Exchange Rates and Uncovered Interest Differentials: The Role of Permanent Monetary Shocks

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Motivation

- Existing empirical work assumes that monetary shocks come in only one flavor.

- However, recent work has shown that it is important to distinguish between transitory and permanent monetary disturbances. Permanent monetary policy shocks, i.e., shocks to long-run inflation expectations, have been shown to be at least as important as transitory monetary policy shocks for explaining the dynamics of changes in output, inflation, and the nominal interest rate in the United States.

- Motivated by these findings, the present paper estimates the effects of monetary policy shocks on exchange rates within an empirical framework that distinguishes transitory from permanent monetary shocks.

This paper finds that:

- permanent monetary shocks explain the majority of short-run movements in nominal exchange rates.

- there is no exchange-rate overshooting in response to monetary shocks, suggesting that existing overshooting results may be the consequence of confounding permanent and transitory impulses.

- transitory tightenings cause deviations from uncovered interest-rate parity in favor of domestic assets, whereas permanent tightenings cause deviations in favor of foreign assets.

Selected Previous Related Literature

Dornbusch (1976): Exchange Rate Overshooting

$$\text{UIP:} \qquad (1+i_t) = (1+i_t^*)\left(\frac{S_{t+1}}{S_t}\right)$$

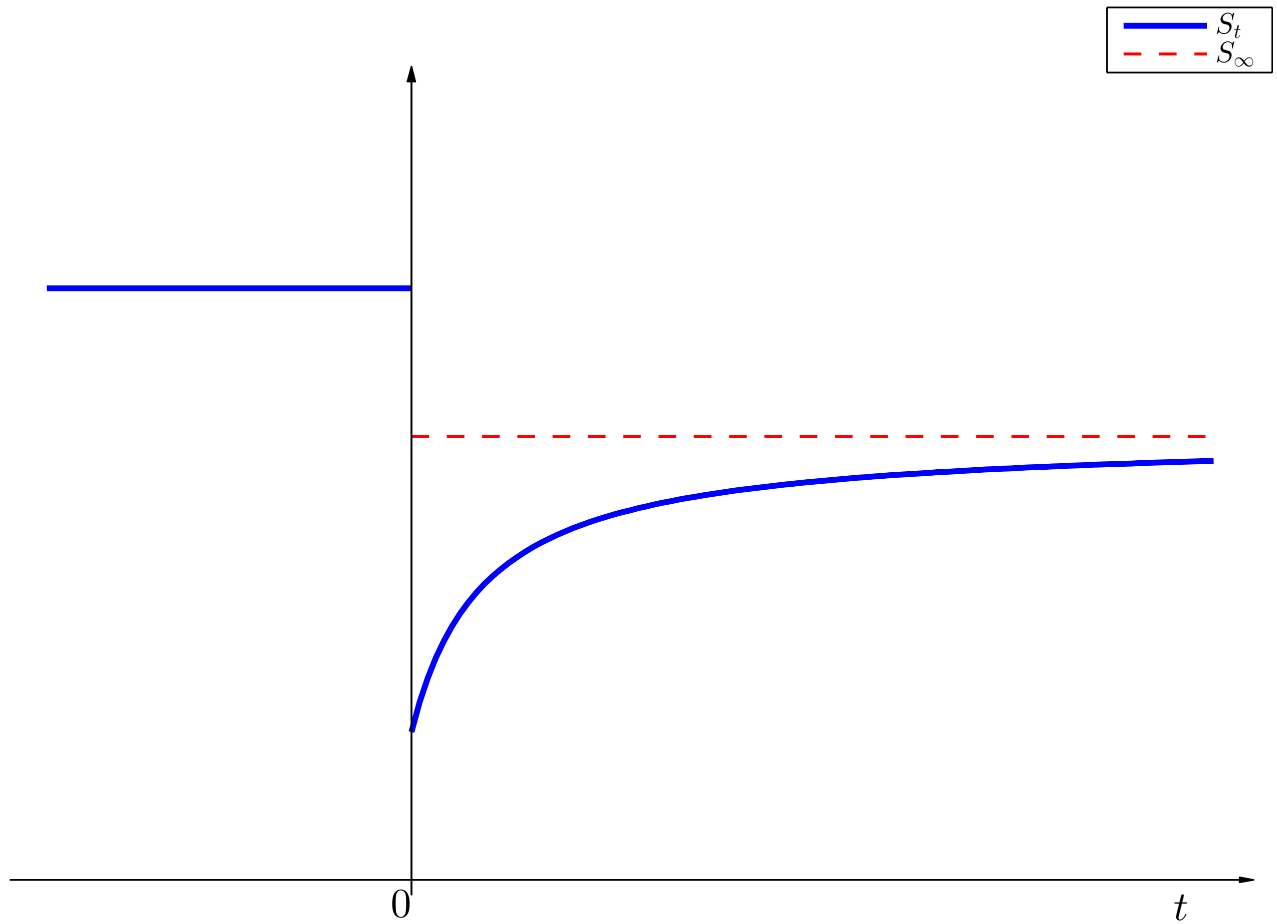
$$\text{Money demand:} \qquad \frac{M_t}{P_t} = L(\underset{-}{i_t}, Y)$$

Long-run neutrality: as $t \to \infty \quad P_t = S_t P_t^*$

i_t = domestic nominal interest rate
i_t^* = foreign nominal interest rate
S_t = exchange rate (domestic-currency price of foreign currency)
M_t = domestic money supply
P_t = domestic price level.

Experiment: A contractionary monetary shock, $M_0 \downarrow$.

Dornbusch's Overshooting Result



The figure depicts the dynamics of the nominal exchange rate, S_t, in response to a reduction in the money supply in period 0, as predicted by Dornbusch's overshooting model. S_t is defined as the domestic-currency price of foreign currency.

Empirical Evidence on Exchange Rate Overshooting

Tests of the overshooting result and UIP:

1.) A monetary tightening causes an appreciation of the domestic currency with an overshooting effect either on impact (Kim and Roubini, 2000; Faust and Rogers, 2003; Faust Rogers, Swanson, and Wright, 2003; Bjørnland, 2009; Kim, Moon, and Velasco, 2017) or with a delay (Eichenbaum and Evans, 1995; Scholl and Uhlig, 2008). Main difference across these papers is how the monetary policy shock is identified.

2.) UIP, conditional on a monetary shock, fails, contradicting a key assumption of Dornbusch's model. Specifically, a domestic tightening generates excess returns on domestic assets.

Effects of Permanent Monetary Policy Shocks on Real Exchange Rates

An increase in the U.S. inflation target causes a temporary depreciation of the U.S. real exchange rate (De Michelis and Iacoviello, 2016).

Effects of Romer and Romer Shocks on Exchange Rates

Eichenbaum and Evans (1995, Fig. IV) and Hettig, Müller, and Wolf (2018) find that the exchange rate overshooting result, immediate or delayed, is not robust to this type of identification scheme.

This paper

Empirical Model

The model is an open-economy extension of Uribe (2018). Let

$$\begin{bmatrix} y_t \\ \pi_t \\ i_t \\ \epsilon_t \\ i_t^* \end{bmatrix} = \begin{bmatrix} \text{log of real US output} \\ \text{US inflation} \\ \text{US nominal interest rate} \\ \text{change in dollar exchange rate} \\ \text{foreign nominal interest rate} \end{bmatrix}$$

The cyclical components of these variables are assumed to be stationary (though unobservable):

$$\begin{bmatrix} \widehat{y}_t \\ \widehat{\pi}_t \\ \widehat{i}_t \\ \widehat{\epsilon}_t \\ \widehat{i}_t^* \end{bmatrix} \equiv \begin{bmatrix} y_t - X_t \\ \pi_t - X_t^m \\ i_t - X_t^m \\ \epsilon_t - X_t^m + X_t^{m*} \\ i_t^* - X_t^{m*} \end{bmatrix}.$$

where X_t = permanent nonmonetary shock (output trend); X_t^m = permanent monetary shock; X_t^{m*} = foreign permanent monetary shock.

The cyclical components follow an AR process

$$\begin{bmatrix} \widehat{y}_t \\ \widehat{\pi}_t \\ \widehat{i}_t \\ \widehat{\epsilon}_t \\ \widehat{i}^*_t \end{bmatrix} = B(L) \begin{bmatrix} \widehat{y}_{t-1} \\ \widehat{\pi}_{t-1} \\ \widehat{i}_{t-1} \\ \widehat{\epsilon}_{t-1} \\ \widehat{i}^*_{t-1} \end{bmatrix} + C \begin{bmatrix} \Delta X^m_t \\ z^m_t \\ \Delta X_t \\ z_t \\ \Delta X^{m*}_t \end{bmatrix}$$

$$\begin{bmatrix} \Delta X^m_t \\ z^m_t \\ \Delta X_t \\ z_t \\ \Delta X^{m*}_t \end{bmatrix} = \rho \begin{bmatrix} \Delta X^m_{t-1} \\ z^m_{t-1} \\ \Delta X_{t-1} \\ z_{t-1} \\ \Delta X^{m*}_{t-1} \end{bmatrix} + \psi \begin{bmatrix} \nu^1_t \\ \nu^2_t \\ \nu^3_t \\ \nu^4_t \\ \nu^5_t \end{bmatrix},$$

where X^m_t = permanent monetary shock; z^m_t = transitory monetary shock; X_t = permanent nonmonetary shock; z_t = transitory non-monetary shock; and X^{m*}_t = foreign permanent monetary shock. Innovations $\nu^i_t \sim$ iid $\mathcal{N}(0,1)$, for $i = 1, \ldots, 5$, ρ and ψ are diagonal 5×5 matrices. (To simplify the exposition constants are omitted.)

5 Observables and corresponding observation equations

(1) Δy_t, output growth rate.

(2) $r_t \equiv i_t - \pi_t$, interest-rate-inflation differential.

(3) Δi_t, time difference of domestic nominal rate.

(4) $\Delta \epsilon_t$, time difference of devaluation rate.

(5) Δi_t^*, time difference of foreign nominal rate.

We then have the following **observation equations**:

$$\begin{aligned}
\Delta y_t &= \widehat{y}_t - \widehat{y}_{t-1} + \Delta X_t \\
r_t &= \widehat{i}_t - \widehat{\pi}_t \\
\Delta i_t &= \widehat{i}_t - \widehat{i}_{t-1} + \Delta X_t^m \\
\Delta \epsilon_t &= \widehat{\epsilon}_t - \widehat{\epsilon}_{t-1} + \Delta X_t^m - \Delta X_t^{m*} \\
\Delta i_t^* &= \widehat{i}_t^* - \widehat{i}_{t-1}^* + \Delta X_t^{m*}
\end{aligned} \tag{1}$$

Identification Assumptions

1. Output (y_t) is cointegrated with the permanent nonmonetary shock (X_t).

2. Inflation (π_t) and the nominal interest rate (i_t) are cointegrated with the permanent monetary shock (X_t^m).

3. The foreign nominal interest rate (i_t^*) is cointegrated with the foreign permanent monetary shock (X_t^{m*}).

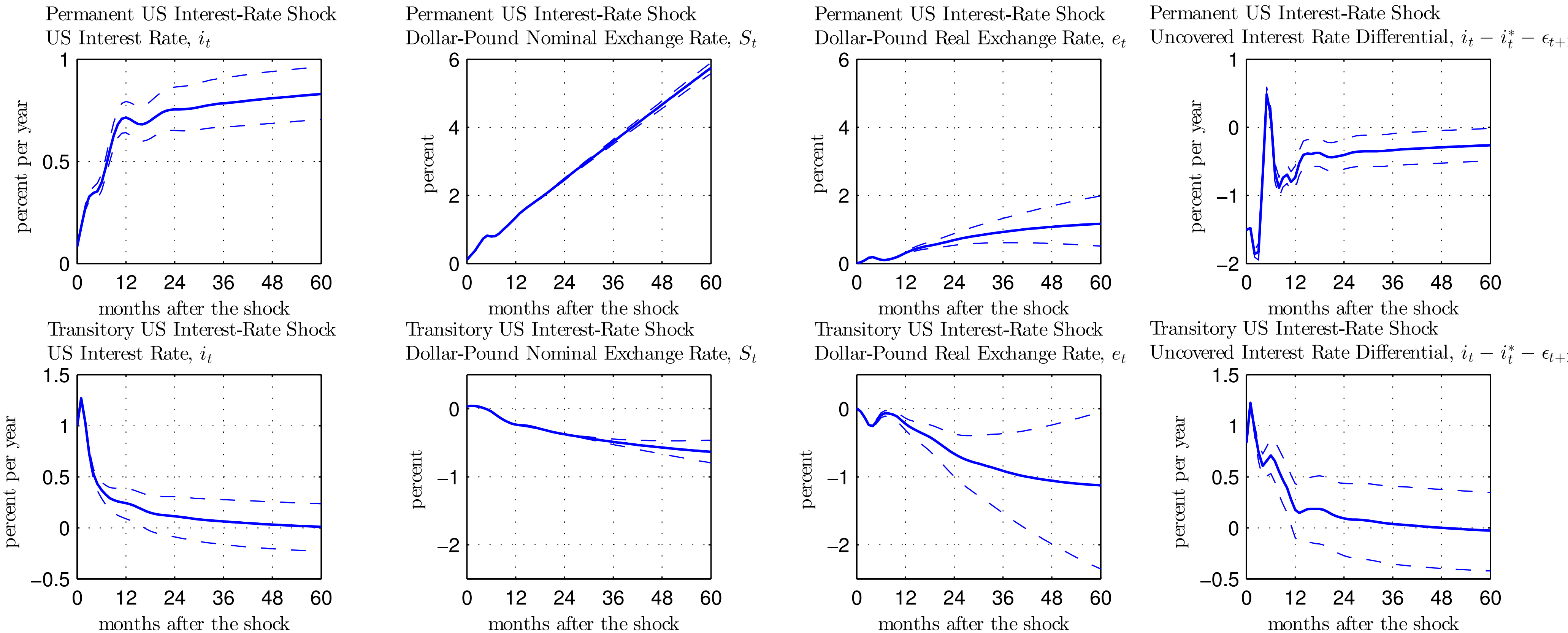
4. The depreciation rate (ϵ_t) is cointegrated with ($X_t^m - X_t^{m*}$).

5. A transitory monetary shock that increases the interest rate ($z_t^m \uparrow$) has a nonpositive impact effect on output and inflation: $C_{12}, C_{22} \leq 0$. (Implemented by imposing restrictions on prior distribution.)

At the posterior mean, we find that the parameters are identifiable based on the Iskrev (2010) test.

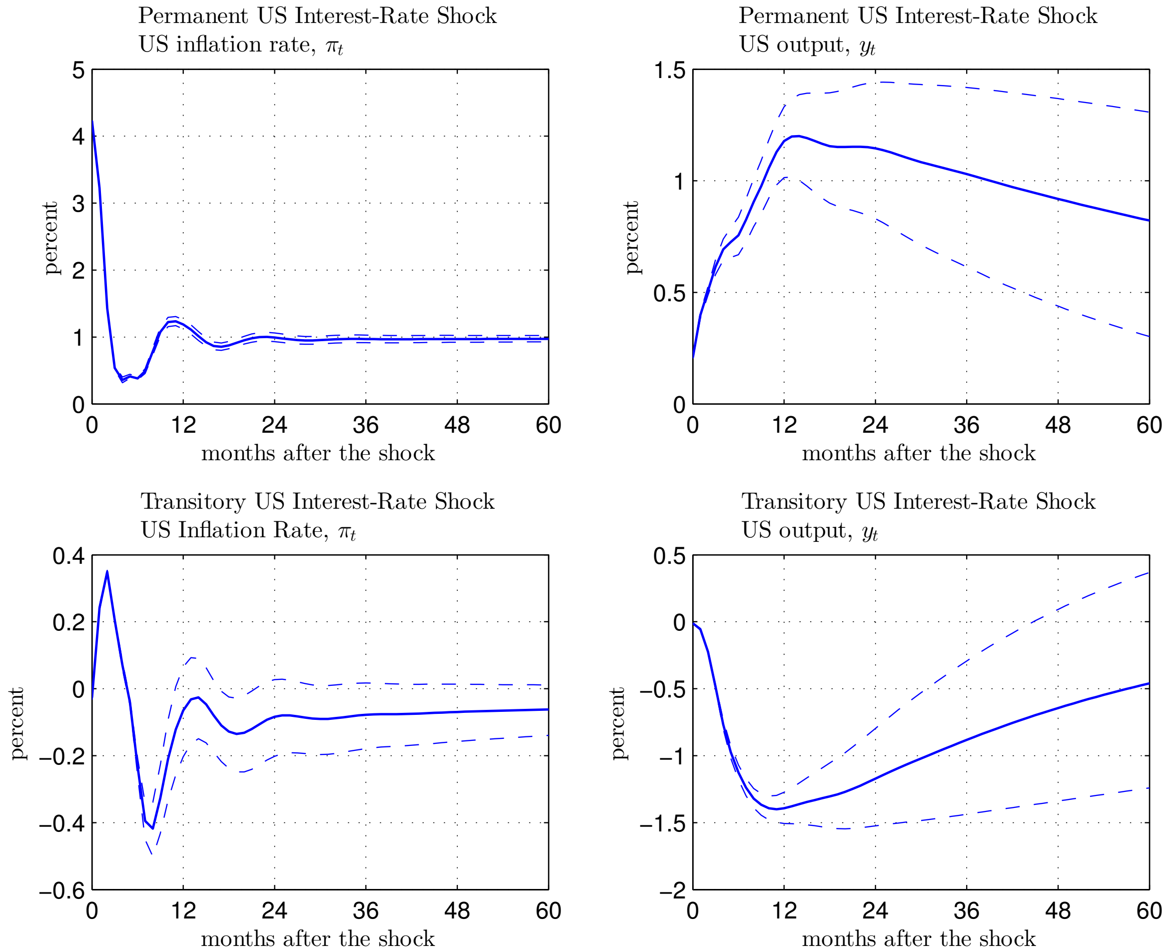
United States – United Kingdom

Impulse Responses to Permanent and Transitory U.S. Monetary Shocks Foreign country is the United Kingdom



Solid lines: posterior mean estimates from MCMC chain of length 1 million.
Broken lines: asymmetric 95-percent Sims-Zha error bands.

Impulse Responses of U.S. Inflation and Output to Permanent and Transitory U.S. Monetary Shocks: United Kingdom



The Importance of Permanent Monetary Shocks for Exchange Rates

Forecast Error Variance Decomposition at Horizon 12 months. US-UK pair

	Δy_t	π_t	i_t	$\ln S_t$	$\ln e_t$	i_t^*	UID
Permanent Monetary Shock, X_t^m	0.10	$\boxed{0.83}$	$\boxed{0.23}$	$\boxed{0.23}$	0.00	0.01	0.05
Transitory Monetary Shock, z_t^m	0.08	0.01	0.23	0.00	0.00	0.01	0.01
Permanent Nonmonetary Shock, X_t	0.26	0.07	0.47	0.50	0.98	0.06	0.93
Transitory Nonmonetary Shock, z_t	0.52	0.05	0.00	0.00	0.01	0.00	0.00
Permanent For. Mon. Shock, X_t^{m*}	0.03	0.04	0.06	$\boxed{0.26}$	0.00	0.92	0.01

Notes. Δy_t, U.S. output growth; π_t, U.S. inflation; i_t, the Federal Funds rate; $\ln S_t$, dollar-pound nominal exchange rate; $\ln e_t$, the dollar-pound real exchange rate; i_t^*, U.K. nominal interest rate; UID$= i_t - i_t^* - \epsilon_{t+1}$, uncovered interest rate differential; $\epsilon_t \equiv \ln(S_t/S_{t-1})$, dollar devaluation rate.

Conclusions

The innovation of the present paper is to allow for permanent and transitory monetary shocks. Estimation on monthly post-Bretton-Woods data from the United States, the United Kingdom, and Japan shows that:

- permanent monetary shocks explain the majority of short-run movements in nominal exchange rates.

- there is no exchange-rate overshooting, either of the immediate or delayed type, in response to monetary shocks, suggesting that existing overshooting results may be the consequence of confounding permanent and transitory impulses.

- transitory tightenings cause deviations from uncovered interest-rate parity in favor of domestic assets, whereas permanent tightenings cause deviations in favor of foreign assets.

Extras

Measurement Errors

$$o_t = \begin{bmatrix} \Delta y_t \\ r_t \\ \Delta i_t \\ \Delta \epsilon_t \\ \Delta i_t^* \end{bmatrix} + \mu_t \tag{2}$$

where μ_t is a 5-by-1 vector of measurement errors distributed i.i.d. $N(\emptyset, R)$, with R diagonal.

Estimation

Let

$$\widehat{Y}_t \equiv \begin{bmatrix} \widehat{y}_t \\ \widehat{\pi}_t \\ \widehat{i}_t \\ \widehat{\epsilon}_t \\ \widehat{i}^*_t \end{bmatrix}; \quad u_t \equiv \begin{bmatrix} \Delta X^m_t \\ z^m_t \\ \Delta X_t \\ z_t \\ \Delta X^{m*}_t \end{bmatrix}; \quad \nu_t \equiv \begin{bmatrix} \nu^1_t \\ \nu^2_t \\ \nu^3_t \\ \nu^4_t \\ \nu^5_t \end{bmatrix}$$

Assuming a lag length of L months, the empirical model can be written as

$$\widehat{Y}_t = \sum_{i=1}^{L} B_i \widehat{Y}_{t-i} + C u_t \tag{3}$$

$$u_t = \rho u_{t-1} + \psi \nu_t \tag{4}$$

Estimation: State Space Form

Let

$$\xi_t \equiv \begin{bmatrix} \widehat{Y}_t \\ \widehat{Y}_{t-1} \\ \vdots \\ \widehat{Y}_{t-L+1} \\ u_t \end{bmatrix}$$

Then the system composed of equations (1), (2), (3), and (4) can be written as

$$\xi_{t+1} = F\xi_t + P\nu_{t+1}$$

$$o_t = H'\xi_t + \mu_t$$

We wish to estimate the matrices F, P, and H, which are known functions of the primitive matrices B_i, $i = 1, \ldots L$, C, ρ, ψ, and R.
The state vector ξ_t is latent, and the vector o_t is observable.
The likelihood of the data can be readily obtained, for example, via the Kalman filter.
We estimate the model using Bayesian techniques.

Prior Distributions

Parameter	Distribution	Mean.	Std. Dev.
Main diagonal elements of B_1	Normal	0.95	0.5
All other elements of B_i, $i = 1, \ldots, L$	Normal	0	0.25
C_{21}, C_{31}, C_{55}	Normal	-1	1
$-C_{12}, -C_{22}$	Gamma	1	1
All other estimated elements of C	Normal	0	1
ρ_{ii}, $i = 1, 2, 3, 5$	Beta	0.3	0.2
ρ_{44}	Beta	0.7	0.2
ψ_{ii}, $i = 1, \ldots, 5$	Gamma	1	1
R_{ii}	Uniform$\left[0, \frac{\text{var}(o_t)}{10}\right]$	$\frac{\text{var}(o_t)}{10\times 2}$	$\frac{\text{var}(o_t)}{10\times\sqrt{12}}$
Mean of o_t	Normal	mean(o_t)	$\sqrt{\frac{\text{var}(o_t)}{T}}$

Notes. The lag length, L, is assumed to be 6 months. The sample length, T, equals 513 months.

Variant: The Real Exchange Rate

To estimate the effects of temporary and permanent monetary shocks on the **real exchange rate**, e_t,

$$e_t = \ln \left(\frac{S_t P_t^*}{P_t} \right),$$

we replace the nominal depreciation rate,

$$\epsilon_t = \ln S_t - \ln S_{t-1},$$

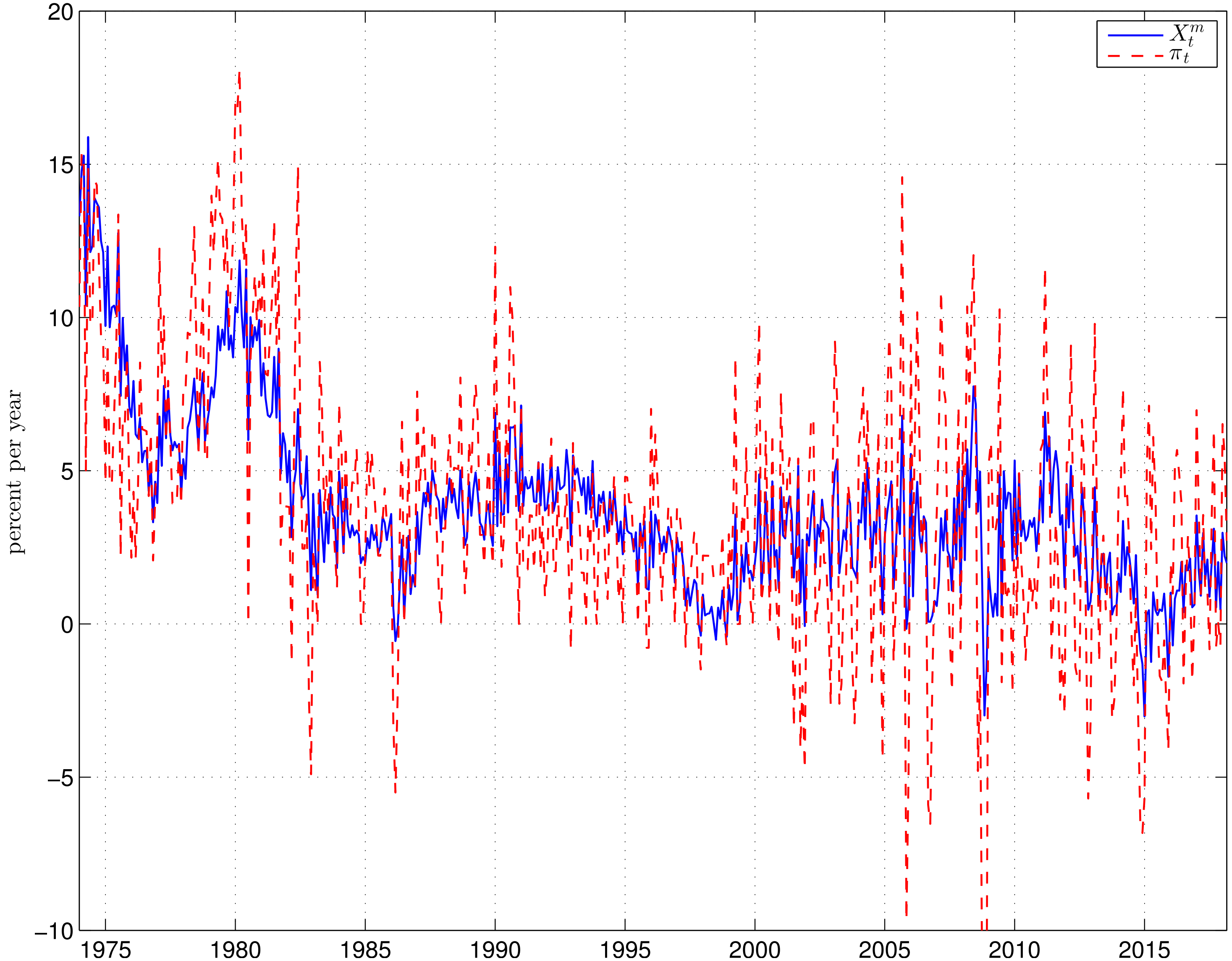
by the real depreciation rate,

$$\epsilon_t^r = e_t - e_{t-1}.$$

The Data

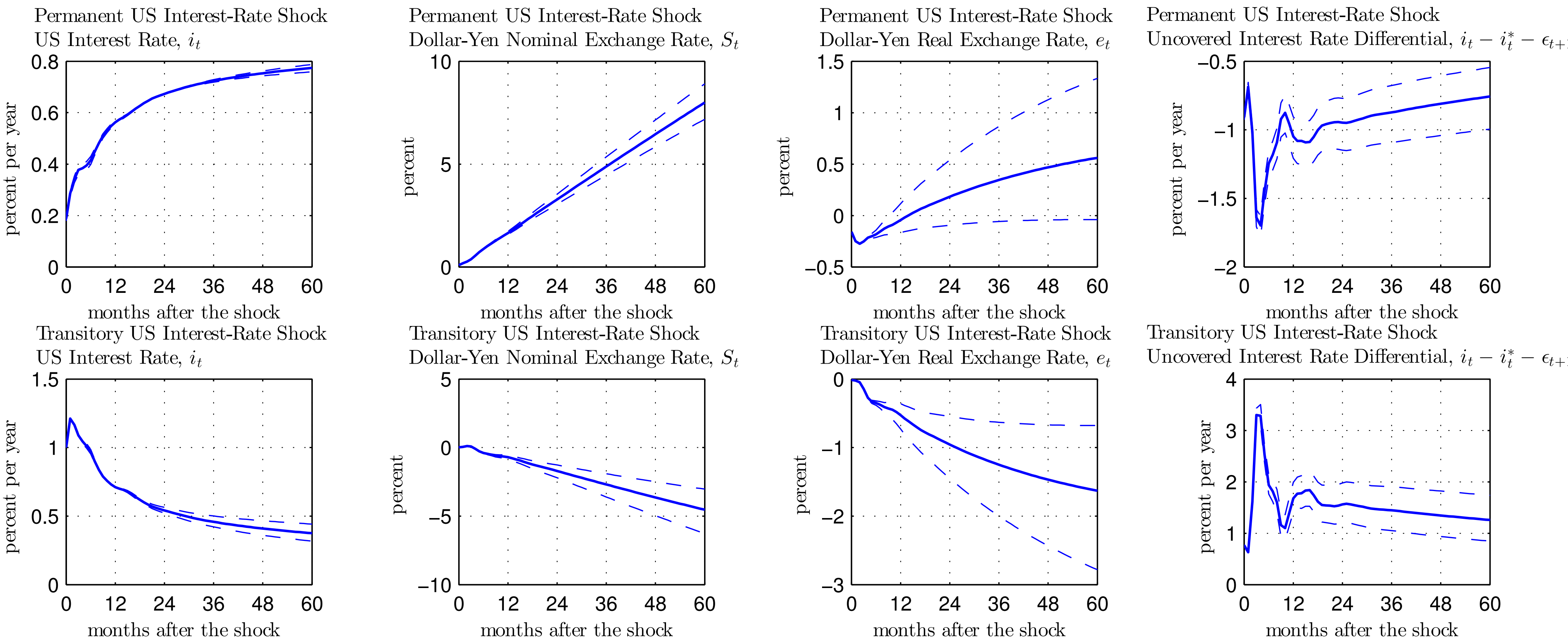
- Domestic country: U.S.; Foreign country: U.K. or Japan
- Monthly: 1974:1–2018:3.
- y_t = U.S. industrial production (Source: OECD MEI)
- P_t = U.S. CPI index (Source: OECD MEI)
- i_t = Federal Funds rate (Source: FRB)
- S_t = \$–£ or \$–¥ nominal exchange rate (Source: FRED)
- i_t^* = Official bank rate (Source: BOE) or Call rate (Source: BOJ)
- P_t^* = U.K. or JP CPI index (Source: OECD MEI)

U.S. Inflation and Its Permanent Component



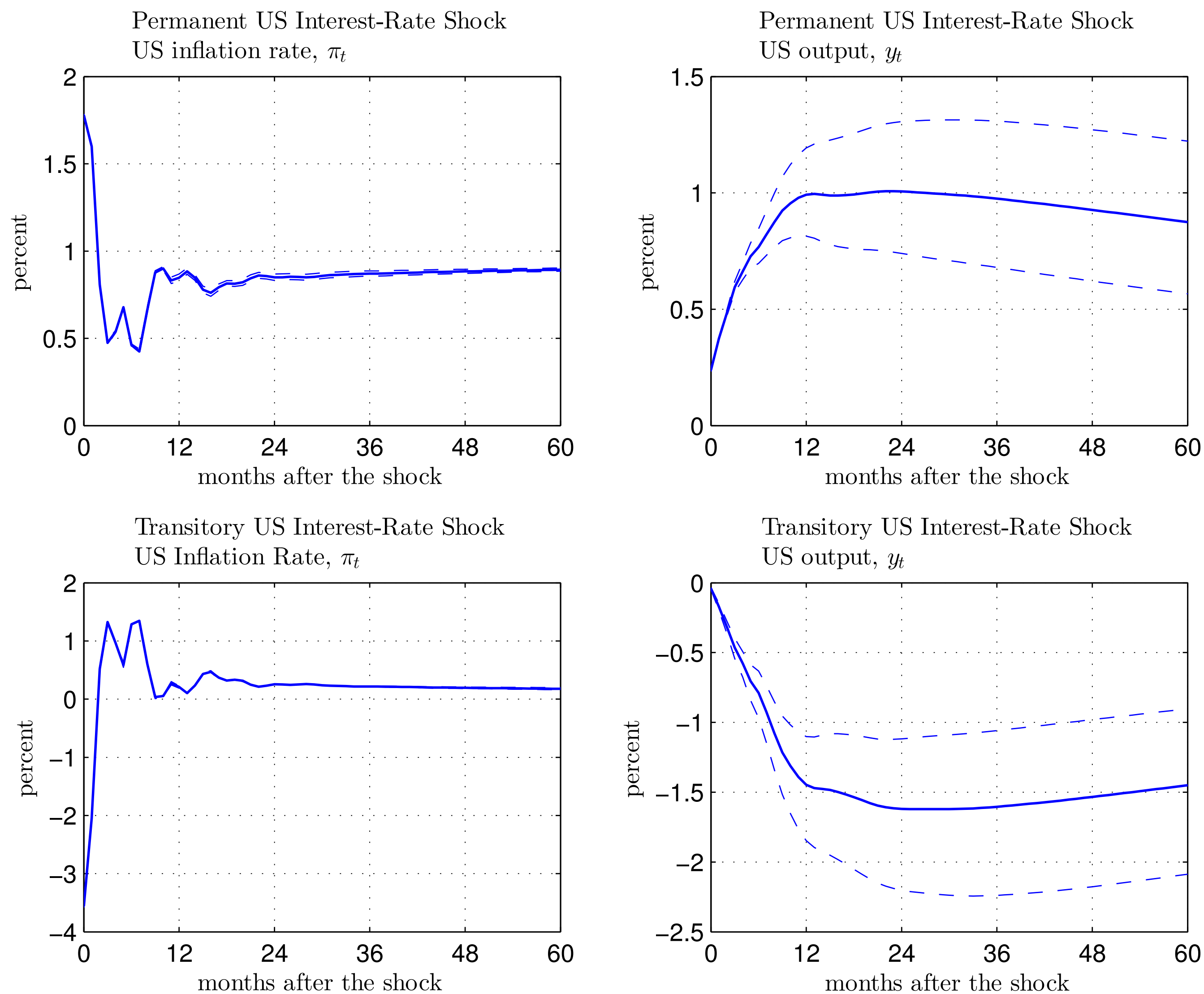
JAPAN

Impulse Responses to Permanent and Transitory U.S. Monetary Shocks: Foreign country is Japan



Solid lines: posterior mean estimates from MCMC chain of length 1 million.
Broken lines: asymmetric 95-percent Sims-Zha error bands.

Impulse Responses of U.S. Inflation and Output to Permanent and Transitory U.S. Monetary Shocks: Foreign country is Japan



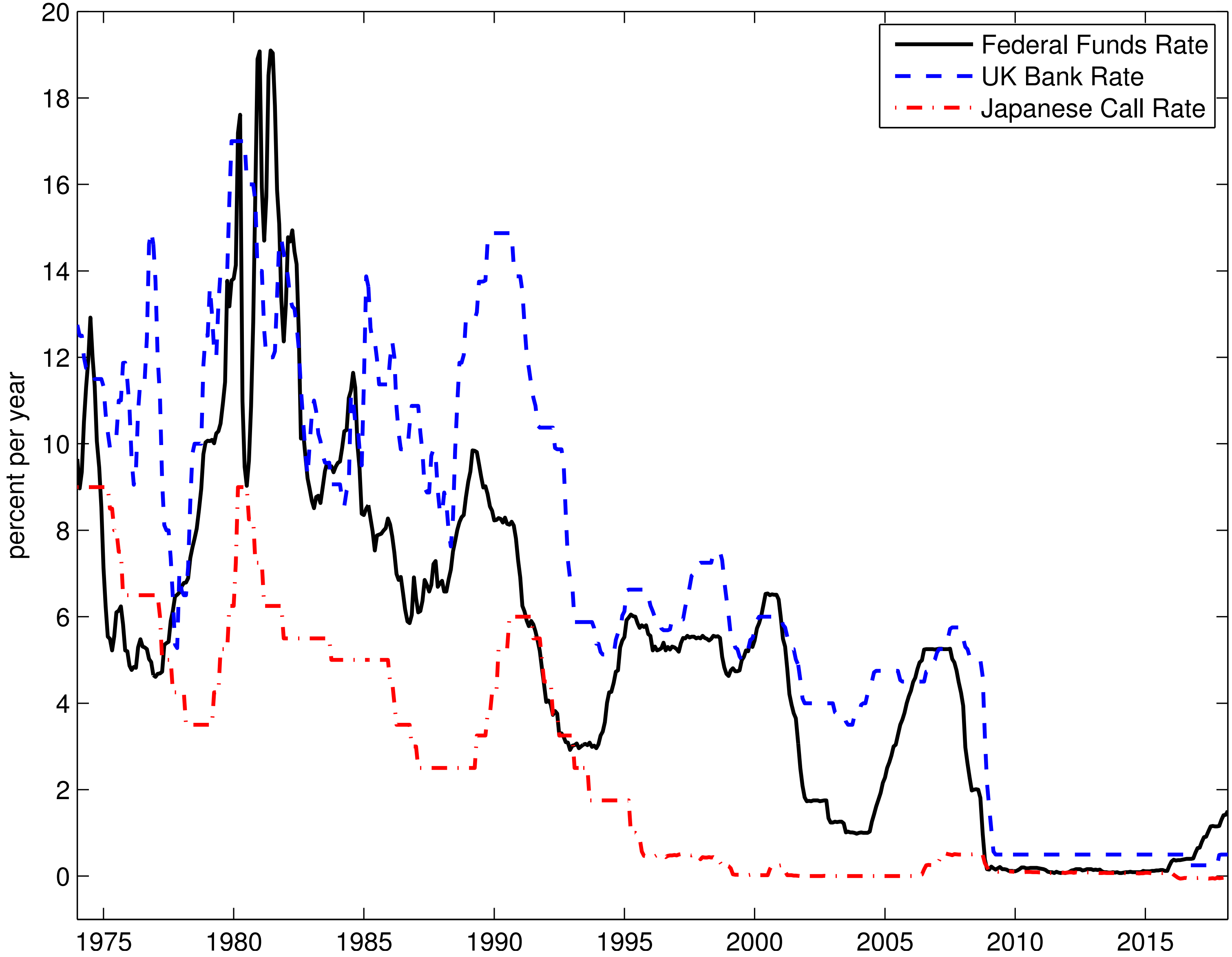
The Importance of Permanent Monetary Shocks for Exchange Rates

Forecast Error Variance Decomposition at Horizon 36 months. US-Japan pair

	Δy_t	π_t	i_t	$\ln S_t$	$\ln e_t$	i_t^*	UID
Permanent M Shock, X_t^m	0.26	$\boxed{0.82}$	$\boxed{0.57}$	$\boxed{0.50}$	0.01	0.00	0.12
Transitory M Shock, z_t^m	0.04	0.07	0.08	0.01	0.01	0.00	0.03
Permanent NonM Shock, X_t	0.18	0.07	0.33	0.35	0.98	0.06	0.81
Transitory NonM Shock, z_t	0.44	0.04	0.01	0.02	0.00	0.00	0.01
Permanent Foreign M Shock, X_t^{m*}	0.08	0.01	0.02	$\boxed{0.12}$	0.00	0.93	0.03

Notes. Uncovered interest rate differential (UID)$= i_t - i_t^* - \epsilon_{t+1}$. Δy_t, U.S. output growth; π_t, U.S. inflation; i_t, the Federal Funds rate; $\ln S_t$, dollar-yen nominal exchange rate; $\ln e_t$, the dollar-yen real exchange rate; i_t^*, Japanese nominal interest rate; $\epsilon_t \equiv \ln(S_t/S_{t-1})$, devaluation rate.

Cointegrated Monetary Policies?



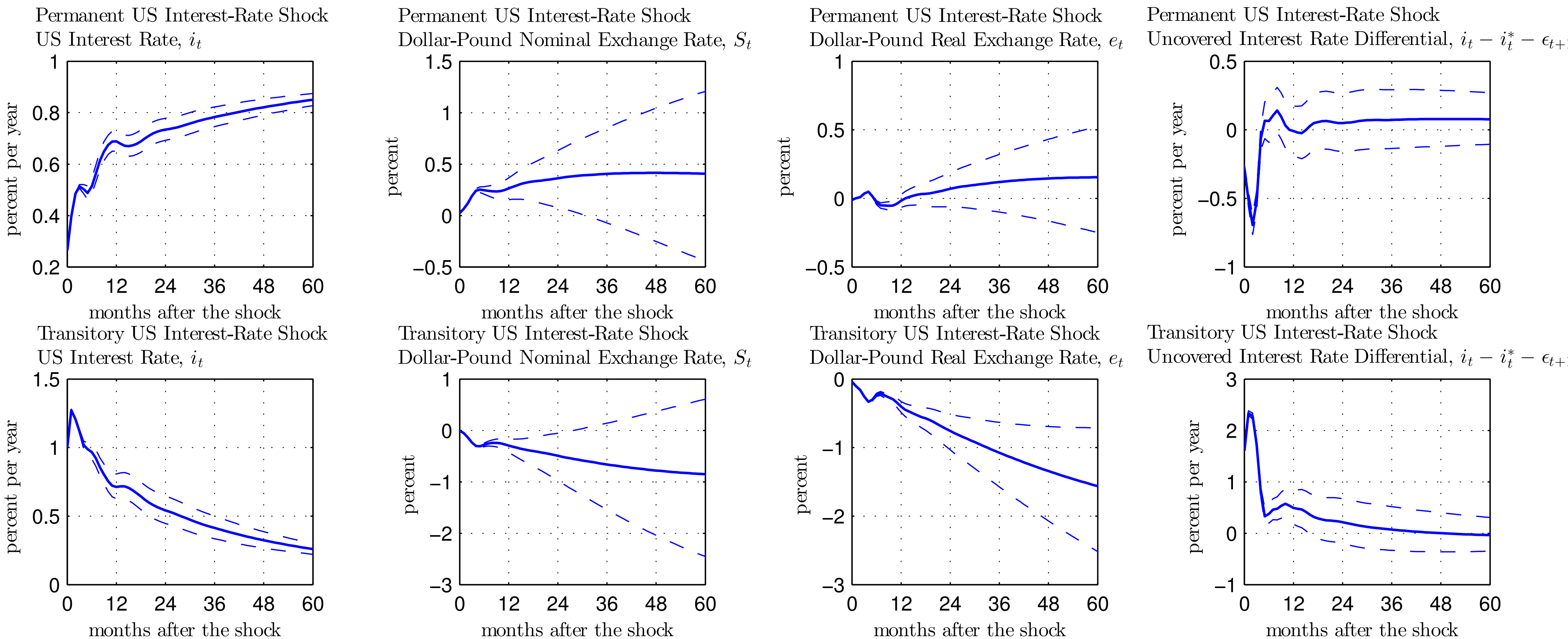
Model with only one permanent monetary shock

$$\begin{bmatrix} \Delta X_{t+1}^m \\ z_{t+1}^m \\ \Delta X_{t+1} \\ z_{t+1} \\ X_{t+1}^m - X_{t+1}^{m*} \end{bmatrix} = \rho \begin{bmatrix} \Delta X_t^m \\ z_t^m \\ \Delta X_t \\ z_t \\ X_t^m - X_t^{m*} \end{bmatrix} + \psi \begin{bmatrix} \nu_{t+1}^1 \\ \nu_{t+1}^2 \\ \nu_{t+1}^3 \\ \nu_{t+1}^4 \\ \nu_{t+1}^5 \end{bmatrix}$$

The assumption that $X_t^m - X_t^{m*}$ is stationary induces stationarity in both the interest rate differential, $i_t - i_t^*$, and the devaluation rate, $\epsilon_t \equiv \ln(S_t/S_{t-1})$. $\rightarrow$ We can include ϵ_t as an observable.

$$o_t = \begin{bmatrix} \Delta y_t \\ r_t \\ \Delta i_t \\ \epsilon_t \\ i_t - i_t^* \end{bmatrix} + \mu_t$$

Impulse Responses to Permanent and Transitory U.S. Monetary Shocks Under Cointegrated U.S. and U.K. Monetary Policies



Solid lines: posterior mean estimates from MCMC chain of length 1 million.
Broken lines: asymmetric 95-percent Sims-Zha error bands.

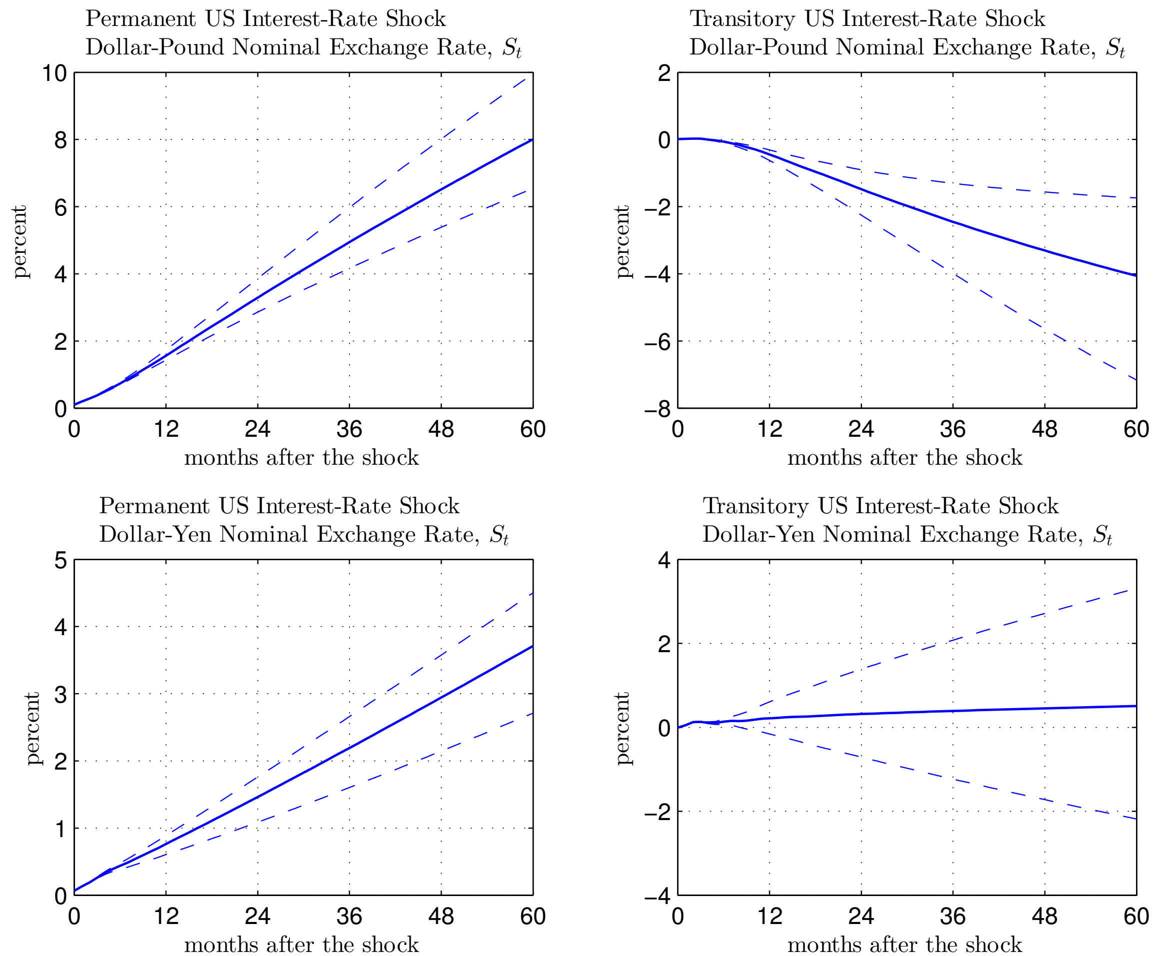
Excluding the Post-Volcker Era

• Kim, Moon, and Velasco (JPE, 2017) argue that delayed overshooting is circumscribed to the pre-1987 period. (Instantaneous overshooting is a feature of the post Volcker sample.)

• The present paper, by contrast, argues that once one allows for both transitory and permanent monetary shocks, the overshooting effect, instantaneous or delayed, disappears altogether.

• The next figure shows that our finding of no overshooting is robust to truncating the sample in December of 1987, the end of the Volcker era.

No Exchange Rate Overshooting Pre 1987



Baseline model estimated on the 1974:1-1987:12 sample.

The Importance of Permanent Monetary Shocks for Exchange Rates

Forecast Error Variance Decomposition at Horizon 36 months. US-UK pair

	Δy_t	π_t	i_t	$\ln S_t$	$\ln e_t$	i_t^*	UID
Permanent M Shock, X_t^m	0.10	$\boxed{0.84}$	$\boxed{0.35}$	$\boxed{0.37}$	0.07	0.01	0.05
Transitory M Shock, z_t^m	0.08	0.01	0.06	0.00	0.01	0.01	0.01
Permanent NonM Shock, X_t	0.27	0.06	0.51	0.05	0.71	0.05	0.90
Transitory NonM Shock, z_t	0.50	0.03	0.00	0.00	0.20	0.00	0.00
Permanent Foreign M Shock, X_t^{m*}	0.05	0.05	0.08	$\boxed{0.58}$	0.00	0.94	0.04

Notes. Δy_t, U.S. output growth; π_t, U.S. inflation; i_t, the Federal Funds rate; $\ln S_t$, dollar-pound nominal exchange rate; $\ln e_t$, the dollar-pound real exchange rate; i_t^*, U.K. nominal interest rate; UID$= i_t - i_t^* - \epsilon_{t+1}$, uncovered interest rate differential; $\epsilon_t \equiv \ln(S_t/S_{t-1})$, dollar devaluation rate.

Forecast Error Variance Decomposition at Horizons between 12 and 48 months: United Kingdom

	Δy_t	π_t	i_t	$\ln S_t$	$\ln e_t$	i_t^*	uid
Permanent Monetary Shock, X_t^m							
Horizon 12 months	0.10	0.83	0.23	0.23	0.00	0.01	0.05
Horizon 24 months	0.10	0.83	0.31	0.36	0.03	0.01	0.05
Horizon 36 months	0.10	0.84	0.35	0.37	0.07	0.01	0.05
Horizon 48 months	0.10	0.85	0.37	0.36	0.10	0.00	0.05
Transitory Monetary Shock, z_t^m							
Horizon 12 months	0.08	0.01	0.23	0.00	0.00	0.01	0.01
Horizon 24 months	0.08	0.01	0.10	0.00	0.00	0.01	0.01
Horizon 36 months	0.08	0.01	0.06	0.00	0.01	0.01	0.01
Horizon 48 months	0.08	0.01	0.05	0.00	0.02	0.01	0.01
Permanent Nonmonetary Shock, X_t							
Horizon 12 months	0.26	0.07	0.47	0.50	0.98	0.06	0.93
Horizon 24 months	0.27	0.07	0.51	0.14	0.88	0.05	0.91
Horizon 36 months	0.27	0.06	0.51	0.05	0.71	0.05	0.90
Horizon 48 months	0.27	0.06	0.49	0.03	0.59	0.04	0.89
Transitory Nonmonetary Shock, z_t							
Horizon 12 months	0.52	0.05	0.00	0.00	0.01	0.00	0.00
Horizon 24 months	0.51	0.04	0.00	0.00	0.09	0.00	0.00
Horizon 36 months	0.50	0.03	0.00	0.00	0.20	0.00	0.00
Horizon 48 months	0.50	0.03	0.00	0.00	0.28	0.00	0.00
Permanent Foreign Monetary Shock, X_t^{m*}							
Horizon 12 months	0.03	0.04	0.06	0.26	0.00	0.92	0.01
Horizon 24 months	0.04	0.05	0.07	0.50	0.00	0.93	0.03
Horizon 36 months	0.05	0.05	0.08	0.58	0.00	0.94	0.04
Horizon 48 months	0.05	0.05	0.09	0.61	0.00	0.95	0.05

Note. uid$= i_t - i_t^* - \epsilon_{t+1}$.

Forecast Error Variance Decomposition at Horizons between 12 and 48 months: Japan

	Δy_t	π_t	i_t	$\ln S_t$	$\ln e_t$	i^*_t	uid
Permanent Monetary Shock, X^m_t							
Horizon 12 months	0.28	0.73	0.55	0.39	0.01	0.01	0.11
Horizon 24 months	0.26	0.80	0.58	0.54	0.01	0.00	0.12
Horizon 36 months	0.26	0.82	0.57	0.50	0.01	0.00	0.12
Horizon 48 months	0.26	0.83	0.56	0.48	0.02	0.00	0.12
Transitory Monetary Shock, z^m_t							
Horizon 12 months	0.04	0.15	0.26	0.01	0.00	0.01	0.03
Horizon 24 months	0.04	0.10	0.13	0.01	0.00	0.00	0.03
Horizon 36 months	0.04	0.07	0.08	0.01	0.01	0.00	0.03
Horizon 48 months	0.04	0.05	0.06	0.01	0.01	0.00	0.03
Permanent Nonmonetary Shock, X_t							
Horizon 12 months	0.13	0.03	0.12	0.51	0.99	0.12	0.84
Horizon 24 months	0.17	0.05	0.26	0.32	0.99	0.08	0.82
Horizon 36 months	0.18	0.07	0.33	0.35	0.98	0.06	0.81
Horizon 48 months	0.19	0.08	0.35	0.38	0.96	0.05	0.81
Transitory Nonmonetary Shock, z_t							
Horizon 12 months	0.48	0.08	0.00	0.01	0.00	0.01	0.01
Horizon 24 months	0.45	0.05	0.00	0.02	0.00	0.00	0.01
Horizon 36 months	0.44	0.04	0.01	0.02	0.00	0.00	0.01
Horizon 48 months	0.44	0.03	0.01	0.01	0.00	0.00	0.01
Permanent Foreign Monetary Shock, X^{m*}_t							
Horizon 12 months	0.08	0.01	0.06	0.07	0.00	0.85	0.01
Horizon 24 months	0.08	0.01	0.03	0.11	0.00	0.90	0.02
Horizon 36 months	0.08	0.01	0.02	0.12	0.00	0.93	0.03
Horizon 48 months	0.08	0.01	0.02	0.12	0.00	0.94	0.03

Note. uid$= i_t - i^*_t - \epsilon_{t+1}$.

The State Space Representation

Now including the constants, which were omitted earlier.

$$\widehat{Y}_t \equiv \begin{bmatrix} y_t - X_t - E(y_t - X_t) \\ \pi_t - X_t^m - E(\pi_t - X_t^m) \\ i_t - X_t^m - E(i_t - X_t^m) \\ \epsilon_t - X_t^m + X_t^{m*} - E(\epsilon_t - X_t^m + X_t^{m*}) \\ i_t^* - X_t^{m*} - E(i_t^* - X_t^{m*}) \end{bmatrix}; u_t \equiv \begin{bmatrix} \Delta X_t^m - E(\Delta X_t^m) \\ z_t^m \\ \Delta X_t - E(\Delta X_t) \\ z_t \\ \Delta X_t^{m*} - E(\Delta X_t^{m*}) \end{bmatrix}$$

$$\widehat{Y}_t = \sum_{i=1}^{L} B_i \widehat{Y}_{t-i} + C u_t$$

$$u_t = \rho u_{t-1} + \psi \nu_t$$

$$\xi_t \equiv \begin{bmatrix} \widehat{Y}_t' & \widehat{Y}_{t-1}' & \dots & \widehat{Y}_{t-L+1}' & u_t' \end{bmatrix}'$$

$$\xi_{t+1} = F \xi_t + P \nu_{t+1}$$

$$o_t = A' + H' \xi_t + \mu_t$$

$V = 5$, number of variables included in the vector $\widehat{Y}_t$,
$S = 5$, number of shocks in the vector ν_t,
$L = 6$, number of lags.

$$B \equiv [B_1 \cdots B_L]; F = \begin{bmatrix} B & C\rho \\ \left[I_{V(L-1)}\, \emptyset_{V(L-1),V}\right] & \emptyset_{V(L-1),S} \\ \emptyset_{S,VL} & \rho \end{bmatrix}; P = \begin{bmatrix} C\psi \\ \emptyset_{V(L-1),S} \\ \psi \end{bmatrix}$$

$$A = \begin{bmatrix} E(\Delta X_t) & E(i_t - \pi_t) & E(\Delta X_t^m) & E(\Delta X_t^m - \Delta X_t^{m*}) & E(\Delta X_t^{m*}) \end{bmatrix}$$

$$H' = \begin{bmatrix} M_\xi & \emptyset_{V,V(L-2)} & M_u \end{bmatrix},$$

$$M_\xi = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & -1 \end{bmatrix}; M_u = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Prior for the elements of the matrix A: Normal, mean(o_t), standard deviation, $\sqrt{\frac{\text{var}(o_t)}{T}}$, where T denotes the sample length, 531 months.

Observation equations in model with only one permanent monetary shock

$$\Delta y_t = \widehat{y}_t - \widehat{y}_{t-1} + \Delta X_t$$

$$r_t = \widehat{i}_t - \widehat{\pi}_t$$

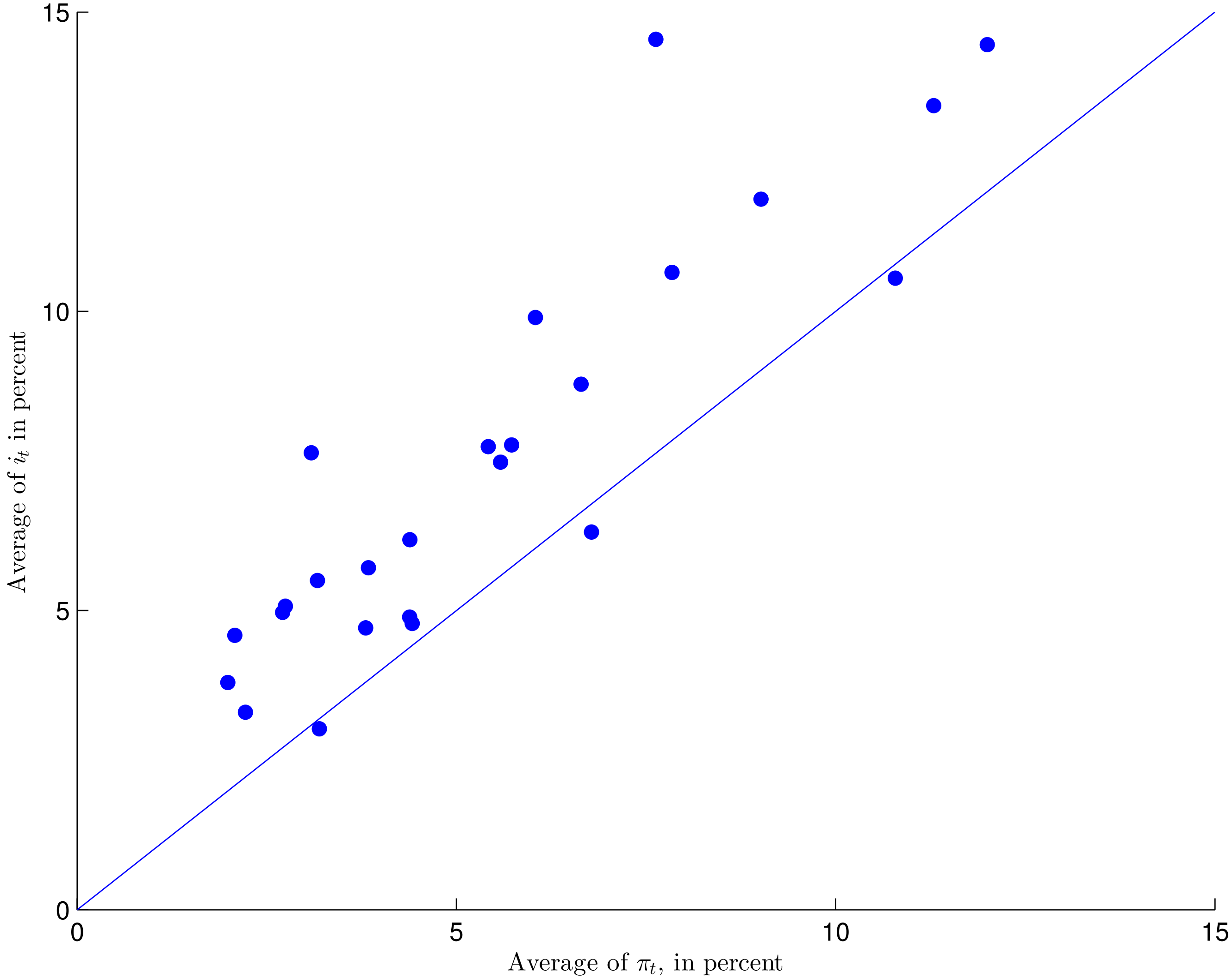
$$\Delta i_t = \widehat{i}_t - \widehat{i}_{t-1} + \Delta X_t^m$$

$$\epsilon_t = \widehat{\epsilon}_t + X_t^m - X_t^{m*}$$

$$i_t - i_t^* = \widehat{i}_t - \widehat{i}_t^* + X_t^m - X_t^{m*}.$$

Note that only the last two observation equations differ from their baseline counterparts.

Cross-Country Evidence on the Long-Run Fisher Effect
Long-Run Averages of Inflation and Nominal Interest Rates



25 OECD countries. Average sample period is 1989 to 2012.