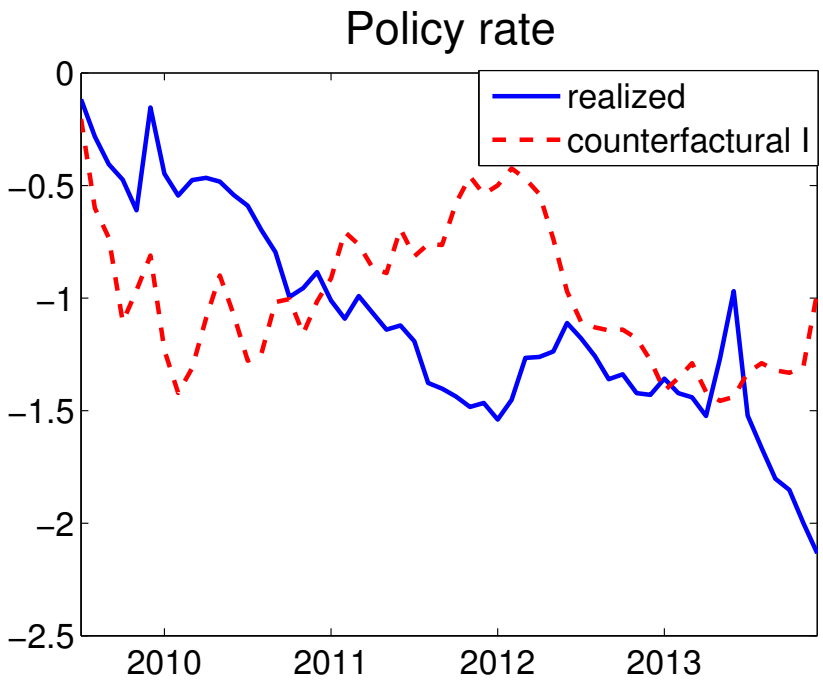
Historical decomposition

What if there had been no monetary policy shocks?

- realized: $\varepsilon_t^{\mathrm{MP}} = \hat{\varepsilon}_t^{\mathrm{MP}}$
- counterfactual: $\varepsilon_t^{\mathrm{MP}} = 0$ for ZLB

Unconventional monetary policy

- reduced the shadow rate by 0.4% between 2011 and 2013.



Historical decomposition

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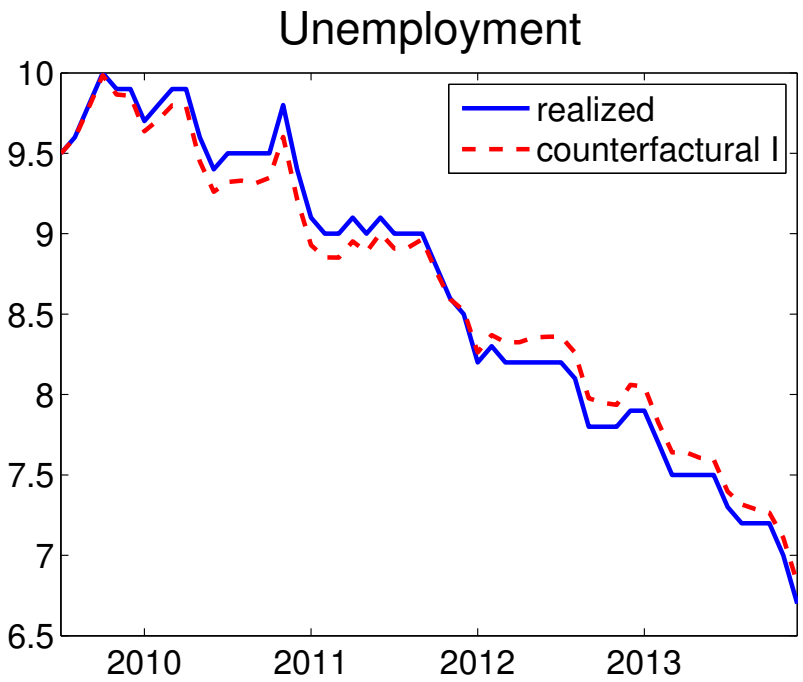
Unconventional monetary policy

- reduced unemployment by 0.13% in Dec 2013. ▸ More



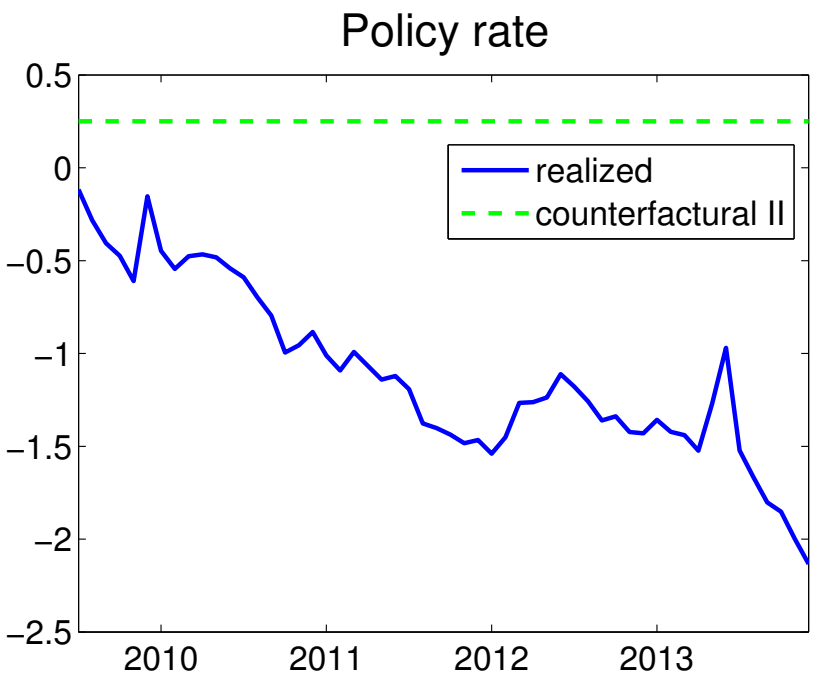
Counterfactual II

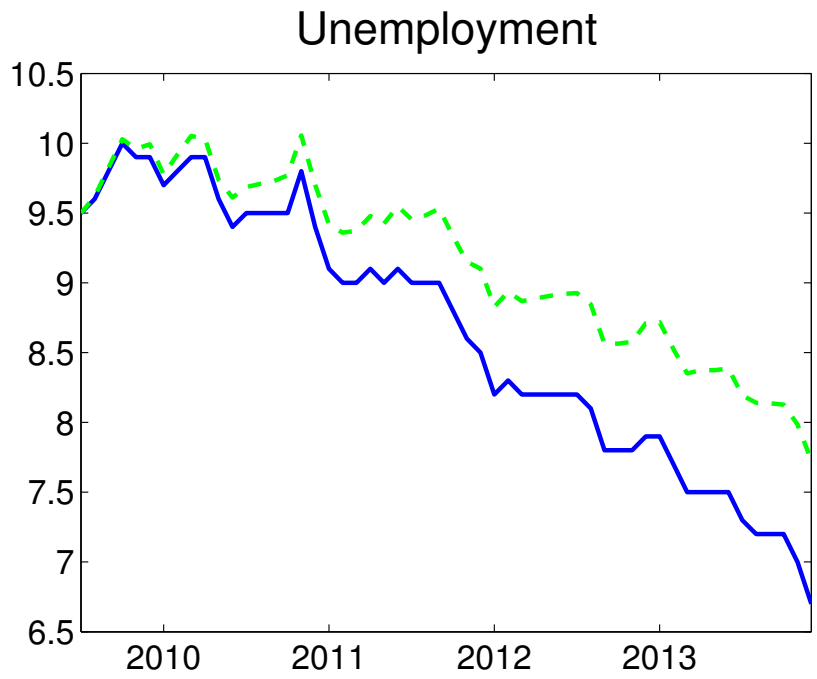
What if the shadow rate had been kept at $\underline{r}$?

- counterfactual: $\varepsilon_t^{\mathrm{MP}}$ is such that $s_t^o = \underline{r}$ at ZLB

Unconventional monetary policy

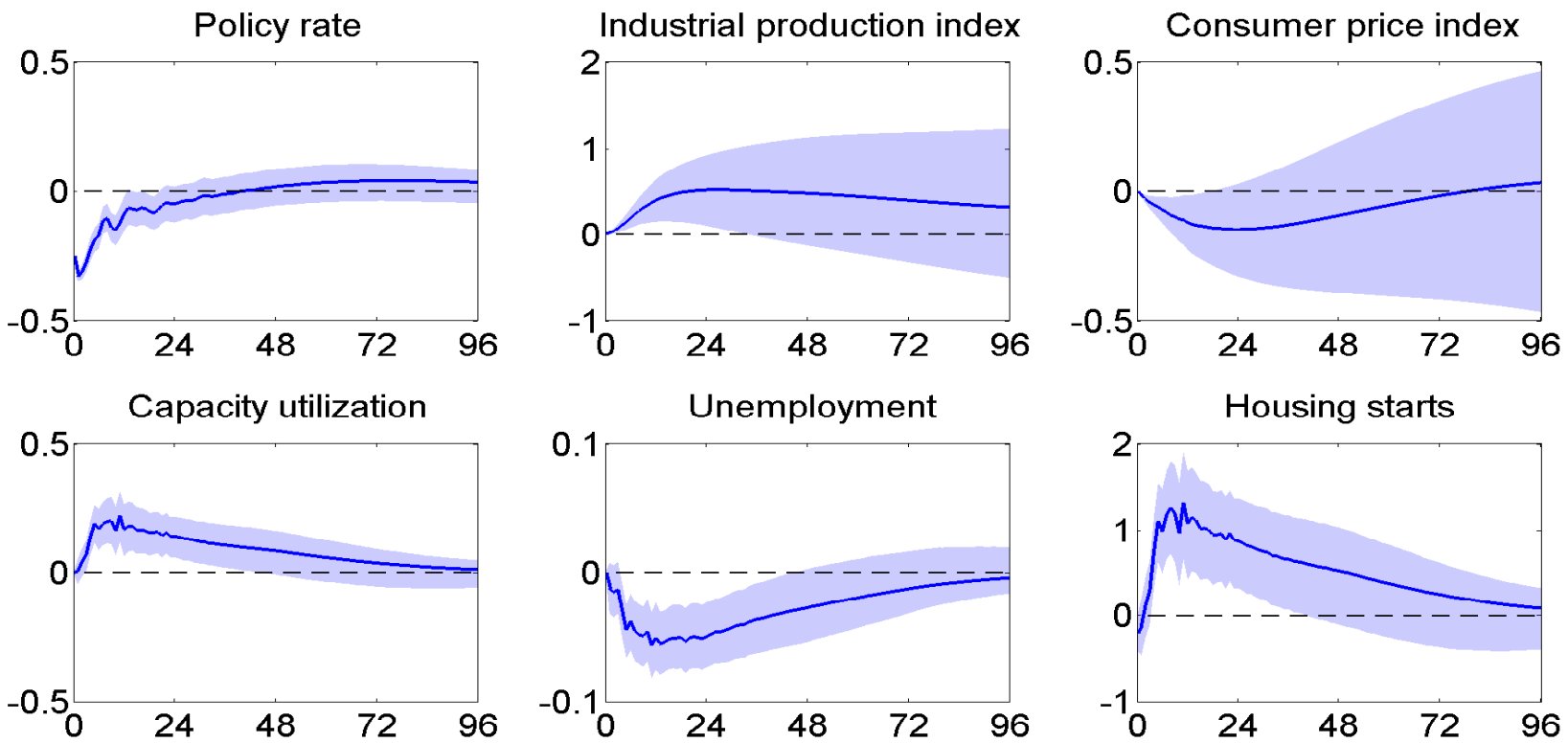
- reduced unemployment by 1% in December 2013 More





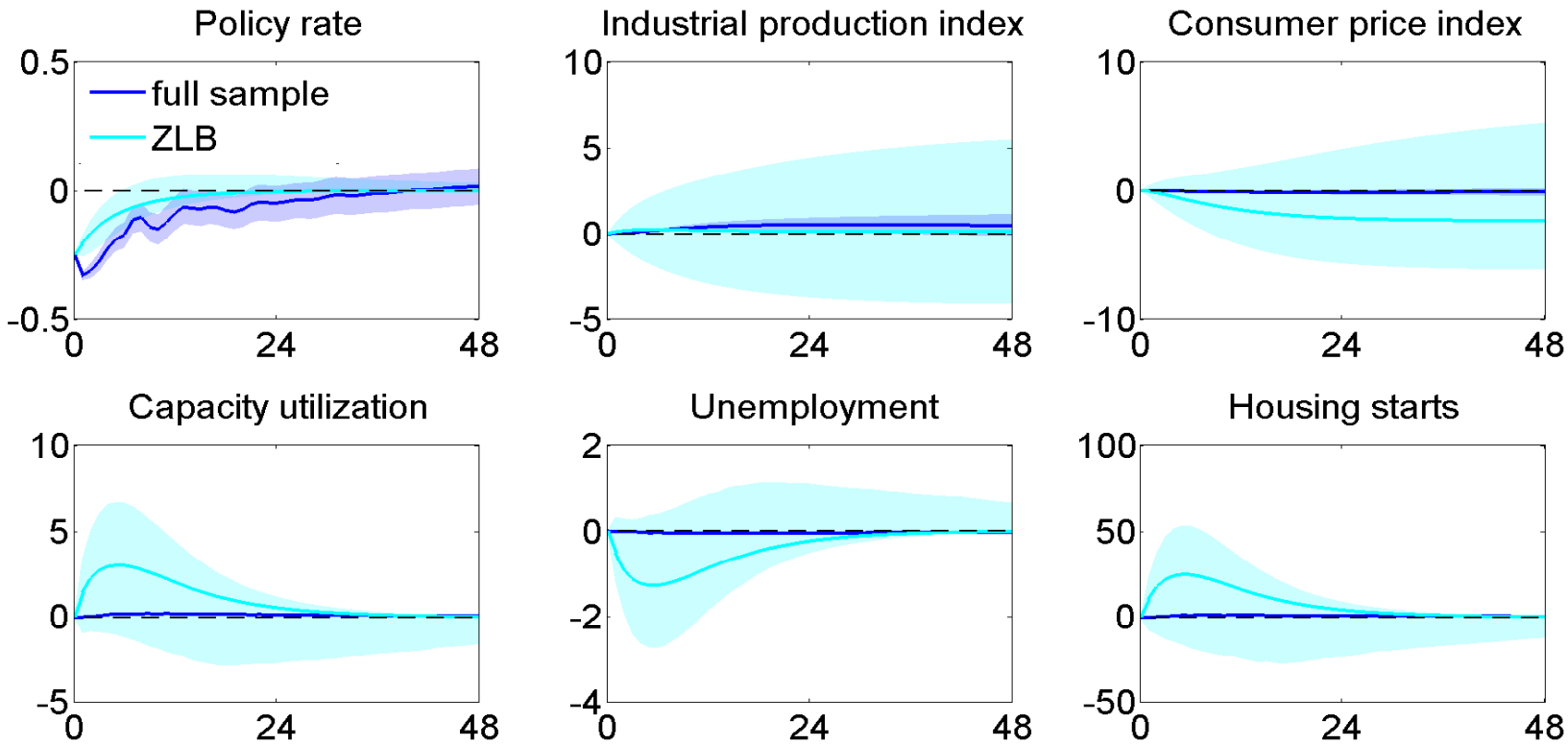
Impulse resposne: full sample

A -25bps monetary policy shock



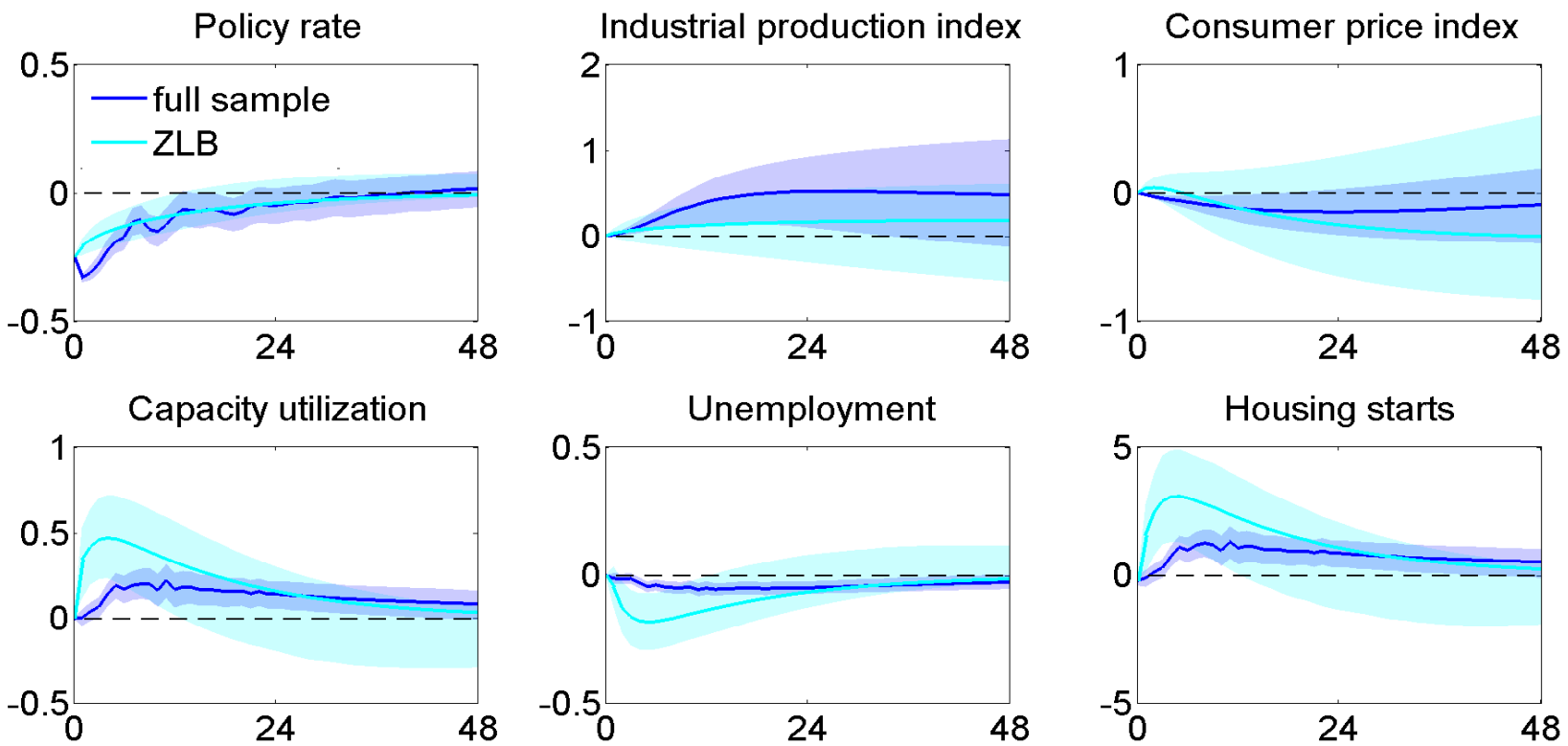
Full sample FAVAR(13) vs. ZLB FAVAR(1)

ZLB with effective federal funds rate



Full sample FAVAR(13) vs. ZLB FAVAR(1)

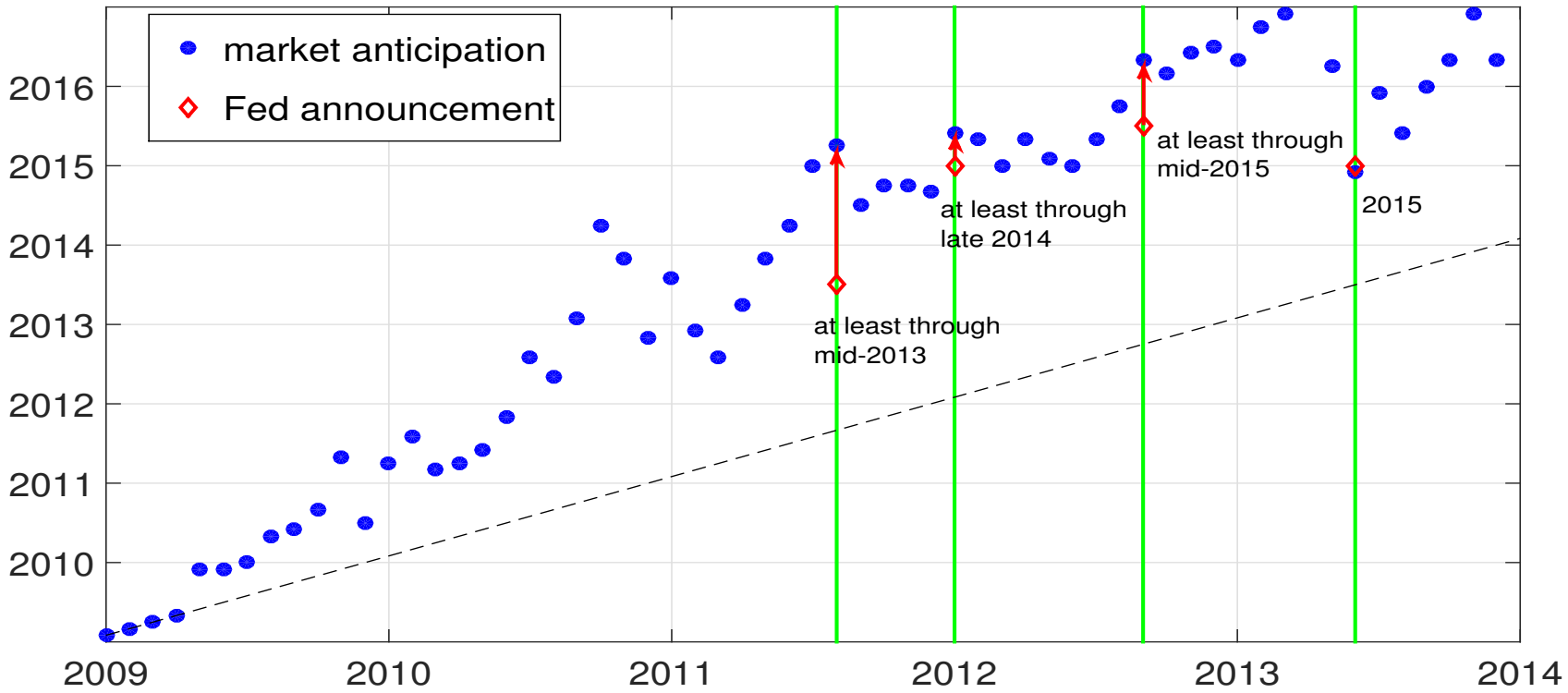
ZLB with shadow rate



Forward guidance

ZLB duration

$$\tau_t = \inf\{\tau_t \geq 0 | s_{t+\tau} \geq \underline{r}\}.$$



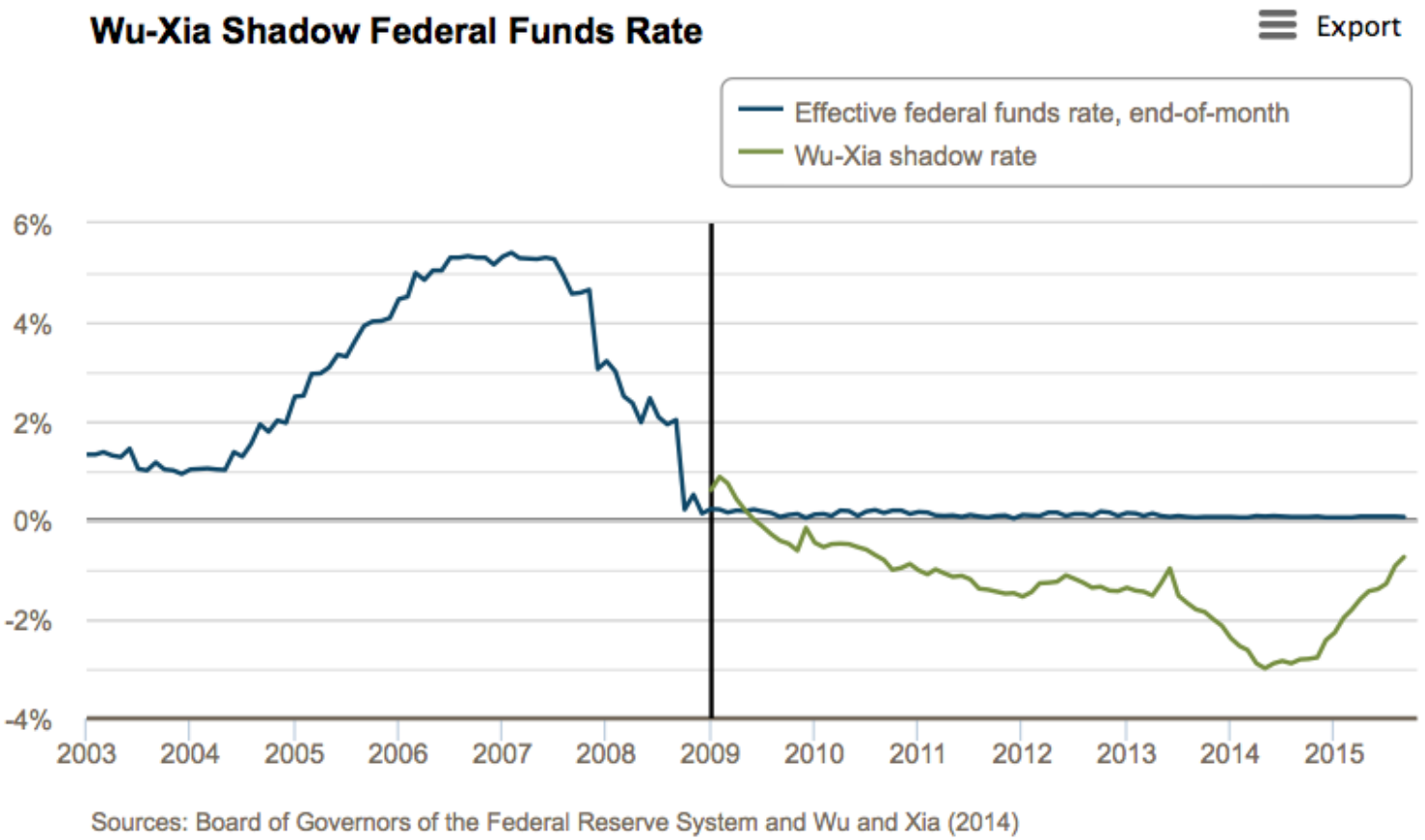
Conclusion

Method

- Develop an approximation for bond prices in the SRTSM

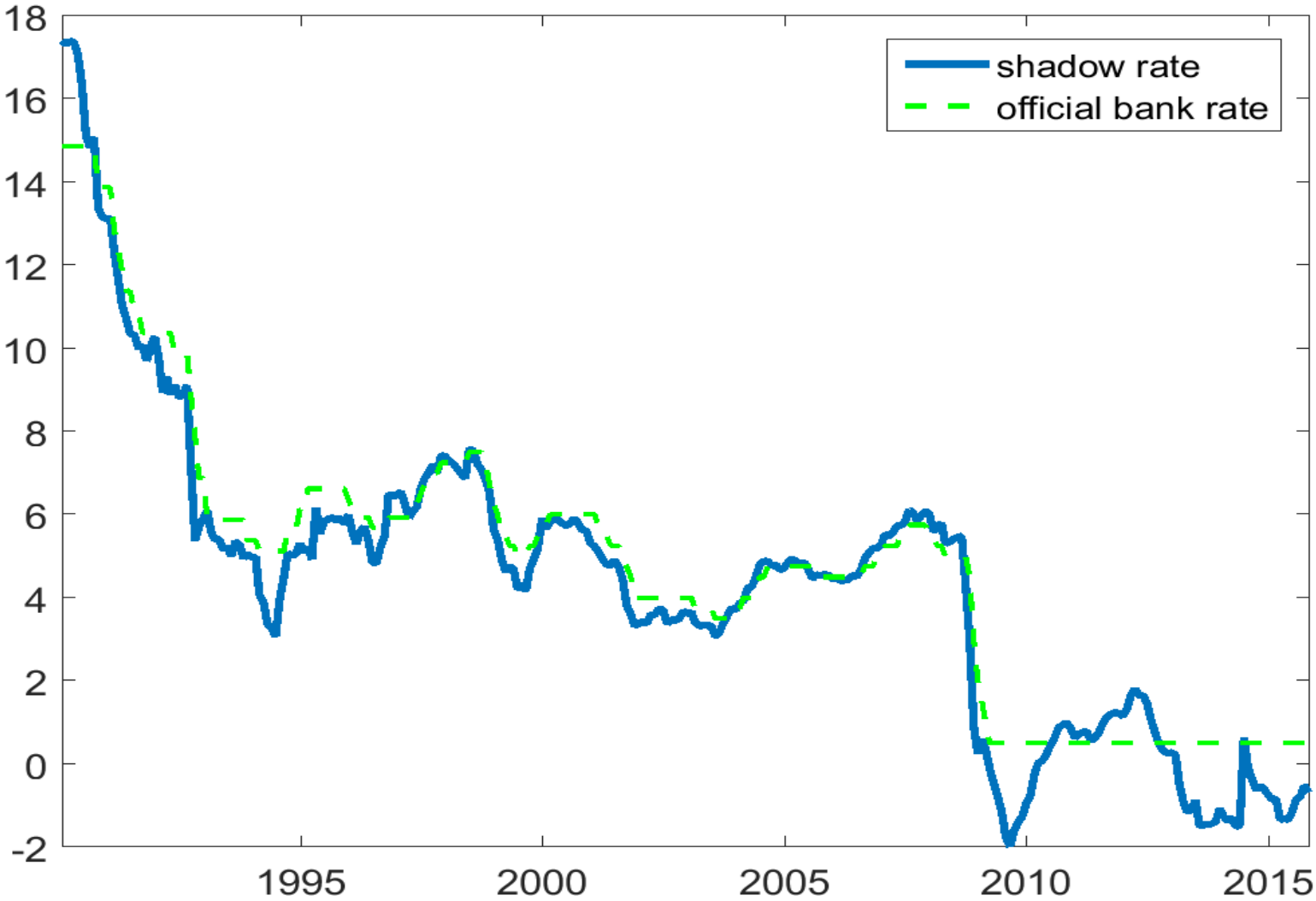
Economics

- The shadow rate exhibits similar dynamic correlations with economic variables after the Great Recession as the fed funds rate did earlier in data.
- Unconventional monetary policy lowered the unemployment rate by 0.13% in December 2013.



Source: www.frbatlanta.org/cqer/researchcq/shadow_rate.cfm

ECB shadow rate



Pricing kernel

Factor dynamics:

$$X_{t+1} = \mu + \rho X_t + \Sigma \varepsilon_{t+1}, \quad \varepsilon_{t+1} \sim N(0, I).$$

Pricing kernel

$$\begin{aligned} m_{t+1} &= r_t + \frac{1}{2}\lambda_t'\lambda_t + \lambda_t'\varepsilon_{t+1} \\ \lambda_t &= \lambda_0 + \lambda_1 X_t \end{aligned}$$

where $\mu^{\mathbb{Q}} = \mu - \Sigma\lambda_0$, and $\rho^{\mathbb{Q}} = \rho - \Sigma\lambda_1$

Pricing equation

$$P_t^n = \mathbb{E}_t[\exp(-m_{t+1})P_{t+1}^{n-1}]$$

Back

Bond recursions

$$
\begin{aligned}
a_n &= \delta_0 + \delta_1' \left(\sum_{j=0}^{n-1} \left(\rho^{\mathbb{Q}}\right)^j \right) \mu^{\mathbb{Q}} - \frac{1}{2} \delta_1' \left(\sum_{j=0}^{n-1} \left(\rho^{\mathbb{Q}}\right)^j \right) \Sigma\Sigma' \left(\sum_{j=0}^{n-1} \left(\rho^{\mathbb{Q}}\right)^j \right)' \delta_1, \\
b_n' &= \delta_1' \left(\rho^{\mathbb{Q}}\right)^n.
\end{aligned}
$$

Back

Model specification

$\underline{r} = 0.25$, interest rate on reserves

three factors

Normalization: restrict $\mathbb{Q}$ parameters

Repeated eigenvalues

$$\rho^{\mathbb{Q}} = \begin{bmatrix} \rho_1^{\mathbb{Q}} & 0 & 0 \\ 0 & \rho_2^{\mathbb{Q}} & 1 \\ 0 & 0 & \rho_2^{\mathbb{Q}} \end{bmatrix}.$$

Back

Kalman filters

State equation

$$X_{t+1} = \mu + \rho X_t + \Sigma \varepsilon_{t+1}, \varepsilon_{t+1} \sim N(0, I)$$

observation equation for SRTSM $\Rightarrow$ extended Kalman filter

$$f^o_{n,n+1,t} = \underbrace{\underline{r} + \sigma^{\mathbb{Q}}_n g\left(\frac{a_n + b_n' X_t - \underline{r}}{\sigma^{\mathbb{Q}}_n}\right)}_{f^{SRTSM}_{n,n+1,t}} + \eta_{nt}, \eta_{nt} \sim N(0, \omega)$$

observation equation for GATSM $\Rightarrow$ Kalman filter

$$f^o_{n,n+1,t} = \underbrace{a_n + b_n' X_t}_{f^{GATSM}_{n,n+1,t}} + \eta_{nt}, \eta_{nt} \sim N(0, \omega)$$

Back

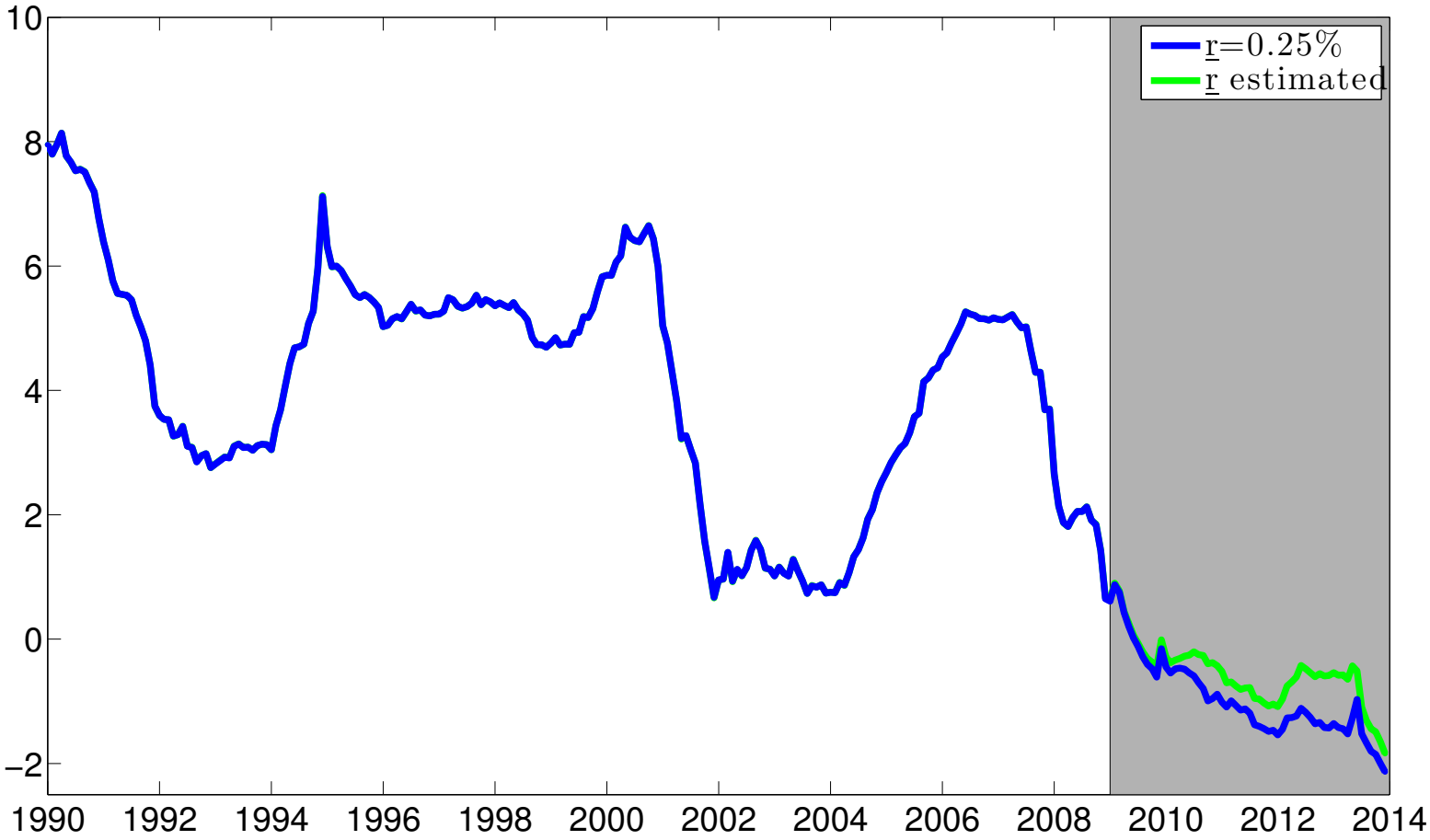
Approximation error for ZLB

Average absolute approximation error between 2009M1 and 2013M1

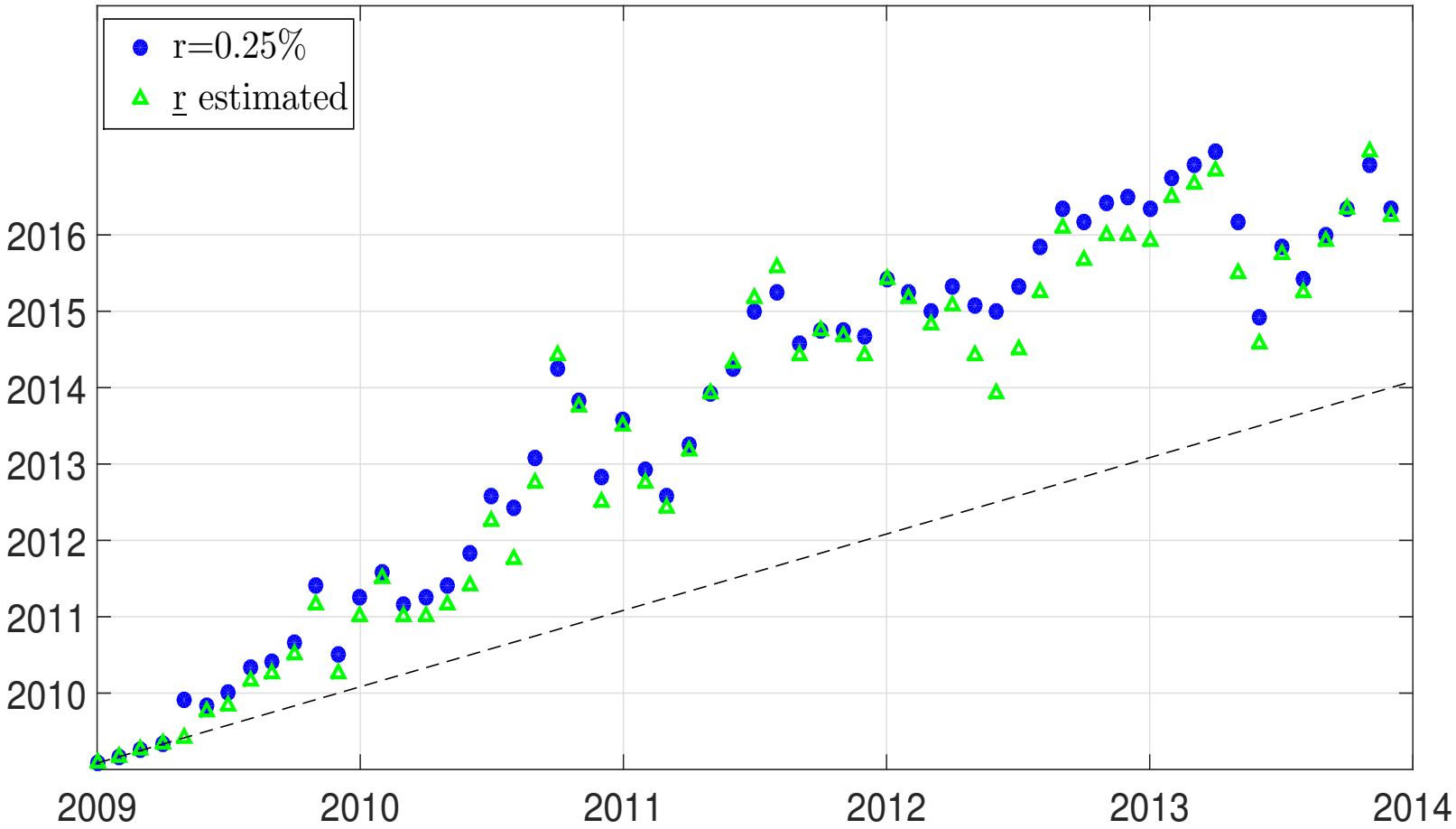
	3M	6M	1Y	2Y	5Y	7Y	10Y
forward rate error	0.00	0.01	0.06	0.43	2.50	3.51	5.41
forward rate level	23	26	46	111	326	418	481
yield error	0.00	0.00	0.01	0.10	0.91	1.50	2.37

back

Robustness


r=0.25%
r estimated
10
8
6
4
2
0
−2
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014

Robustness

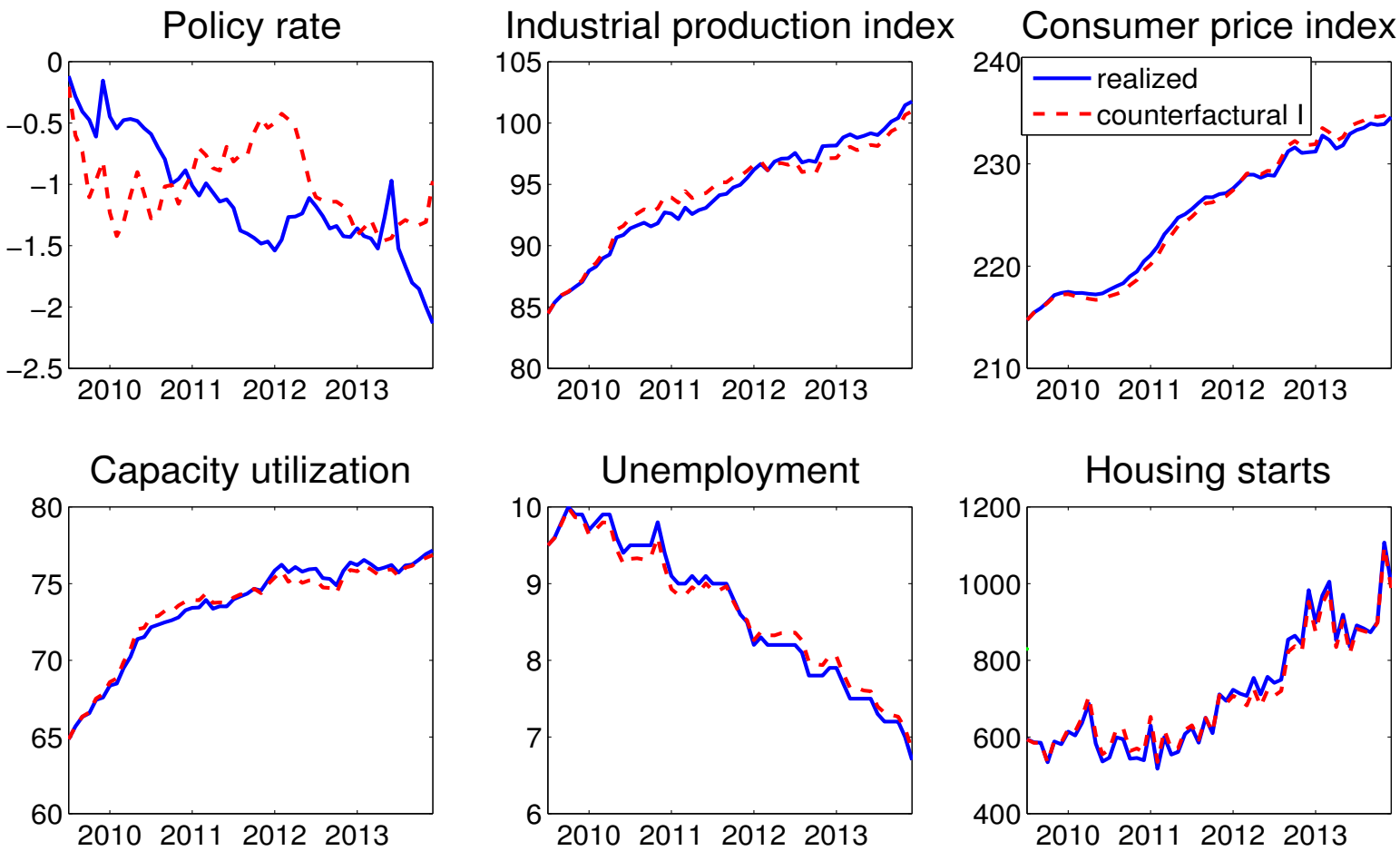

r=0.25%
r estimated
2016
2015
2014
2013
2012
2011
2010
2009
2010
2011
2012
2013
2014

Robustness

		p-value for $\rho_1^{xs} = \rho_3^{xs}$	p-value for $\rho_1^{sx} = \rho_3^{sx}$
	Baseline	0.29	1.00
A1	estimate $\underline{r}$	0.18	1.00
A2	2-factor SRTSM	0.13	0.97
A3	Fama-Bliss	0.38	1.00
A4	5-factor FAVAR	0.70	1.00
A5	6-lag FAVAR	0.09	0.98
	7-lag FAVAR	0.19	0.97
	12-lag FAVAR	0.22	1.00

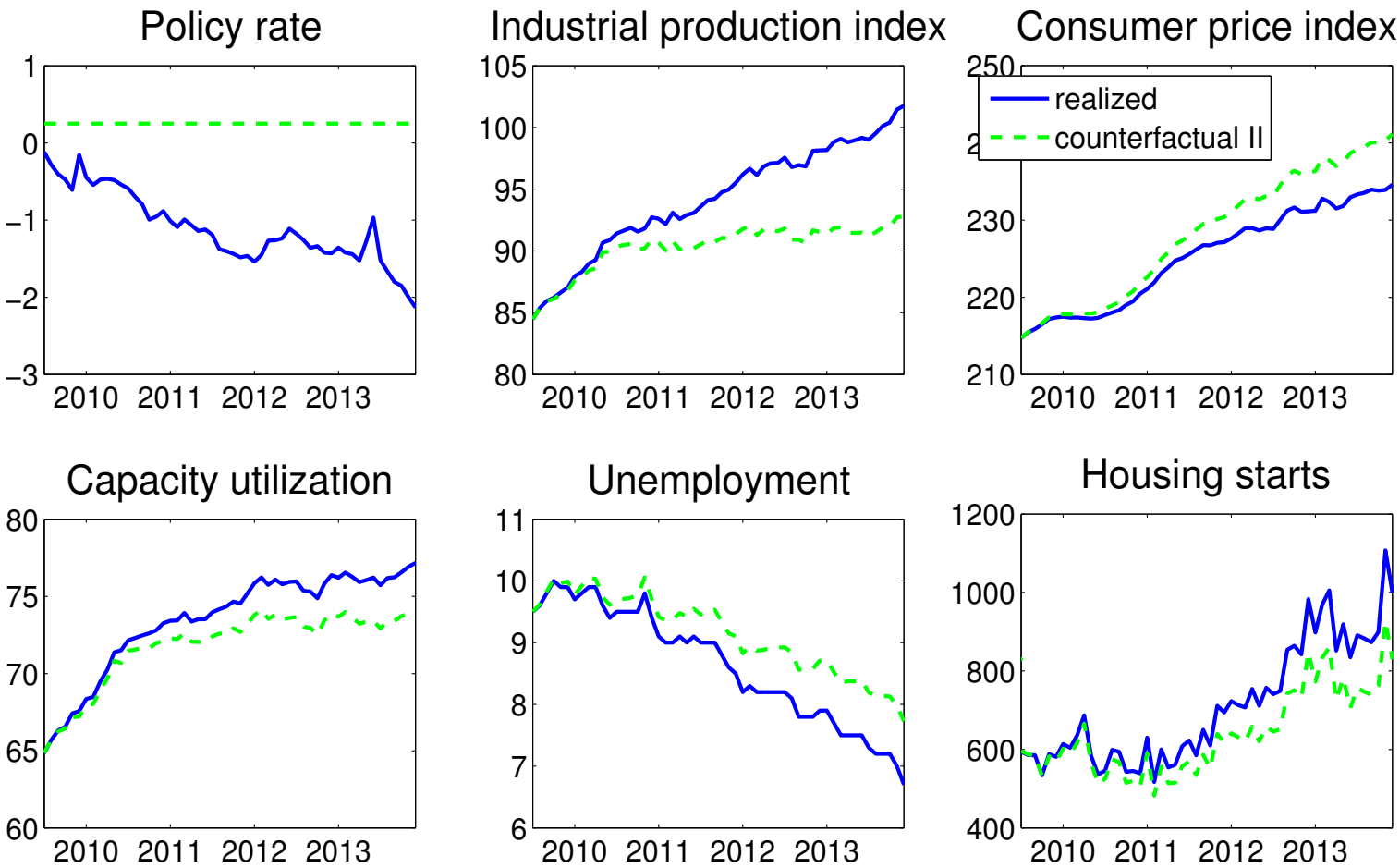
Back

Historical decomposition



Back

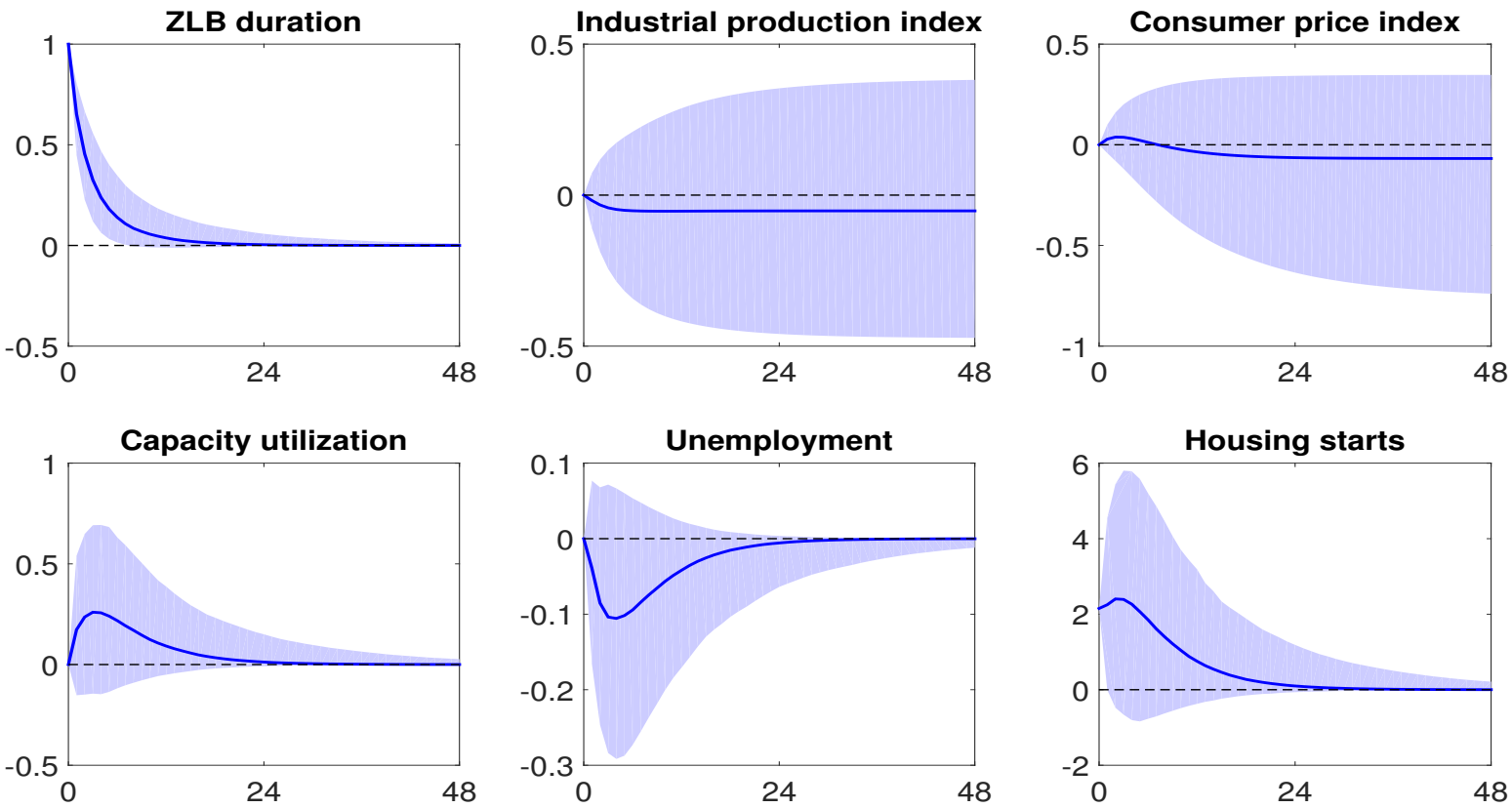
Counterfactual II



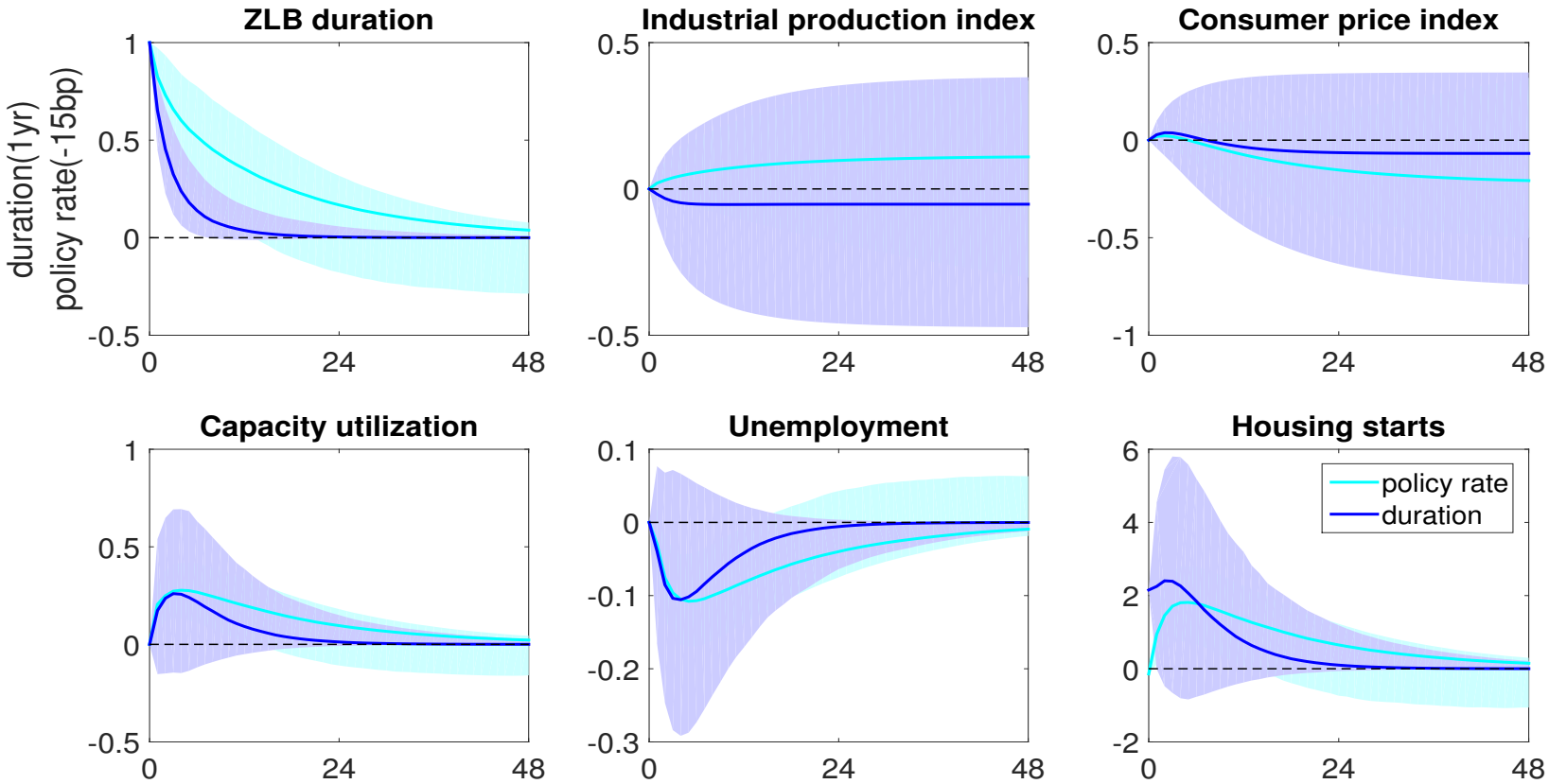
Back

Impulse responses: forward guidance

A monetary policy shock to increase the ZLB by 1 year



Forward guidance vs. shadow rate



Unemployment rate decreases by 0.1% with

- a one year increase in the expected ZLB duration
- 15 basis-point decrease in the policy rate

Back