Econometric Analysis of Monetary Policy at the Zero Lower Bound

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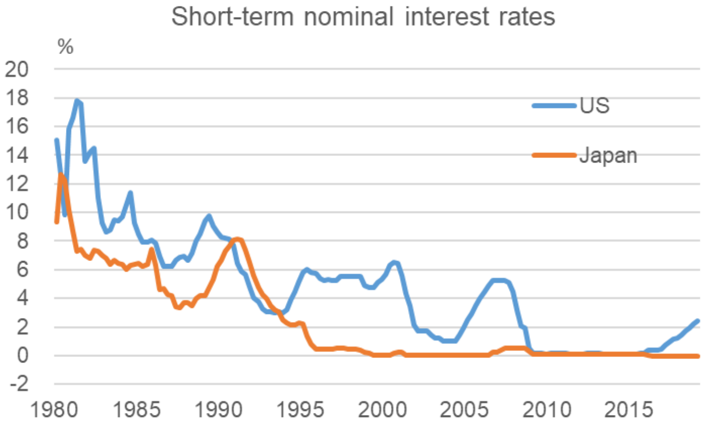
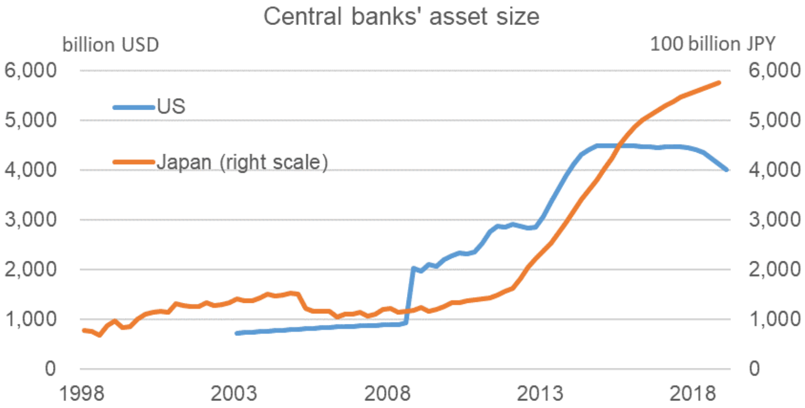
Interest rates reached at the zero lower bound (ZLB)

- Short-term interest rate was a primary tool for monetary policy.



Unconventional monetary policy (UMP)

- Forward guidance (FG) – commitment about interest rates in future
- Quantitative easing (QE) – purchases of long-term government bonds



Two issues of monetary policy at the ZLB

1. Does the ZLB hamper the effectiveness of monetary policy?
   - ZLB irrelevance hypothesis (e.g. Swanson and Williams 2014)
2. How effective is UMP under the ZLB?

Our approach: theory and evidence

- Theoretical model
  - Simple New Keynesian model with:
  - QE – long-term government bond purchases
  - FG – keeping interest rates low for long
  - Explains ZLB irrelevance hypothesis
- Empirical model
  - Structural VAR (Mavroeidis 2019) with
  - ZLB
  - QE and FG in a similar spirit to the theoretical model

Main results

1. ZLB is empirically relevant for both Japan and the US
    - ZLB irrelevance hypothesis is rejected
2. In the US, UMP has been quite (but not fully) effective
    - Roughly 75% as effective as conventional one on impact

Related literature

- QE theory: Andres et al (2004); Chen et al. (2012); Harrison (2012); Gertler and Karadi (2013); Liu et al. (2019)
- FG theory: Reifschneider and Williams (2000)
- Empirical method: Mavroeidis (2019); Hayashi and Koeda (2019)
- ZLB irrelevant hypothesis: Swanson and Williams (2014); Debortoli et al. (2019)

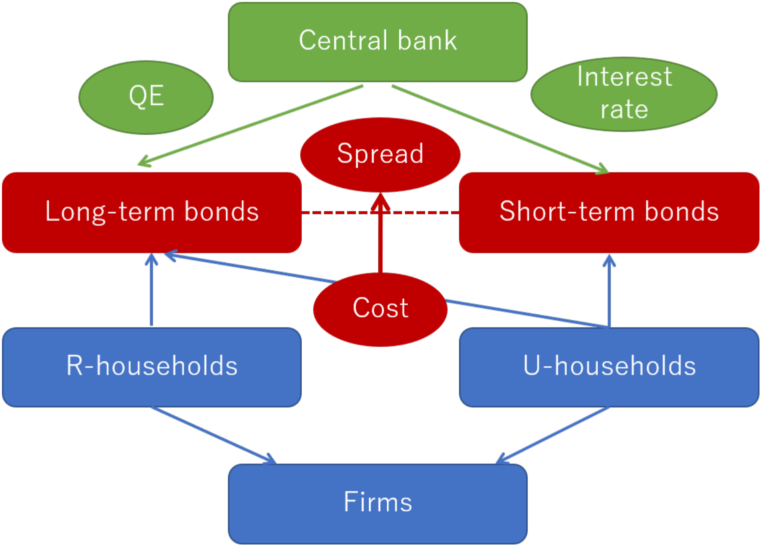
Outline

1. Macroeconomic model of UMP
2. Empirical model and identification at the ZLB
3. Testing ZLB irrelevance hypothesis
4. Impact of monetary policy

Model overview

- Based on 3-equation New Keynesian model
- Interest rate i_t bounded below by 0 (ZLB)
- Shadow rate i_t^* – the central bank's "target" interest rate
  - Depends on the Taylor-rule based rate and FG
- FG as in Reifschneider and Williams (2000)
- QE as in Chen et al. (2012)
  - Bond market segmentation makes QE effective
- QE depends on i_t^*

Model illustration



The model

- New Keynesian Phillips Curve

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{y}_t - \chi_a z_t^a$$

- Euler equation, modified to incorporate QE

$$\hat{y}_t = E_t \hat{y}_{t+1} - \frac{1}{\sigma}\left((1-\lambda^*)\hat{i}_t + \lambda^* \hat{i}_t^* - E_t \hat{\pi}_{t+1}\right) - \chi_z z_t^b$$

- Interest rate rule, modified to incorporate FG

$$\hat{i}_t = \max\left\{\hat{i}_t^*, \frac{-i}{1+i}\right\}, \qquad \hat{i}_t^* = \hat{i}_t^{\text{Taylor}} - \alpha\left(\hat{i}_t - \hat{i}_t^{\text{Taylor}}\right),$$

$$\hat{i}_t^{\text{Taylor}} = \rho_i \hat{i}_{t-1}^* + (1-\rho_i)\left(r_\pi \hat{\pi}_t + r_y \hat{y}_t\right) + \epsilon_t^i,$$

Notation:

output (y); inflation (π); interest rate (i); shadow rate (i^*); Taylor-rule-based rate (i^{Taylor}); productivity shock (z^a); demand shock (z^b); monetary policy shock (ϵ^i).

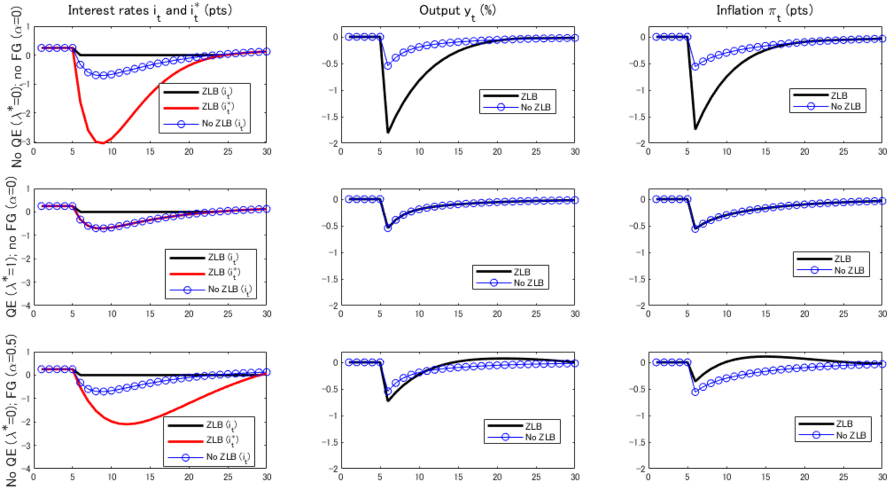
Why do long-term rate and long-term gvt bonds disappear?

- QE under ZLB for long-term gvt bonds: $\hat{b}_{L,t} = \eta_{i^*} \times i_t^*$.
- Long-term rate spread: $\hat{\zeta}_t = \eta_{b_L} \times \hat{b}_{L,t}$.
- Expected long-term rate: $E_t \hat{R}_{L,t+1} = ... + \eta_\zeta \times \hat{\zeta}_t$

  $=>$ Both $E_t \hat{R}^L_{t+1}$ and $\hat{b}_{L,t}$ can be replaced by i_t^*.
- The efficacy of QE: $\lambda^* \propto \eta_{i^*} \times \eta_{b_L} \times \eta_\zeta$
- VAR(1) representation in (π_t, y_t, i_t^*) when $\lambda^* = 1$ and $\alpha = 0$

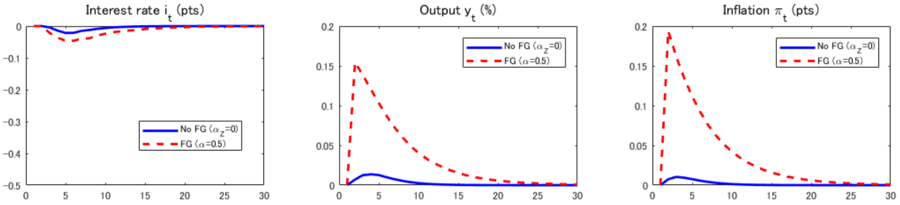
  $\Rightarrow$ ZLB is empirically irrelevant.

Effects of QE and FG



Effects of a monetary policy shock at the ZLB

Figure: Impulse responses to a 1% increase in the interest rate at the ZLB



- ZLB caused by a severe demand shock
- Average of simulated responses 1000 times

Outline

Empirical model (Mavroeidis 2019)

- $Y_{1t} = \{\text{inflation, output, long-term rate, ...}\}$; $Y_{2t} = $ policy rate.
- $Y^*_{2t} = $ shadow rate, representing desired policy stance
- **C**ensored and **K**inked **S**tructural **VAR** (**CKSVAR**):

$$\begin{aligned} Y_{1t} =& \beta\left(\lambda Y^*_{2t} + (1-\lambda) Y_{2t}\right) + B_1 X_t + B^*_{12} X^*_{2t} + \epsilon_{1t}, \\ Y^*_{2t} =& -\alpha Y_{2t} + (1+\alpha)\left(\gamma Y_{1t} + B_2 X_t + B^*_{22} X^*_{2t} + \epsilon_{2t}\right), \\ Y_{2t} =& \max\{Y^*_{2t}, b_t\} \end{aligned}$$

where $X_t = \{Y_{t-1}, ..., Y_{t-p}\}$ and $X^*_{2t} = \{Y^*_{2t-1}, ..., Y^*_{2t-p}\}$.

- λ and α similar to the macroeconomic model

The model: special cases

- **K**inked **SVAR** ($\lambda = \alpha = 0$, no shadow rate):

$$Y_{1t} = \beta Y_{2t} + B_1 X_t + \varepsilon_{1t} \tag{1}$$
$$Y_{2t} = \max\{\gamma Y_{1t} + B_2 X_t + \varepsilon_{2t}, b_t\}, \tag{2}$$

where X_t is exogenous and predetermined, ε_t iid shocks, $\varepsilon_{1t} \perp\!\!\!\perp \varepsilon_{2t}$.

- **C**ensored **SVAR** ($\lambda = 1$, $\alpha = 0$): linear SVAR in (Y_1, Y_2^*)

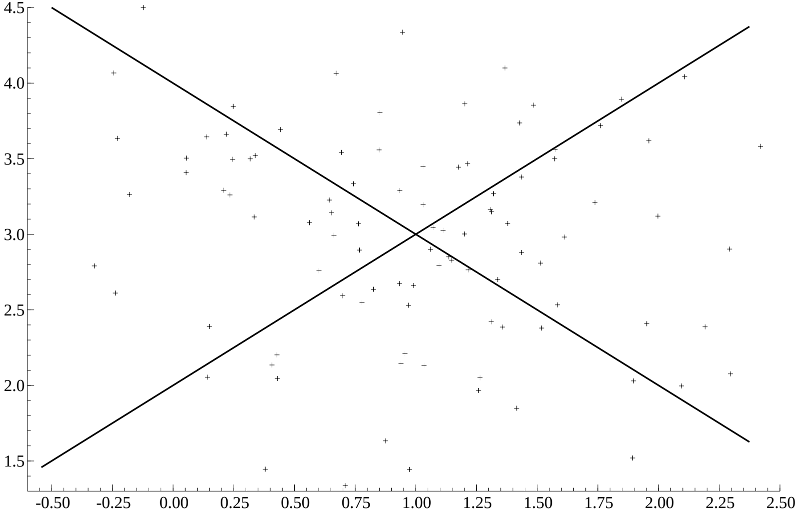
$$Y_{1t} = \beta Y_{2t}^* + B_1 X_t^* + \varepsilon_{1t}, \tag{3}$$
$$Y_{2t}^* = \gamma Y_{1t} + B_2 X_t^* + \varepsilon_{2t}, \tag{4}$$
$$Y_{2t} = \max\{Y_{2t}^*, b_t\}, \tag{5}$$

where X_t^* includes Y_{2t-j}^* but *not* Y_{2t-j}.

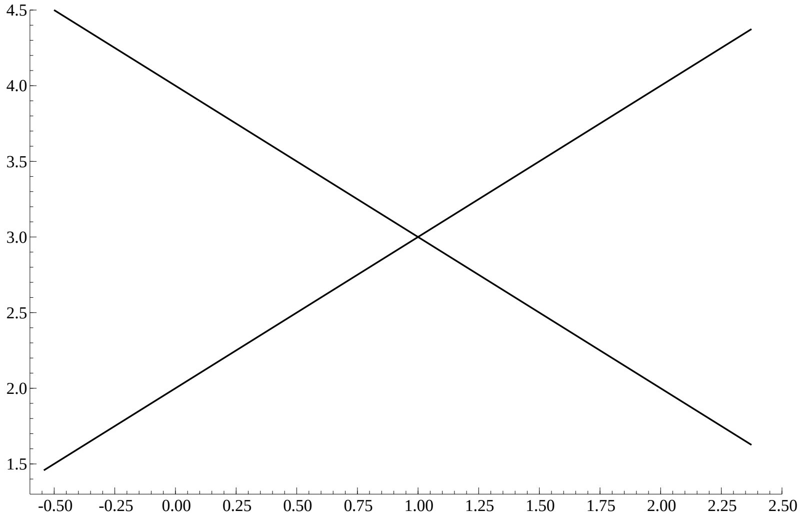
Mavroeidis (2019) "Identification at the ZLB"

- SVARs subject to occasionally binding constraints (CKSVAR)
- Uses occasionally binding constraints for identification
- Unconventional policy via "shadow rate" and FG
- The method can:
  1. Identify IRF to monetary policy shocks
  2. Obtain bounds on efficacy of unconventional policy
  3. Test the "ZLB irrelevance" hypothesis

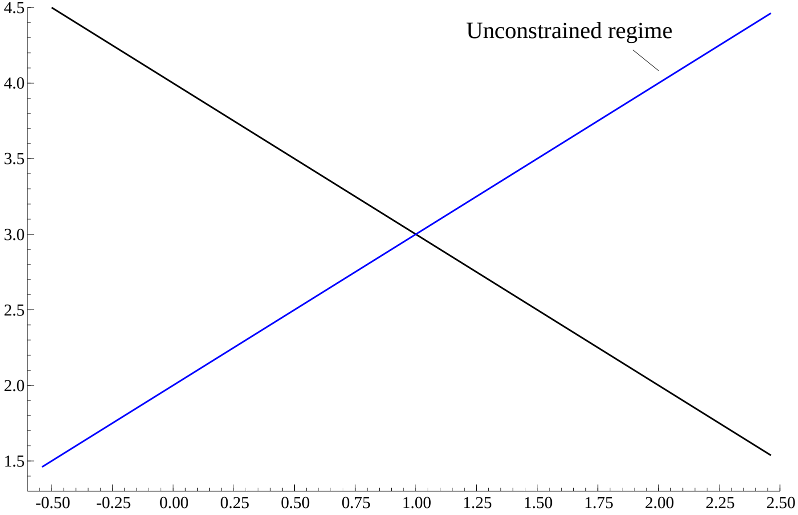
The intuition behind identification at the ZLB



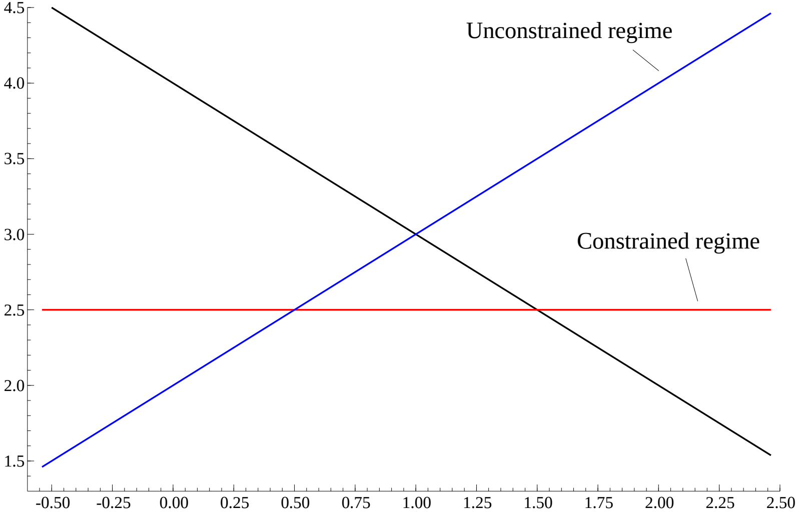
The intuition behind identification at the ZLB



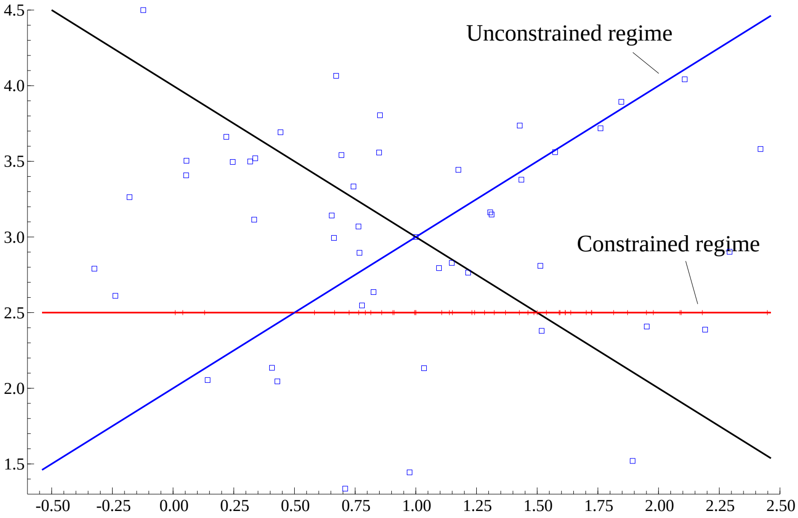
The intuition behind identification at the ZLB



The intuition behind identification at the ZLB



The intuition behind identification at the ZLB



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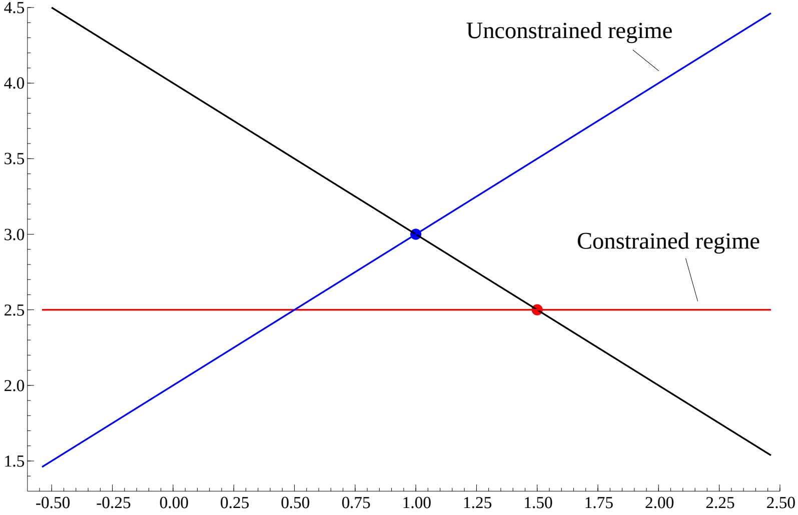


Mapping the DSGE model to the CKSVAR

- In general, no analytical mapping of the DSGE to the CKSVAR
  - No analytical solutions to the DSGE
- Different interpretation of efficacy of UMP
  - In DSGE, $\lambda^* = 0$ means no effect of QE, but FG can still be effective
  - In CKSVAR, $\lambda = 0$ means no contemporaneous effect of any UMP
- Perfect mapping when $\lambda = 1$ and $\alpha = 0$ (ZLB irrelevance)
  - Solution to the DSGE: linear SVAR in π_t, y_t, i_t^*
- CKSVAR has high power in detecting deviations from $\lambda = 1, \alpha = 0$
- $\xi \equiv \lambda(1 + \alpha)$ can be identified, but not separately.

Partial identification of ξ (Mavroeidis 2019)

- Reduced form of CKSVAR for Y_1t has kink at ZLB:

$$Y_{1t} = C_1 X_t + C_{12}^* X_{2t}^* + u_{1t} - \widetilde{\beta} D_t \left(C_2 X_t + C_{22}^* X_{2t}^* + u_{2t} - b_t \right)$$
$$D_t := 1_{\{Y_{2t} = b_t\}},$$

where

$$\widetilde{\beta} = (1 - \xi) (I - \xi \beta \gamma)^{-1} \beta, \quad (1)$$
$$\gamma = \left(\Omega_{12}' - \Omega_{22} \beta' \right) \left(\Omega_{11} - \Omega_{12} \beta' \right)^{-1} \quad (2)$$

- $\widetilde{\beta}$, Ω are identified, but β, γ, ξ are not
- Identified set consists of all β, γ, ξ that solve (1)-(2) for given $\widetilde{\beta}$, Ω

Outline

Implications of ZLB irrelevance hypothesis

- ZLB empirically irrelevant in the US
  (Swanson and Williams, 2018; Debortoli et al., 2019)
  - Structural VAR without short rate
  - Found similar impulse responses across no-ZLB and ZLB regimes
- Irrelevance hypothesis implies:
  1. Short rates are redundant once long rates are included

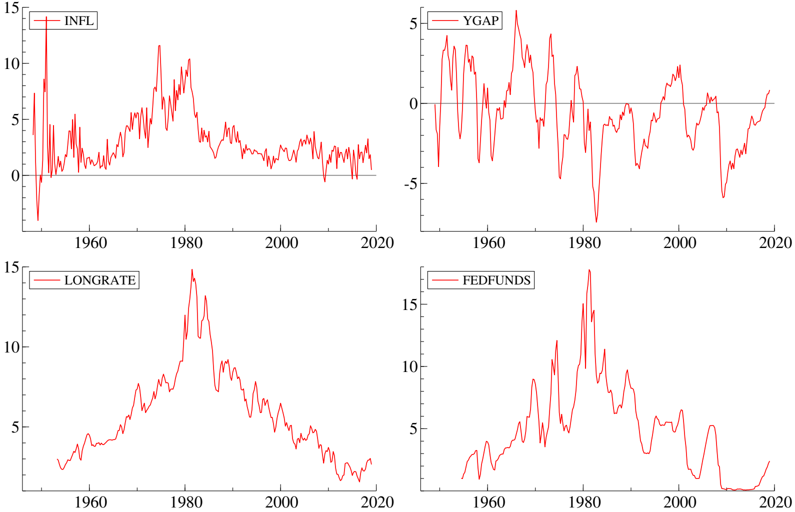
     Can be tested as exclusion restrictions on short rates in CKSVAR
  2. UMP as effective as conventional policy at all horizons

     Can be tested as null hypothesis that CKSVAR reduces to a CSVAR

Data

- The US
  - Quarterly: 1960Q1–2018Q4
  - Inflation (GDP deflator); Output gap; Federal funds rate; 10-year government bond yields
  - Effective lower bound of 0.2 percent
- Japan
  - Quarterly: 1974Q4–2019Q1
  - Inflation (CPI); Output growth; Call rate; 9-year government bond yields
  - Effective lower bound of 0.05 percent

U.S. data


INFL
15
10
5
0
1960
1980
2000
2020
YGAP
5
0
-5
1960
1980
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LONGRATE
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1980
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FEDFUNDS
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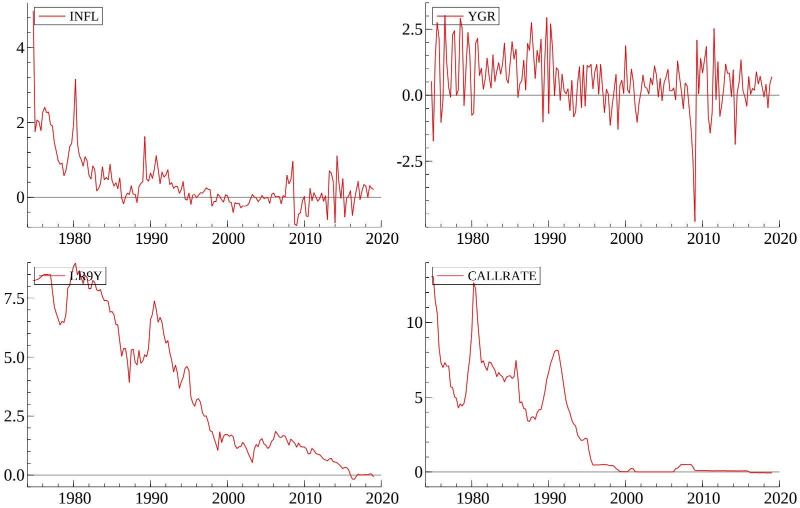
Japanese data



Test for excluding i_t (KSVAR)

United States							
p	lik	par	pv-p	aic	LR	df	pval
5	-210.8	97	-	2.60	52.52	18	0.000
4	-217.9	81	0.577	2.53	49.19	15	0.000
3	-229.3	65	0.249	2.50	40.89	12	0.000
2	-262.1	49	0.000	2.66	40.55	9	0.000
1	-287.0	33	0.000	2.75	33.24	6	0.000
Japan							
p	lik	par	pv-p	aic	LR	df	pval
6	117.8	113	-	-0.06	26.72	21	0.180
5	101.7	97	0.009	-0.05	25.00	18	0.125
4	93.1	81	0.025	-0.14	23.25	15	0.079
3	85.7	65	0.058	-0.24	24.86	12	0.016
2	74.5	49	0.031	-0.30	20.25	9	0.016
1	41.1	33	0.000	-0.09	24.32	6	0.000

Test for excluding i_t and i_t^* (CKSVAR)

United States							
p	lik	par	pv-p	aic	LR	df	pval
5	-191.7	117	-	2.60	76.82	33	0.000
4	-200.4	97	0.628	2.52	69.96	27	0.000
3	-212.6	77	0.395	2.46	60.78	21	0.000
2	-252.0	57	0.000	2.64	47.96	15	0.000
1	-279.9	37	0.000	2.72	37.60	9	0.000
Japan							
p	lik	par	pv-p	aic	LR	df	pval
6	143.6	137	-	-0.08	53.13	39	0.025
5	122.8	117	0.003	-0.07	48.50	33	0.040
4	111.6	97	0.010	-0.17	41.12	27	0.040
3	102.4	77	0.030	-0.30	39.40	21	0.009
2	87.4	57	0.010	-0.35	28.32	15	0.020
1	51.2	37	0.000	-0.16	23.97	9	0.004

Robustness of exclusion restriction tests

The results are robust:

- Monetary aggregates are included for the US
- For the sub-period from 1984q1 for the US
- 10-year yields are used instead of 9-year for Japan (1988q1-)

Testing CSVAR against CKSVAR

Country	p	LR	df	pval	sample
US	3	25.63	15	0.042	1960-2019
US	3	24.19	15	0.062	1984-2019
Japan	2	24.43	11	0.011	1974-2019

- p: VAR order (determined by AIC – results similar for $p+1$)
- LR: likelihood ratio statistic for $\xi = 1$
- Conclusion: Reject ZLB irrelevance hypothesis for the US and Japan

Testing exclusion of long rates

- Previous results included long rates in VAR
- Is it OK to exclude them, as we use to before ZLB?
  - (i.e., does i_t^* capture the unconventional policy adequately)?

US, Yes							
p	lik	par	pv-p	AIC	LR	df	pval
5	-210.8	97	-	2.597	9.632	10	0.473
4	-217.9	81	0.577	2.533	8.026	8	0.431
3	-229.3	65	0.249	2.504	5.145	6	0.525
Japan, Maybe not							
p	lik	par	pv-p	AIC	LR	df	pval
5	101.7	97	0.009	-0.05	29.23	10	0.001
4	93.1	81	0.025	-0.14	21.97	8	0.005
3	85.7	65	0.058	-0.24	18.34	6	0.005
2	74.5	49	0.031	-0.30	20.70	4	0.000

Outline

1. Macroeconomic model of UMP
2. Empirical model and identification at the ZLB
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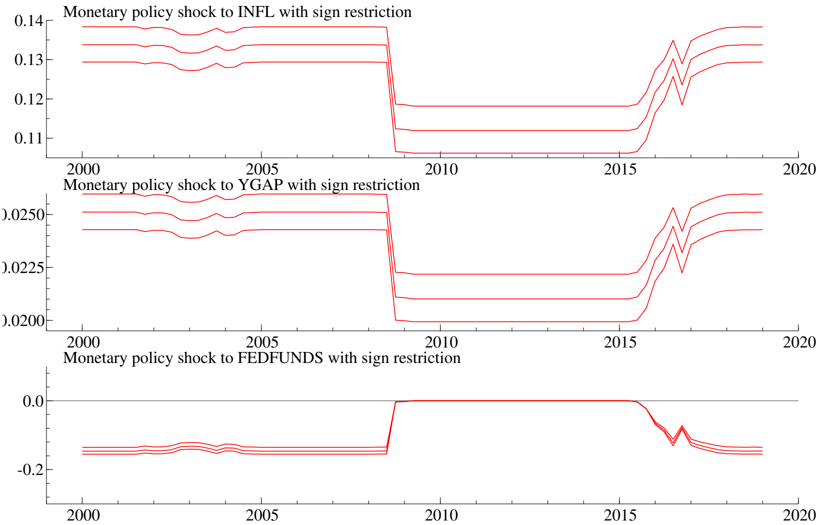
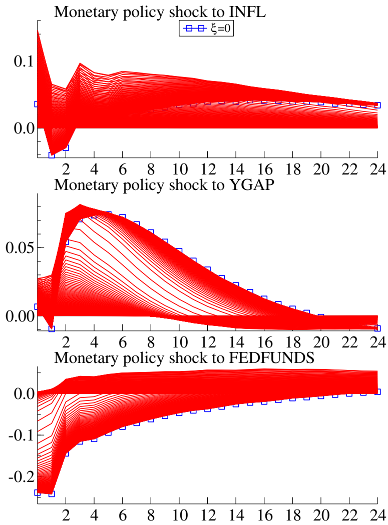
Efficacy of UMP for the US

- The identified set on ξ without any restriction is [0,0.78]
- Tightened further if imposed sign restrictions over *entire* sample: $\xi \in [0.74, 0.76]$
  - Sign restrictions: a -25pb monetary policy shock has nonpositive effects on interest rate, inflation, and output over the first 4 quarters
- Interpretation: UMP would be roughly 75% as effective as conventional policy *on impact*
- Range does not account for sampling uncertainty, which is substantial

Impact effect of -25bp mp shock over time



IRFs to -25pb mp shock in US in 2019Q1



Relative efficacy of UMP at other horizons in the US

- ξ only captures the relative efficacy of UMP on impact
- At longer horizons...
- Can be gauged by differences of IRFs during ZLB and non-ZLB
  - Let $\xi_{i,h}$ = differences of IRF to monetary policy shock of variable i at horizon h over ZLB versus non-ZLB regime
  - The hypothesis that $\xi_{i,h} = 1$ for all i, h is rejected

Conclusions

- New Keynesian model with QE and FG to motivate empirical analyses
- Agnostic empirical model for analyzing monetary policy s.t. ZLB
  - Methodology based on CKSVAR of Mavroeidis (2019)
- ZLB is empirically relevant for the US and Japan
- Unconventional policy has been quite (but not fully) effective in US
- For Japan, work in progress