The long-run effects of monetary policy

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The views expressed herein are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Federal Reserve Bank of San Francisco or the Board of Governors of the Federal Reserve System.
Are there circumstances in which changes in aggregate demand can have an appreciable, persistent effect on aggregate supply?

— Chair Janet Yellen

**Question:**
monetary interventions → macro outcomes 10-12 yrs after

**Methods:**
- **Long panel + data:** 125 yrs, 17 countries, output (capital, labor, TFP)
- **Monetary experiments:** trilemma
- **Methods:** local projections instrumental variables
- **Robustness:** exclusion restriction evaluation, structural breaks, alternate identifications, control for global business cycle, sample cuts
outline & findings

**panel data:**
- large persistent effects with instrument + regression control for pegs
- robust to sample cuts, various robustness checks
- growth accounting: capital and TFP persistently lower, labor returns to pre-trend

**US quarterly data & Romer-Romer shocks:**
- evidence from long samples imply possibility of hysteresis
- persistently lower capital stock

**reconciling new facts in a medium scale DSGE model:**
- embed reduced form hysteresis effects → hysteresis elasticity
- hysteresis effects contingent on policy rule
some of the existing literature

identified responses to monetary shocks

interest rates and productivity
- Caballero, Hoshi, & Kashyap (2008), Gopinath, Kalemli-Özcan, Karabarbounis, & Villegas-Sánchez (2017)

empirical evidence on hysteresis
annual 1890–2015 (excluding world wars) for 17 advanced economies

Jordà, Schularick & Taylor (2017)  
www.macrohistory.net/data/  
Interest rates, output, price level, investment, house prices, stock prices, consumption ...  

Bergeaud, Cette & Lecat (2016)  
www.longtermproductivity.com  
hours worked, number of employees, capital stock (machines and buildings)...
trilemma: a quasi-natural experiment

**theory of trilemma:** peg + open to capital $\rightarrow$ correlated interest rates

**instrument:** base rate movements $\rightarrow$ home rate movements

**local average treatment effect:** (Jordà, Schularick and Taylor 2019)
- identification for open pegs, not for floats or bases
instrument construction

some definitions: Jordà, Schularick and Taylor (2019, JME)

3 subpopulations: bases, pegs, floats

$q_{i,t} \in \{0, 1\}$ if peg in $t$ and $t - 1$

$k_{i,t} \in [0, 1]$ Quinn, Schindler, and Toyoda (2011), 1 is open

$z_{i,t} = k_{i,t}(\Delta r_{b(i,t),t} - \Delta \hat{r}_{b(i,t),t})$ using $x_{b(i,t),t}$ controls

- intervention: $\Delta r_{i,t}$ 3-mo govt. bill
- instrument: $z_{i,t}$: relevant and not weak

First Stage: $\Delta r_{i,t} = a_i + z_{i,t}b + x_{i,t}g + \eta_{i,t}$

<table>
<thead>
<tr>
<th>pegs ($q = 1$)</th>
<th>floats ($q = 0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All years</td>
</tr>
<tr>
<td>$b$</td>
<td>0.52***</td>
</tr>
<tr>
<td>$t$-statistic</td>
<td>[8.62]</td>
</tr>
</tbody>
</table>
implementation details

x: 2 lags, variables in log differences $\times 100$, except interest rates and credit to GDP ratio

- log real GDP pc; log real C pc; log real I pc
- log CPI
- short-term (3m) + long-term (5y) govt. rates
- log real stock prices; log real house prices
- credit to GDP

annual sample: 17 advanced economies, yearly 1890-2015
local average treatment effect—LATE
panel local projections with external instruments: LP-IV

Under relevance, exogeneity and monotonicity, for pegs only, i.e., $q = 1$

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + x_{i,t}\gamma_h + \Delta r_{i,t}\beta_h + \nu_{i,t+h}$$

$$\Delta r_{i,t} = a_i + x_{i,t}g + z_{i,t}b + \eta_{i,t}$$

$h = 0, \ldots, H-1$

$$\mathcal{R}_{LATE} = E(y_1 - y_0 | \Delta r, x, z; q = 1) = \beta = (\beta_0, \ldots, \beta_{H-1})'$$

why LATE?

LP-IV only valid for pegs, not bases or floats

if economies drawn from same distribution, then LATE = ATE
the long shadow

(a) Full sample

Real GDP

(b) Post-WW2

Real GDP

‡ confidence bands: 68% and 90%, cluster robust se
short term nominal interest rate

(a) Full sample

(b) Post-WW2

IV

OLS

Multiplier 11/23
robustness exercises

- use GDP per capita, exclude Great Recession
- (current and future) structural breaks in TFP, GDP, GDP per capita (Bai Perron 1998)
- exclusion restriction: spillover correction through synthetic control function (Conley, Hansen & Rossi 2012)
- exclusion restriction: global gdp growth
- exclusion restriction: base country GDP growth
- exclusion restriction: current account, exchange rate with respect to float
- 5 lags of control variables, control variables in levels
Solow decomposition

(a) Full sample

(b) Post-WW2

util adjustment
Confidence Bands
taking stock

panel LP-IVs

- using 125 years of data find persistent effects of monetary shocks
- persistently lower capital and TFP
- pass a variety of robustness exercises

next

- do we see similar effects for the US?
US: LP-IV + RR instruments


‡ confidence bands: 68% and 90%

Evans (1992) critique
US: decomposition

‡ confidence bands: 68% and 90%
US: decomposition II


Samples
CPI
taking stock

Panel LP-IVs

- use 125 years of data show persistent effects of monetary shocks
- persistently lower capital and TFP
- pass a variety of robustness exercises

LP-IVs and monetary policy shocks for US

- eight years out, lower output and capital stock
- Evans (1992) critique for quarterly utilization -adjusted TFP

How do we reconcile these new facts?
Endogenous TFP growth models (learning-by-doing, innovation, ...)

what we do

We embed hysteresis effects in a reduced form/ accounting sense


- no micro level data to test or discriminate among mechanisms (yet)

- reduced form eqn enough to test whether macro implications exist and are large enough to be of interest

- identify a moment that quantitative models need to match

- show implications for policy rules in a set of micro-founded models that map to the reduced form eqn
medium-scale NK DSGE model

Christiano-Eichenbaum-Evans (2005), Smets-Wouters (2007)
+ hysteresis effects (Stadler 1990, Delong and Summers 2012)

what the model needs?

\[ \log Z_t = \log Z_{t-1} + \mu_t + \eta \log \left( \frac{Y_{t-1}}{Y_{t-1}^f} \right) \]


the key moment to match

\( \eta \) - hysteresis elasticity \( \in (0.18, 0.48) \)

<table>
<thead>
<tr>
<th>pegs (trilemma)</th>
<th>US (RR)</th>
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<tbody>
<tr>
<td>( \eta )</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Delong & Summers (2012): \( \eta \approx 0.24 \)
comparison of policy rules

$\eta = 0.18$, Taylor Rule: $1 + i_t = (1 + i_{t-1})^{0.8} \left[ \left( \pi_t / \pi_{SS} \right)^{1.5} y_t^{0.05} \right]^{1-0.8} \left( y_t / y_{t-1} \right)^{0.2} \epsilon_t^{mp}$

Hysteresis target $1 + i_t = (1 + i_{t-1})^{0.8} \left[ \left( \pi_t / \pi_{SS} \right)^{1.5} y_t^{0.05} h_t^{0.2} \right]^{1-0.8} \left( y_t / y_{t-1} \right)^{0.2} \epsilon_t^{mp}$; where $h_t = h_{t-1} + g_t - g_t^f$
Policy Implications

Usual prescription of inflation stabilization works

- Nominal rigidities introduce the textbook inefficiency with long-run effects.
- Results hold in a set of recent endogenous growth DSGE models.

Alternate tool: hysteresis targeting

- If hysteresis elasticity $\eta$ high enough, reasons for policymakers to account for such effects.
- Need quantitative models to understand the normative implications.
Summary

- use 125 years of data to investigate persistent effects
- identification with quasi-natural experiment (trilemma) + RR instrument
- capital does not recover
- Evans (1992) critique for quarterly utilization -adjusted TFP
- model: aggressive inflation stabilization / hysteresis correction does not generate appreciable persistent effects
additional slides
### Home—base country links by era

<table>
<thead>
<tr>
<th>Base country interest rate</th>
<th>Pre-WW1</th>
<th>Interwar</th>
<th>Bretton Woods</th>
<th>Post-BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK (Gold standard/BW base)</td>
<td>All countries</td>
<td></td>
<td>Sterling bloc: AUS*</td>
<td></td>
</tr>
<tr>
<td>UK/USA/France composite (Gold standard base)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA (BW/Post-BW base)</td>
<td></td>
<td></td>
<td>All other countries</td>
<td>Dollar bloc: AUS, CAN, CHE, JPN, NOR</td>
</tr>
<tr>
<td>Germany (EMS/ERM/Eurozone base)</td>
<td></td>
<td></td>
<td></td>
<td>All other countries</td>
</tr>
</tbody>
</table>

* we treat AUS as moving to a dollar peg in 1967

[Back]
### Summary Statistics

**Average Peg:** 21 years (note: gold + Bretton Woods)
Obstfeld and Rogoff (1995): 5 yrs (developing countries)

Pegs are more open than floats

**Average Degree of Capital Openness:** \( \bar{k} \)

<table>
<thead>
<tr>
<th></th>
<th>Pegs ((q = 1))</th>
<th>Floats ((q = 0))</th>
<th>Pegs ((q = 1))</th>
<th>Floats ((q = 0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Years</td>
<td>0.87 (0.21)</td>
<td>0.70 (0.31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post WW2</td>
<td>0.76 (0.24)</td>
<td>0.74 (0.30)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
how often do countries switch exchange rate regime?
excluding wars

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>%</td>
<td>Frequency</td>
<td>%</td>
<td>Frequency</td>
<td>%</td>
</tr>
<tr>
<td>float to peg</td>
<td>19</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>no change</td>
<td>954</td>
<td>96</td>
<td>191</td>
<td>93</td>
<td>763</td>
<td>97</td>
</tr>
<tr>
<td>peg to float</td>
<td>19</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>992</td>
<td>100</td>
<td>205</td>
<td>100</td>
<td>787</td>
<td>100</td>
</tr>
</tbody>
</table>
first-stage iv evidence

\[ \Delta r_{i,t} = a_i + z_{i,t}b + x_{i,t}g + \eta_{i,t} \]

<table>
<thead>
<tr>
<th>Pegs ((q = 1))</th>
<th>All years</th>
<th>PreWW2</th>
<th>PostWW2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b)</td>
<td>0.52***</td>
<td>0.35**</td>
<td>0.56***</td>
</tr>
<tr>
<td>(t)-statistic</td>
<td>[8.62]</td>
<td>[2.05]</td>
<td>[8.97]</td>
</tr>
<tr>
<td>Obs</td>
<td>672</td>
<td>148</td>
<td>524</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Floats ((q = 0))</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(b)</td>
<td>0.16*</td>
<td>-0.09</td>
<td>0.19**</td>
</tr>
<tr>
<td>(t)-statistic</td>
<td>[1.92]</td>
<td>[-1.66]</td>
<td>[2.34]</td>
</tr>
<tr>
<td>Obs</td>
<td>316</td>
<td>57</td>
<td>259</td>
</tr>
</tbody>
</table>
identification with external instruments

assumptions

**relevance and exogeneity assumption:**

\[
\begin{align*}
L(\Delta r|x, z; q = 1) & \neq L(\Delta |x; q = 1) & \text{relevance} \\
L(y_j|x, \Delta r, z; q = 1) &= L(y_j|x, \Delta r; q = 1) & \text{for } j = 0, 1 & \text{exogeneity}
\end{align*}
\]

\[L(\Delta r|x, z)\] refers to linear projection of \(\Delta r\) on \(x\) and \(z\)

in IV identification depends on covariances only

also need **monotonicity** for \(z \rightarrow \Delta r: \frac{\partial E(\Delta r|x,z)}{\partial z} \geq 0\)
persistence of the shock

(a) Full sample

Short term real interest rate

(b) Post-WW2

Short term real interest rate
GDP and CPI

(a) Full sample

(b) Post-WW2

real GDP

price level

real GDP

price level

real GDP

price level

real GDP

price level

IV
OLS

Back
Responses of real GDP at years 0 to 10 (100 × log change from year 0 baseline).

<table>
<thead>
<tr>
<th>Year</th>
<th>(a) Full Sample</th>
<th>OLS-IV</th>
<th>(b) Post-WW2</th>
<th>OLS-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LP-OLS (1)</td>
<td>LP-IV (2)</td>
<td>p-value (3)</td>
<td>LP-OLS (4)</td>
</tr>
<tr>
<td>$h = 0$</td>
<td>0.08** (0.03)</td>
<td>-0.04 (0.09)</td>
<td>0.18</td>
<td>0.05** (0.02)</td>
</tr>
<tr>
<td>$h = 2$</td>
<td>-0.27 (0.16)</td>
<td>-1.63*** (0.39)</td>
<td>0.00</td>
<td>-0.21 (0.13)</td>
</tr>
<tr>
<td>$h = 4$</td>
<td>-0.11 (0.26)</td>
<td>-2.22*** (0.56)</td>
<td>0.00</td>
<td>-0.01 (0.21)</td>
</tr>
<tr>
<td>$h = 6$</td>
<td>-0.01 (0.29)</td>
<td>-2.55*** (0.67)</td>
<td>0.00</td>
<td>0.11 (0.22)</td>
</tr>
<tr>
<td>$h = 8$</td>
<td>-0.30 (0.29)</td>
<td>-3.47*** (0.85)</td>
<td>0.00</td>
<td>0.18 (0.22)</td>
</tr>
<tr>
<td>$h = 10$</td>
<td>-0.33 (0.36)</td>
<td>-4.20*** (1.15)</td>
<td>0.00</td>
<td>0.35 (0.27)</td>
</tr>
<tr>
<td>$h = 12$</td>
<td>-0.58 (0.42)</td>
<td>-6.77*** (2.08)</td>
<td>0.00</td>
<td>0.24 (0.33)</td>
</tr>
<tr>
<td>KP weak IV</td>
<td>68.34 (0.00)</td>
<td>69.18 (0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$H_0$: LATE = 0</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>607</td>
<td>607</td>
<td>482</td>
<td>482</td>
</tr>
</tbody>
</table>
full set of IRFs

- Real GDP per capita
- Real consumption per capita
- Real investment per capita
- Price level
- Short-term interest rate
- Long-term interest rate
- Real house prices
- Real stock prices
- Private credit/GDP
Responses of real GDP per capita at years 0 to 10 (100 × log change from year 0 baseline).

<table>
<thead>
<tr>
<th>Year</th>
<th>(a) Full Sample</th>
<th>OLS-IV</th>
<th>(b) Post-WW2</th>
<th>OLS-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LP-OLS (1)</td>
<td>LP-IV  (2)</td>
<td>p-value (3)</td>
<td>LP-OLS (4)</td>
</tr>
<tr>
<td>$h = 0$</td>
<td>0.07*** (0.03)</td>
<td>-0.07 (0.09)</td>
<td>0.09</td>
<td>0.04** (0.02)</td>
</tr>
<tr>
<td>$h = 2$</td>
<td>-0.28* (0.16)</td>
<td>-1.72*** (0.34)</td>
<td>0.00</td>
<td>-0.25* (0.13)</td>
</tr>
<tr>
<td>$h = 4$</td>
<td>-0.16 (0.26)</td>
<td>-2.53*** (0.50)</td>
<td>0.00</td>
<td>-0.08 (0.21)</td>
</tr>
<tr>
<td>$h = 6$</td>
<td>-0.06 (0.29)</td>
<td>-2.87*** (0.66)</td>
<td>0.00</td>
<td>0.02 (0.23)</td>
</tr>
<tr>
<td>$h = 8$</td>
<td>-0.36 (0.29)</td>
<td>-3.55*** (0.84)</td>
<td>0.00</td>
<td>0.10 (0.22)</td>
</tr>
<tr>
<td>$h = 10$</td>
<td>-0.40 (0.35)</td>
<td>-4.05*** (1.08)</td>
<td>0.00</td>
<td>0.26 (0.24)</td>
</tr>
</tbody>
</table>

KP weak IV 79.66 84.86
$H_0$: LATE = 0 0.00 0.00
Observations 607 607 482 482
synthetic control function: spillover correction
Conley, Hansen and Rossi (2012): “plausibly exogenous”
VAR-\(p\) vs LP: detecting long-run effects

Under invertibility, MA(\(\infty\)) and AR(\(\infty\)) estimate the same

\[
y_t = u_t + \theta_1 u_{t-1} + \theta u_{t-2} + \ldots \quad \iff \quad y_t = \Phi_1 y_{t-1} + \Phi_{t-2} y_{t-2} + \ldots + u_t
\]

i.e.

\[
y_t = (1 + \theta_1 L + \ldots)(1 - \Phi_1 L - \ldots)y_t
\]

In finite samples, estimate AR(\(\infty\)) with AR(\(p\)) \(\rightarrow\) MA terms beyond lag \(p\) based on the estimated \(p\) parameters

When \# of lags \(p\) small, likely introduce bias.
LP-VVARS

Generate data using the estimated IRFs from a MA(12)

Monte Carlo Simulation: AR(2) and AR(4) vs LP (2)

1000 Monte Carlo replications. Sample size: 150 obs
Dynamic multiplier
cumulative change in GDP to the area under the real interest rate path
(fiscal multiplier: Ramey and Zubairy 2018)
controls in levels vs differences

control for variables in levels instead of differences

Real GDP: controls in levels

Real GDP: controls in differences

Back
structural breaks in TFP

\[ y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \sum_{k=1}^{h-1} (D_{i,k,t} + D_{i,k,t+h}) + \Delta r_{i,t}\beta_{h} + x_{i,t}\gamma_{h} + \nu_{i,t+h}, \]

where \( D_{i,k,t+h} \) is country-specific dummy for TFP growth regime \( k \) (Bai-Perron) at horizon \( h = 0, ..., H - 1 \) and \( k \in (1, 5) \)
future global variables: exclusion restriction

\[ y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \Delta r_{i,t} \beta_h + x_{i,t} \gamma_h + G_{t+h} \hat{\gamma}_h + \nu_{i,t+h}, \quad \text{for } h = 0, \ldots, H - 1 \]

where \( G_{t+h} \) is global gdp growth at time \( t + h \)
Structural Breaks in GDP

\[ y_{i,t+h} = \alpha_{i,h} + \sum_{k=1}^{H-1} (D_{i,k,t} + D_{i,k,t+h}) + \Delta r_{i,t} \beta_{h} + x_{i,t} \gamma_{h} + \nu_{i,t+h}, \]

where \( D_{i,k,t+h} \) is country-specific dummy for GDP growth regime \( k \) at horizon \( h = 0, \ldots, H-1 \)
future base country variables: exclusion restriction

\[ y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \Delta r_{i,t} \beta_h + x_{i,t} \gamma_h + B_{b(i,t),t+h} \hat{\gamma}_h + \nu_{i,t+h}, \quad \text{for } h = 0, \ldots, H - 1 \]

\( B_{b(i,t),t+h} \) is gdp growth of base country \( b(i, t) \) at time \( t + h \)
open economy variables: exclusion restriction

\[ y_{i,t+h} - y_{i,t-1} = \alpha_i + \Delta r_{i,t} + x_{i,t} + (CA_{i,t+h}, XRUSD_{i,t+h}) \gamma_h + \nu_{i,t+h} \]

\( CA_{i,t+h} \): current account and \( XRUSD_{i,t+h} \): exchange rate with respect to USD
IRFs to a 100 bps trilemma shocks: 1890-2015

- **real GDP**
- **total hours**
- **capital stock**
- **raw TFP**

Graphs showing the impact of a 100 bps trilemma shock on real GDP, total hours, capital stock, and raw TFP over a 12-year period (1890-2015). The graphs show the percentage change over time, with blue lines representing IV estimates and red dashed lines representing OLS estimates. The shaded areas represent the confidence intervals.
IRFs: Post WW2 Sample

IRFs to a 100 bps trilemma shocks: 1948-2015

- real GDP
- total hours
- capital stock
- raw TFP

Year

Percent

IV

OLS
utilization adjustment

Partial equilibrium model of factor hoarding (Imbs 1999)

\[ Y_t = A_t (K_t u_t)^\alpha (L_t e_t)^{1-\alpha}; \quad \delta_t = \delta u_t^\phi; \quad \phi > 1 \]

**Firm:** \[ \max_{e_t, u_t, K_t} A_t (K_t u_t)^\alpha (L_t e_t)^{1-\alpha} - w(e_t) L_t - (r_t + \delta u_t^\phi) K_t \]

**HH:** \[ \max_{c_t, L_t, e_t} \sum_{t=0}^{\infty} \beta^t \left[ \ln c_t - \chi \frac{(e_t L_t)^{1+\nu}}{1+\nu} \right] \quad \text{s.t. budget constraint} \]

Reduces to a function of structural variables that can be measured directly (normalization: \( \bar{\varepsilon} = \bar{u} = 1 \))

\[ u_t = \left( \frac{Y_t}{K_t} \right)^\delta \frac{\delta}{r+\delta} ; \quad e_t = \left( \frac{Y_t}{C_t} \right)^{1+\nu} \frac{L}{L_t} \]
utilization adjustment
adjust for time-varying factor utilizations (Imbs 1999)

\[ TFP_t \equiv \frac{Y_t}{K_t^\alpha L_t^{1-\alpha}} = A_t \times u_t^\alpha e_t^{1-\alpha} \]
Trade

(a) Full sample

real total exports

(b) Post-WW2

real total exports

real total imports

real total imports

IV

OLS
quarterly data
1969Q2 - 2015Q4, US

Johannes Wieland’s webpage
Greenbook staff forecast errors

Fernald (2014)
Federal Reserve Bank of San Francisco
growth rate of output, capital, labor, labor quality, utilization adjusted
TFP,...
US: LP-IV + RR instruments different subsamples

(a) Full sample: 1969Q2: 2008Q3

(b) Sample: 1973Q2: 2008Q3
US: LP-IV + RR instruments different subsamples

(a) Sample: 1979Q3: 2008Q3

(b) Sample: 1984Q1: 2008Q3
US: LP-IV + RR instruments different subsamples

(a) Sample: 1969Q2: 2002Q4

(b) Sample: 1987Q1: 2008Q3
US: LP-IV + RR instruments different subsamples

(a) Full sample: 1969Q2: 2008Q3

(b) Sample: 1973Q2: 2008Q3
US: LP-IV + RR instruments different subsamples

(a) Sample: 1979Q3: 2008Q3

(b) Sample: 1984Q1: 2008Q3
US: LP-IV + RR instruments different subsamples

(a) Sample: 1969Q2: 2002Q4

(b) Sample: 1987Q1: 2008Q3
comparison of policy rules

$\eta = 0.18$, Taylor Rule:

$$1 + i_t = (1 + i_{t-1})^{0.8} \left[ \left( \frac{\pi_t}{\pi_{SS}} \right)^{\phi_\pi} \left( \frac{y_t}{y_{t-1}} \right)^{0.05} \right]^{1-0.8} \left( \frac{y_t}{y_{t-1}} \right)^{0.2} \epsilon_t^{mp}$$