The Synthetic Dollar Funding Channel of US Monetary Policy

Jongho Lee

Department of Economics, Columbia University

November 17, 2024

Motivation

Violation of covered interest rate parity (CIP) since the GFC

$$\text{CIP Deviation} \equiv \underbrace{R_t^{\$}}_{\text{Direct \$ Rate}} - \underbrace{R_t^* \frac{S_t}{F_t}}_{\text{Synthetic \$ Rate}}$$

Motivation

Violation of covered interest rate parity (CIP) since the GFC

$$\text{CIP Deviation} \equiv \underbrace{R_t^{\$}}_{\text{Direct \$ Rate}} - \underbrace{R_t^* \frac{S_t}{F_t}}_{\text{Synthetic \$ Rate}}$$

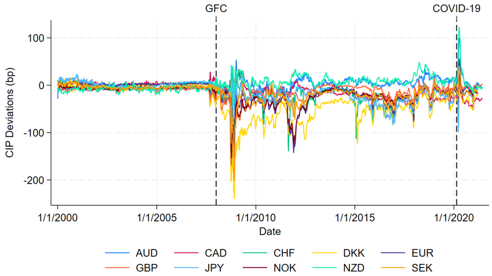
- Synthetic dollar funding: dollar funding through FX swap markets
  1. Borrowing in local currency at R_t^*
  2. Exchanging into USD at spot exchange rate S_t
  3. Covering exchange rate risk at forward exchange rate F_t

Motivation

Violation of covered interest rate parity (CIP) since the GFC

$$\text{CIP Deviation} \equiv \underbrace{R_t^{\$}}_{\text{Direct \$ Rate}} - \underbrace{R_t^{*}\frac{S_t}{F_t}}_{\text{Synthetic \$ Rate}}$$

- Failure of no-arbitrage condition
- Due to strengthened regulations on arbitrage (Du et al., 2018)



Motivation

Emergence of CIP deviation: gap between synthetic and direct $ rates

- CIP deviations < 0: synthetic dollar rate > direct dollar rate

Motivation

Emergence of CIP deviation: gap between synthetic and direct \$ rates

- CIP deviations < 0: synthetic dollar rate > direct dollar rate

Importance of synthetic dollar funding

Motivation

Emergence of CIP deviation: gap between synthetic and direct $ rates

- CIP deviations < 0: synthetic dollar rate > direct dollar rate

Importance of synthetic dollar funding

- Many (low-credit) non-US banks: lack access to direct dollar funding (Rime et al., 2022)
  - Even global banks under financial distress (Ivashina et al., 2015)

Motivation

Emergence of CIP deviation: gap between synthetic and direct \$ rates

- CIP deviations < 0: synthetic dollar rate > direct dollar rate

Importance of synthetic dollar funding

- Many (low-credit) non-US banks: lack access to direct dollar funding (Rime et al., 2022)
  - Even global banks under financial distress (Ivashina et al., 2015)
- Synthetic dollar funding/Total dollar funding: 15-20% past 5 years (Khetan, 2024)

Research Question

Synthetic dollar funding channel: transmission channel of US monetary policy through FX swap markets

Research Question

Synthetic dollar funding channel: transmission channel of US monetary policy through FX swap markets

1. What are the effects of US monetary policy on CIP deviations?

Research Question

Synthetic dollar funding channel: transmission channel of US monetary policy through FX swap markets

1. What are the effects of US monetary policy on CIP deviations?
2. How do the effects amplify spillovers and spillbacks of US monetary policy?

Research Question

Synthetic dollar funding channel: transmission channel of US monetary policy through FX swap markets

1. What are the effects of US monetary policy on CIP deviations?
2. How do the effects amplify spillovers and spillbacks of US monetary policy?

- Key mechanism: CIP deviations driving financial accelerator effects
  - Financial intermediaries price CIP deviations
  - CIP deviations: wedges in dollar funding markets
  - International extension of the credit channel of monetary policy (Bernanke & Gertler, 1995)

Key Takeaways

Empirical findings: Using high-frequency data of G10 currencies,

- US policy rate $\uparrow$ (100bp) $\Rightarrow$ 3-month CIP deviations widen (35bp)
  - Economically significant ($\because$ post-GFC average: 21bp)

Key Takeaways

Empirical findings: Using high-frequency data of G10 currencies,

- US policy rate $\uparrow$ (100bp) $\Rightarrow$ 3-month CIP deviations widen (35bp)
  - Economically significant ($\because$ post-GFC average: 21bp)

Theoretical model: Two-country NK model + FX swap market

Key Takeaways

Empirical findings: Using high-frequency data of G10 currencies,

- US policy rate $\uparrow$ (100bp) $\Rightarrow$ 3-month CIP deviations widen (35bp)
  - Economically significant ($\because$ post-GFC average: 21bp)

Theoretical model: Two-country NK model + FX swap market

- CIP deviation (*cid*): price of the FX swap market

Key Takeaways

Empirical findings: Using high-frequency data of G10 currencies,

- US policy rate $\uparrow$ (100bp) $\Rightarrow$ 3-month CIP deviations widen (35bp)
  - Economically significant ($\because$ post-GFC average: 21bp)

Theoretical model: Two-country NK model + FX swap market

- CIP deviation (*cid*): price of the FX swap market
- Supply: US banks with limit on CIP arbitrage
  - Arbitrage = supply ($\because$ steady-state $cid < 0$)
  - $cid \neq 0$, reflecting the shadow cost of balance sheet space

Key Takeaways

Empirical findings: Using high-frequency data of G10 currencies,

- US policy rate $\uparrow$ (100bp) $\Rightarrow$ 3-month CIP deviations widen (35bp)
  - Economically significant ($\because$ post-GFC average: 21bp)

Theoretical model: Two-country NK model + FX swap market

- CIP deviation (*cid*): price of the FX swap market
- Supply: US banks with limit on CIP arbitrage
  - Arbitrage = supply ($\because$ steady-state $cid < 0$)
  - $cid \neq 0$, reflecting the shadow cost of balance sheet space
- Demand: Non-US banks' currency matching for the USD assets
  - Simplifying assumption: direct dollar funding is unavailable
  - *cid*: intermediation fee for currency matching

Key Takeaways

Synthetic dollar funding channel: irfs to US policy rate ↑

Key Takeaways

Synthetic dollar funding channel: irfs to US policy rate $\uparrow$

1. *cid* widens since US banks' leverage constraints become tighter
   - US policy rate $\uparrow \Rightarrow$ net worth of US banks $\downarrow$
   - Higher shadow cost of balance sheet space $\Rightarrow$ supply $\downarrow$

Key Takeaways

Synthetic dollar funding channel: irfs to US policy rate ↑

1. *cid* widens since US banks' leverage constraints become tighter
   - US policy rate ↑ ⇒ net worth of US banks ↓
   - Higher shadow cost of balance sheet space ⇒ supply ↓
2. Amplification: comparing with the counterfactual with *cid* = 0
   - Widening of *cid*: financial accelerator effect
   - Spillover: larger ↓ in non-US banks' net worth
   - Spillback: larger ↓ in non-US banks' demand for US capital

Key Takeaways

Synthetic dollar funding channel: irfs to US policy rate ↑

1. *cid* widens since US banks' leverage constraints become tighter
   - US policy rate ↑ ⇒ net worth of US banks ↓
   - Higher shadow cost of balance sheet space ⇒ supply ↓
2. Amplification: comparing with the counterfactual with $cid = 0$
   - Widening of *cid*: financial accelerator effect
   - Spillover: larger ↓ in non-US banks' net worth
   - Spillback: larger ↓ in non-US banks' demand for US capital
3. Central bank swap lines: dampen the synthetic dollar funding channel
   - Due to the attenuation of the widening of *cid*

Related Literature

- UIP deviations and macro model: Kollmann (2005), Gabaix and Maggiori (2015), Itskhoki and Mukhin (2021), Akinci et al. (2022), Schmitt-Grohé and Uribe (2022), Devereux et al. (2023)
  - Focus on CIP deviations as barometers for dollar funding costs
- CIP deviations and banks: Ivashina et al. (2015), Iida et al. (2018), Liao and Zhang (2020), Bahaj and Reis (2022), Bacchetta et al. (2024)
  - Infinite horizon & GE model for macro implications
- Convenience yield and macro model: Jiang et al. (2020), Kekre and Lenel (2021), Bianchi et al. (2022)
  - Focus on limit to arbitrage rather than safety or liquidity of USD

Empirical Evidence

Measurement of CIP Deviations

CIP deviations: cross-currency bases measured by ▸ summary

$$cid_{j,t} = r_{\$,t} - (r_{j,t} - \rho_{j,t})$$ ▸ definition

Measurement of CIP Deviations

CIP deviations: cross-currency bases measured by ▸ summary

$$cid_{j,t} = r_{\$,t} - (r_{j,t} - \rho_{j,t})$$ ▸ definition

- $r_{j,t}$: 3-month risk-free rate of currency j
  - Risk-free rate: IBORs
  - 3-month: business cycle frequency & no quarter-end effects

Measurement of CIP Deviations

CIP deviations: cross-currency bases measured by ‣ summary

$$cid_{j,t} = r_{\$,t} - (r_{j,t} - \rho_{j,t})$$ ‣ definition

- $r_{j,t}$: 3-month risk-free rate of currency j
  - Risk-free rate: IBORs
  - 3-month: business cycle frequency & no quarter-end effects
- $\rho_{j,t}$: forward premium ($= F_{j,t}/S_{j,t} - 1$)
  - Mid price of bid & ask rates
- Source: Updated dataset of Du, Im, and Schreger (2018)

Identification of US Monetary Policy Shock

Identification problem: endogeneity of policy rate

- *cid*: market price of synthetic dollar funding
  - *cid* and policy rate: jointly affected by macro-conditions

Identification of US Monetary Policy Shock

Identification problem: endogeneity of policy rate

- *cid*: market price of synthetic dollar funding
  - *cid* and policy rate: jointly affected by macro-conditions

Identification strategy: high-frequency method

- 30-minute changes in FF1, FF4, ED2, ED3, ED4 around each FOMC
  - Key identifying assumption: all the information on monetary policy are priced just before the FOMC
- Factors extracted from the surprises in 5 interest rate futures
  - Single factor (Nakamura and Steinsson, 2018): NS
  - Two factors (Gürkaynak et al., 2005): target and path factor
  - Normalized to have 1-1 relationship with 1-year treasury rate
- Source: Acosta (2023)

Estimation Strategy

Fixed-effect regression in the post-GFC period:

$$\Delta cid_{j,t} = \alpha_j + \beta \Delta mp_t + \epsilon_{j,t}$$

- $\Delta cid_{j,t}$: one-day change in CIP deviations (unit: basis points)
  - Time-zone differences? OTC markets with 24-hour trading
  - $\Delta cid < 0 \Leftrightarrow$ widening of cid ($\because$ $cid < 0$ on average) summary

Estimation Strategy

Fixed-effect regression in the post-GFC period:

$$\Delta cid_{j,t} = \alpha_j + \beta \Delta mp_t + \epsilon_{j,t}$$

- $\Delta cid_{j,t}$: one-day change in CIP deviations (unit: basis points)
  - Time-zone differences? OTC markets with 24-hour trading
  - $\Delta cid < 0 \Leftrightarrow$ widening of cid ($\because$ $cid < 0$ on average) summary
- Δmp_t: US monetary policy shock (unit: percentage points)

Estimation Strategy

Fixed-effect regression in the post-GFC period:

$$\Delta cid_{j,t} = \alpha_j + \beta \Delta mp_t + \epsilon_{j,t}$$

- $\Delta cid_{j,t}$: one-day change in CIP deviations (unit: basis points)
  - Time-zone differences? OTC markets with 24-hour trading
  - $\Delta cid < 0 \Leftrightarrow$ widening of *cid* ($\because$ $cid < 0$ on average) ▸ summary
- Δmp_t: US monetary policy shock (unit: percentage points)
- Sample:
  - G10 currencies (AUD, CAD, CHF, DKK, EUR, GBP, JPY, NOK, NZD, SEK)
  - Jan 2008 - Apr 2021 / Frequency: FOMC announcement

Estimation Results

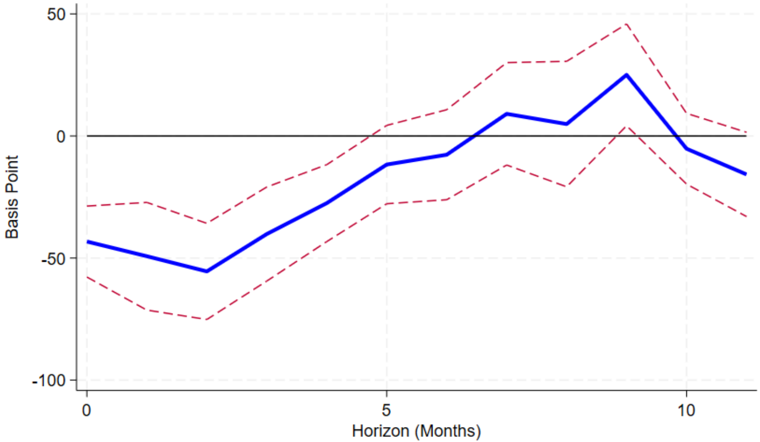
	(1)		(2)
NS	-35.34***	Target	-28.33***
	(13.40)		(6.386)
		Path	-7.006*
			(3.626)
R^2	0.135		0.203
N	1047		1047

Note: Units of the estimates are in basis points. Driscoll-Kraay standard errors are reported in the parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

▸ all maturities ▸ decomposition ▸ term structure ▸ robustness

- $\beta < 0$: US monetary tightening ⇒ widening of CIP deviations
  - Synthetic cost rises by 35bp more than direct cost
  - Effects: target > path ⇒ This paper's focus: *Target* shock

Local Projection



Note: 95% confidence interval

▸ long version

Theoretical Model

Structure of FX Swap Market

- Arbitrageur: US bank
  - CIP deviations < 0: arbitrage strategy is "borrow in \$, lend in €"
  - US bank can approach large and stable pool of \$
  - Arbitrage implies sell \$ and buy € spot $\Rightarrow$ supplier of synthetic dollar funding
- Demander: non-US bank
  - Banks: highly penalized for currency mismatches
  - buy \$ and sell € spot $\Rightarrow$ demander of synthetic dollar funding
- Supported by CLS data (Kloks et al., 2024)

US Bank: Balance Sheet

US Bank i's Portfolio

- US capital assets: $K_{H,i,t} \Rightarrow$ gross return rate in \$: $R_{K,t+1}$
- Risk-less arbitrage: $X_{i,t} \Rightarrow$ gross return rate in \$: $R_t^* S_t / F_t$
  - $\$X_{i,t} \rightarrow €S_t X_{i,t} \rightarrow €R_t^* S_t X_{i,t} \rightarrow \$R_t^* (S_t / F_t) X_{i,t}$

US Bank: Balance Sheet

US Bank i's Portfolio

- US capital assets: $K_{H,i,t} \Rightarrow$ gross return rate in \$: $R_{K,t+1}$
- Risk-less arbitrage: $X_{i,t} \Rightarrow$ gross return rate in \$: $R_t^* S_t/F_t$
  - $\$X_{i,t} \rightarrow €S_t X_{i,t} \rightarrow €R_t^* S_t X_{i,t} \rightarrow \$R_t^*(S_t/F_t)X_{i,t}$

Law of motion of net worth $N_{i,t}$:

$$N_{i,t+1} = R_t N_{i,t} + (R_{K,t+1} - R_t)K_{H,i.t} + \underbrace{\left(R_t^* \frac{S_t}{F_t} - R_t\right)}_{=-cid_t} X_{i.t}$$

- $-cid_t$: return on supplying synthetic dollar funding ($\because$ sell USD spot)

US bank: Value Function

Value function: $V_{i,t} = E_t \left[\Lambda_{t,t+1}\{(1-\sigma)N_{i,t+1} + \sigma V_{i,t+1}\}\right]$

- $\Lambda_{t,t+1}$: SDF of households (holding banks)
- σ: continuation probability (revealed at the beginning of t)
  - Exiting banks: pay out net worth to households
- $V_{i,t} = \nu_t N_{i,t}$: shown by guess and verify method proof
  - $\nu_t = E_t[\Lambda_{t,t+1}(1-\sigma+\sigma\nu_{t+1})(N_{i,t+1}/N_{i,t})] \equiv E_t[\Omega_{t,t+1}(N_{i,t+1}/N_{i,t})]$
  - $\Omega_{t,t+1}$: SDF of US bank
  - $\Omega_{t,t+1} \neq \Lambda_{t,t+1}$ if $\nu_{t+1} \neq 1$

US Bank: Financial Friction

Leverage constraint (Gertler & Kiyotaki, 2011):

$$V_{i,t} \geq \left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right) Q_t K_{H,i,t} + \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right) X_{i,t}$$

- θ: parameters for the degree of regulation on each asset
- θ_{X1}, θ_{X2}: limit on CIP arbitrage
  - Pre-GFC (counterfactual): $\theta_{X1} = \theta_{X2} = 0$
- θ_{H2}, θ_{X2}: introduced for closing the model (Devereux et al., 2023)
  - External stationarity device (Schmitt-Grohé and Uribe, 2003)
  - State-dependent regulation

US Bank: Supply of FX Swap

Optimality condition for $X_{i,t}$: For Lagrangian multiplier μ_t of the leverage constraint,

$$\underbrace{E_t\left[\Omega_{t,t+1}\right]}_{\text{Bank SDF}}\underbrace{\left(R_t^*\frac{S_t}{F_t}-R_t\right)}_{=-cid_t}=\mu_t\left(\theta_{X1}+\theta_{X2}\frac{X_t}{P_t}\right)$$

- Upward-sloping inverse supply function in $-cid_t$
- cid_t: non-zero even up to first-order unless $\theta_{X1}=\theta_{X2}=0$
  - Pre-GFC ($\theta_{X1}=\theta_{X2}=0$): $cid_t=0$ (perfectly elastic)
- As $\mu_t\uparrow$, CIP deviations widen, *i.e* $-cid_t\uparrow$
  - CIP deviations reflect bank balance sheet costs

Non-US Bank: Balance sheet

<u>Non-US Bank *i*'s Portfolio</u>

- Non-US capital assets: $K^*_{F,i,t}$ $\Rightarrow$ gross return rate in €: $R^*_{F,t+1}$
- US capital assets: $K^*_{H,i,t}$ $\Rightarrow$ gross return rate in \$: $R_{K,t+1}$
  - Assumption: cannot issue \$ deposits $\Rightarrow$ all deposits are in €
  - Currency mismatch between $K^*_{H,i,t}$ and liabilities
  - Different degree of regulation on currency matching/mismatches

    $\Rightarrow$ hedge ratio (x^*) is optimally chosen

Non-US Bank: Demand for FX Swap

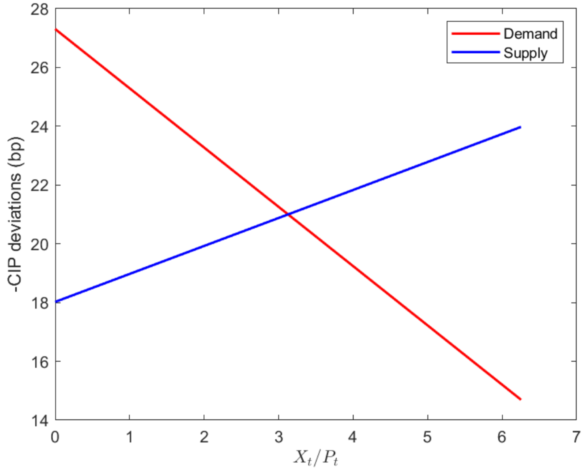
Optimality condition:

$$E_t\left[\Omega^*_{t,t+1}\frac{S_{t+1}}{S_t}\underbrace{\left(R_{K,t+1} - R^*_t\frac{S_t}{F_t}\right)}_{R_{K,t+1}-(R_t-cid_t)}\right] = \mu^*_t\left(\theta^*_{X1} + \theta^*_{X2}\frac{x^*_t S_t Q_t K^*_{H,t}}{P^*_t}\right)$$

- Effective cost of dollar funding: $R^*_t S_t/F_t$ ($\because$ no direct dollar funding)
- Downward-sloping inverse demand function in $-cid_t$ ▸ eqm
- cid_t: intermediation fee for currency matching
  - If non-US banks can fund USD directly, then excess return is $R_{K,t+1} - R_t$

Equilibrium: FX Swap Market

Market clearing condition: $X_t = x_t^* Q_t K_{H,t}^*$ ▸ supply ▸ demand



Other Sectors

- Household: chooses consumption, labor, and deposits ‣ household
- Capital-good producer: installs capital ‣ capital-good producer
  - Subject to quadratic capital adjustment cost
  - Price of capital (Tobin's Q) $\neq$ price of investment-good
- Firm: produces each variety using labor and capital ‣ firm
  - Price rigidity à la Rotemberg (1982) and local currency pricing
- Wholesalers: assemble varieties into a final good ‣ wholesaler
  - Demand functions faced by monopolistically competitive firms
- Retailers: assemble domestic and imported goods ‣ retailer
  - Home-bias and elasticity of substitution between domestic and imported goods
- Monetary policy and fiscal policy ‣ policy

Results

Calibration: Banking Sector

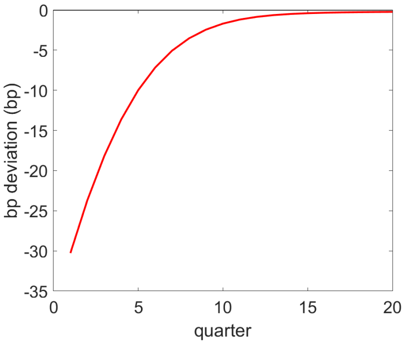
Frequency: quarterly

Parameter	Value	Target
$\sigma = \sigma^*$	0.95	Average survival horizon of 5 years
θ_{X1}	0.11	CIP deviation of -21bp
θ^*_{X1}	0.19	RoW capital excess return of 100bp
θ_{X2}	0.005	Devereux et al. (2023)
θ^*_{X2}	0.005	Devereux et al. (2023)

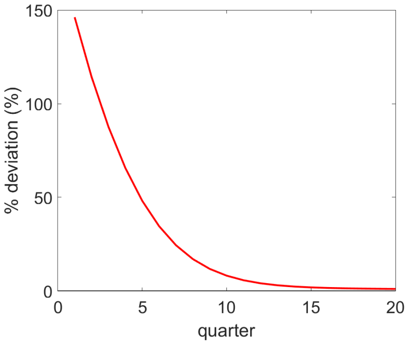
▸ calibration ▸ sensitivity

IRFs: CIP Deviations

Shock: 1pp US monetary policy shock



(a) CIP Deviations (*cid*)

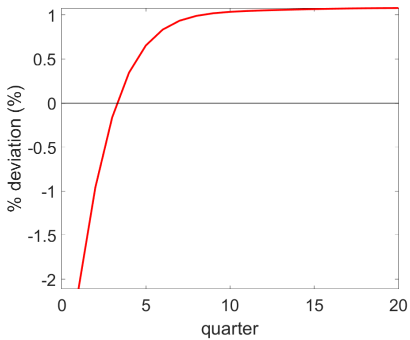


(b) Lagrange Multiplier (μ)

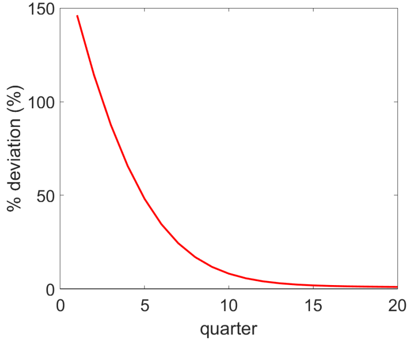
- $R \uparrow \Rightarrow N \downarrow \Rightarrow$ Tighter limit on CIP arbitrage $\Rightarrow \mu \uparrow$
- Supply of synthetic dollar funding $\downarrow$

IRFs: CIP Deviations

Shock: 1pp US monetary policy shock



(a) CIP Deviations (*cid*)

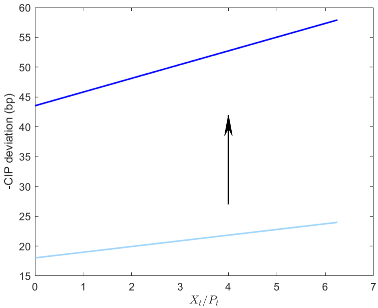


(b) Lagrange Multiplier (μ)

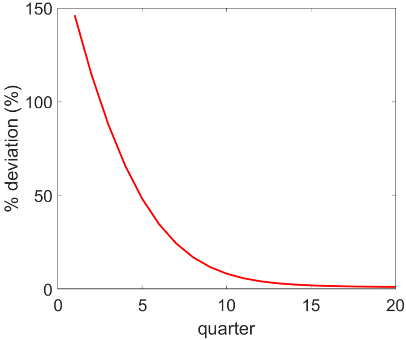
- $R \uparrow \Rightarrow N \downarrow \Rightarrow$ Tighter limit on CIP arbitrage $\Rightarrow \mu \uparrow$
- Supply of synthetic dollar funding $\downarrow$

IRFs: CIP Deviations

Shock: 1pp US monetary policy shock



(a) CIP Deviations (*cid*)

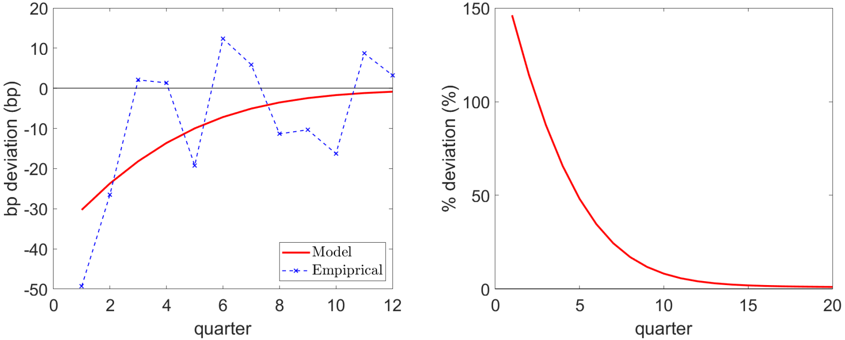


(b) Lagrange Multiplier (μ)

- $R \uparrow \Rightarrow N \downarrow \Rightarrow$ Tighter limit on CIP arbitrage $\Rightarrow \mu \uparrow$
- Supply of synthetic dollar funding $\downarrow$

IRFs: CIP Deviations

Shock: 1pp US monetary policy shock

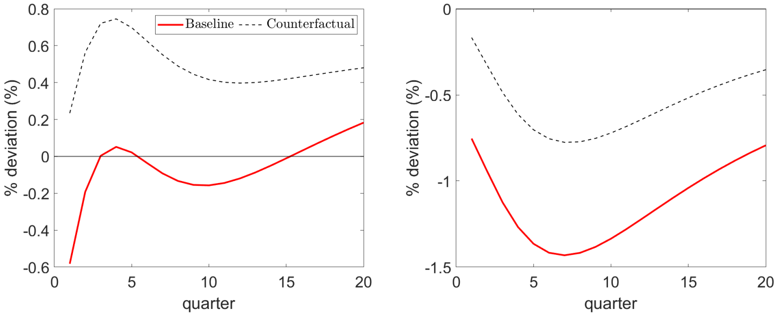


(a) CIP Deviations (*cid*) (b) Lagrange Multiplier (μ)

- $R \uparrow \Rightarrow N \downarrow \Rightarrow$ Tighter limit on CIP arbitrage $\Rightarrow \mu \uparrow$
- Supply of synthetic dollar funding $\downarrow$

IRFs: Synthetic Dollar Funding

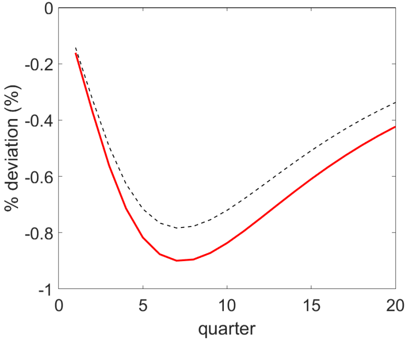
Baseline vs Counterfactual ($\theta_{X1} = \theta_{X2} = 0$)



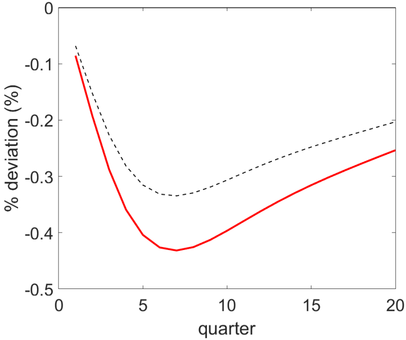
(a) Synthetic Dollar Funding (X/P) (b) US Capital Holdings by non-US (K_H^*)

- Lower X/P: due to the decrease in supply schedule
- Lower K_H^*: due to larger *cid* and lower X/P
  - Cost of currency matching in K_H^*: CIP deviations

Amplification of Spillover and Spillback



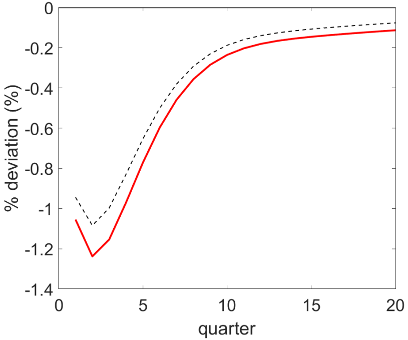
(a) US Capital (K)



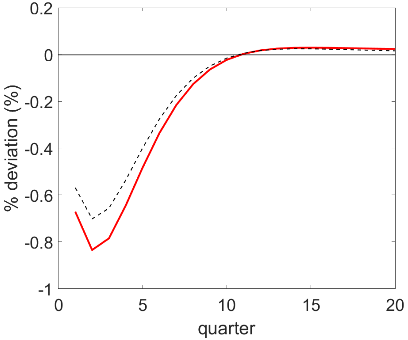
(b) Non-US Capital (K^*)

- Decrease in K: X/P and $K_H^* \downarrow$
- Decrease in K^*: Larger cid $\Leftrightarrow$ higher intermediation fees $\Rightarrow$ $N^* \downarrow$

Amplification of Spillover and Spillback



(a) US Output (Y)



(b) Non-US Output (Y^*)

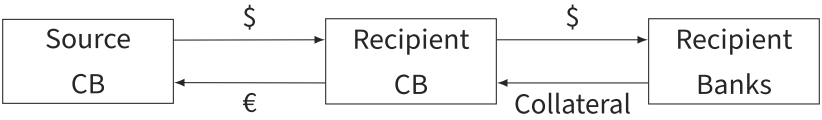
‣ investment ‣ consumption ‣ inflation ‣ exchange rate ‣ price of capital

- Amplification effects of 15-20% with persistence

Central Bank Swap Lines and Synthetic Dollar Funding Channel

Central Bank Swap Lines

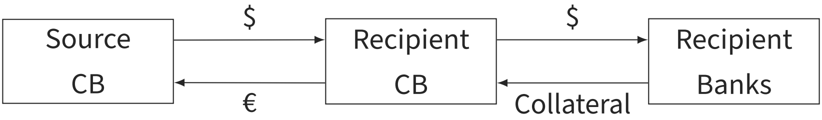
Lender of last resort: collateralized public liquidity line



- Policy instrument: swap spread ss_t over a risk-free rate
- $-cid_t \leq ss_t$: ceiling on CIP deviations (Bahaj and Reis, 2022)
  - International version of discount window policy

Central Bank Swap Lines

Lender of last resort: collateralized public liquidity line



- Policy instrument: swap spread ss_t over a risk-free rate
- $-cid_t \leq ss_t$: ceiling on CIP deviations (Bahaj and Reis, 2022)
  - International version of discount window policy

Question: what does this imply for the synthetic dollar funding channel?

- Effect on CIP deviations and synthetic dollar funding costs?
- Implication for the amplification effects?
- Caveat: Focusing on positive rather than normative analysis

Modelling Swap Line Policy

Swap Line Policy: described by (ss_t, X_t^{SL}) ▸ Eqm

- Policy instrument: occasionally binding constraint

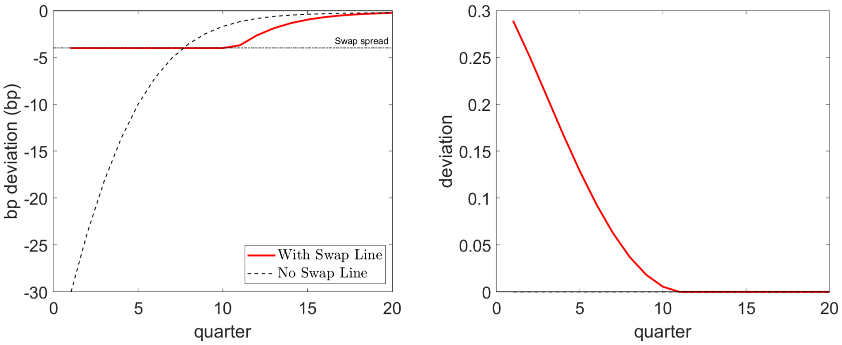
$$-cid_t \equiv R_t - R_t^* \frac{S_t}{F_t} \leq ss_t$$

  - ss_t = 25bp: swap spreads of standing facilities

- Market clearing condition: $X_t + X_t^{SL} = x_t^* Q_t K_{H,t}^*$
- Complementary slackness condition:

$$(cid_t + ss_t)X_t^{SL} = 0$$

Transmission Channel: With v.s. Without Swap Lines



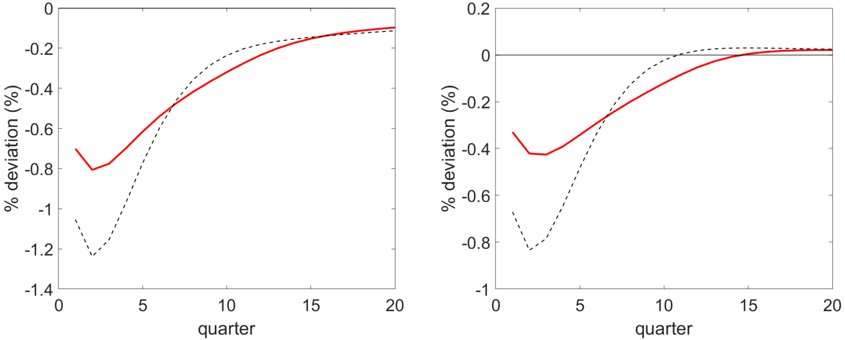
(a) CIP Deviations (*cid*)

(b) Swap Lending (X^{SL})

- $R \uparrow \Rightarrow$ Downward pressure on *cid* $\Rightarrow$ Ceiling binds: less widening
- $X_t^{SL} > 0$ when ceiling binds

Transmission Channel: With v.s. Without Swap Lines

Change in impulse responses:



(a) US Output (b) Non-US Output

- Synthetic dollar funding channel: dampened
  - Swap line policy affects monetary transmission

Conclusion

Conclusion

Empirical findings: In the post-GFC periods,

- US monetary tightening: larger deviations from CIP

Theoretical model: 2-country NK model + FX swap market

- CIP deviations: price in the FX swap market
  - Supply: US banks with limit on CIP arbitrage
  - Demand: Non-US banks' currency matching for the USD assets

Synthetic dollar funding channel: irfs to US monetary tightening

- Widening of CIP deviations: due to tighter limit on CIP arbitrage
- Amplification of spillovers and spillbacks: due to widening of CIP deviations
- Central bank swap lines: dampen the synthetic dollar funding channel

Appendix

Summary Statistics of CIP Deviations

	3M		1Y		2Y		3Y	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
Mean	-2.48	-20.93	0.25	-17.82	0.49	-16.31	0.60	-15.11
Median	-2.40	-17.87	0.18	-15.94	0.56	-15.01	0.74	-13.97
S.D.	5.42	20.99	2.11	14.29	1.99	12.79	2.10	12.43
Autocorr.	0.52	0.75	0.72	0.78	0.72	0.79	0.72	0.79

	5Y		7Y		10Y	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
Mean	0.76	-13.29	0.58	-12.02	0.34	-10.13
Median	1.06	-12.08	1.03	-10.70	0.75	-8.70
S.D.	2.51	12.63	2.79	12.89	3.12	13.14
Autocorr.	0.72	0.79	0.72	0.79	0.73	0.79

Note: This table presents summary statistics of CIP deviations for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. For each maturity, each statistic of CIP deviations is a simple average of the statistics across G10 currencies. The pre-GFC period is from 1/1/2000 to 12/31/2007 while the post-GFC period is from 1/1/2008 to 4/30/2021.

back

Estimation Results: All Maturities

	3M	1Y	2Y	3Y	5Y	7Y	10Y
NS	-35.34***	-5.095	-0.526	-0.303	0.602	1.267	0.445
	(13.40)	(3.505)	(1.330)	(0.713)	(1.021)	(0.793)	(0.597)
R^2	0.135	0.021	0.001	0.000	0.001	0.003	0.001

	3M	1Y	2Y	3Y	5Y	7Y	10Y
Target	-28.33***	-3.471*	-0.289	0.031	0.998	1.658	0.256
	(6.386)	(1.785)	(1.051)	(0.674)	(0.936)	(1.042)	(0.312)
Path	-7.006*	-1.662	-0.297	-0.397	-0.459	-0.445	0.148
	(3.626)	(1.776)	(0.865)	(0.584)	(0.846)	(0.836)	(0.476)
R^2	0.203	0.027	0.001	0.001	0.006	0.011	0.001
N	1047	1022	1028	1030	1031	1039	1024

Note: Units of the estimates are in basis points. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

back

Decomposition

	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid	-35.34***	-5.095	-0.526	-0.303	0.602	1.267	0.445
	(13.40)	(3.505)	(1.330)	(0.713)	(1.021)	(0.793)	(0.597)
$\Delta r^{\$}$	6.602**	62.48***	79.87***	84.59***	83.06***	42.52***	65.55***
	(3.221)	(0.299)	(6.324)	(0.017)	(0.138)	(0.057)	(14.87)
$-\Delta r^{j}$	-2.063*	-9.465**	-12.30***	-12.75**	-12.35*	-11.75*	-10.95**
	(2.576)	(3.846)	(4.180)	(4.147)	(3.943)	(3.558)	(2.782)
$\Delta \rho^{j}$	-39.88**	-58.52***	-67.65***	-71.35***	-70.42***	-30.30***	-54.20***
	(15.71)	(4.729)	(4.744)	(4.920)	(6.026)	(5.770)	(11.80)

Note: Units of the estimates are in basis points. Driscoll-Kraay standard errors are reported in the parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

▸ back

Cumulative Explained Variance of Δcid

Δcid	PC1	PC2	PC3
AUD	0.5619	0.7057	0.8214
CAD	0.6540	0.7931	0.8694
CHF	0.6450	0.8091	0.8848
DKK	0.4929	0.6478	0.7882
EUR	0.7088	0.8761	0.9287
GBP	0.6045	0.7832	0.8625
JPY	0.6730	0.8411	0.9085
NOK	0.4275	0.5852	0.7076
NZD	0.5778	0.7269	0.8519
SEK	0.5829	0.7596	0.8568

Note: For each currency, principal components of Δcid with maturities of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year are extracted for the post-GFC (08-) periods. Three principal components are displayed in this table for simplicity.

Factor Loadings on PC1 and PC2

PC1	AUD	CAD	CHF	DKK	EUR	GBP	JPY	NOK	NZD	SEK
3m	0.0455	0.2110	0.2350	0.0906	0.2558	0.2013	0.2212	0.2025	0.0618	0.1593
1y	0.4122	0.3551	0.3600	0.3747	0.3421	0.3177	0.3688	0.3137	0.3264	0.3495
2y	0.4182	0.4015	0.4123	0.4050	0.4131	0.4225	0.4140	0.4211	0.4228	0.3887
3y	0.4698	0.4212	0.4302	0.4227	0.4211	0.4376	0.4353	0.4624	0.4537	0.4208
5y	0.4535	0.3975	0.3983	0.4432	0.4110	0.4426	0.4191	0.4365	0.4492	0.4316
7y	0.3341	0.4037	0.4015	0.3975	0.3967	0.3816	0.3928	0.4047	0.4012	0.4225
10y	0.3393	0.4121	0.3745	0.3927	0.3785	0.3835	0.3524	0.3394	0.3773	0.3995
PC2	AUD	CAD	CHF	DKK	EUR	GBP	JPY	NOK	NZD	SEK
3m	0.9714	0.8115	0.6376	0.1987	0.6790	0.6854	0.6777	0.5256	0.8273	0.6488
1y	0.1122	0.3449	0.4304	0.3776	0.5064	0.5162	0.3793	0.5214	0.3882	0.4093
2y	0.0552	0.1276	0.2240	0.4569	0.0894	0.1269	0.2062	0.2126	0.1545	0.3167
3y	-0.0205	-0.0893	0.0128	0.3072	-0.0862	-0.0540	0.0284	0.0957	0.0205	0.0636
5y	-0.0196	-0.1977	-0.2951	-0.2034	-0.2257	-0.1940	-0.2483	-0.2209	-0.1332	-0.2574
7y	-0.1481	-0.3089	-0.3573	-0.4724	-0.3236	-0.3120	-0.3614	-0.3807	-0.2399	-0.3433
10y	-0.1339	-0.2525	-0.3783	-0.5003	-0.3339	-0.3313	-0.4015	-0.4516	-0.2555	-0.3507

Note: This table presents factor loadings on the first two principal components for each currency during the post-GFC (08-) periods. The first panel shows the factor loadings on the first principal component while the second panel displays those on the second principal component. Each column indicates factor loadings for each G10 currency.

Principal Components and US Monetary Policy

	PC1		PC2	
	(1)	(2)	(3)	(4)
NS	-1.231		-5.991**	
	(1.925)		(2.309)	
Target		-0.405		-4.939***
		(1.297)		(1.059)
Path		-0.952		-0.979
		(1.413)		(0.564)
R^2	0.001	0.001	0.082	0.131
N	1002	1002	1002	1002

Note: This table presents the regression results of principal components of Δcid on 1%p contractionary US monetary policy shock. For each principal component, there are two columns: the left column is the estimation result when *NS* is used as the US monetary policy shock whereas the right column is the one when *Target* and *Path* are used as proxies for the shock. Standard errors clustered across currencies are reported in the parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

▸ back

Robustness Check

Different choices of the dependent variable

- Two-day changes in CIP deviations results
- Changes in absolute values of CIP deviations results

Different choices of the explanatory variable

- Information-robust monetary policy shocks results
- Monetary policy shocks robust to Fed response to news channel results

back

Robustness Check: Two-day Window

	3M		1Y		2Y		3Y	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NS	-25.32**		-13.13**		-5.939*		-5.592*	
	(10.55)		(6.474)		(3.291)		(3.228)	
Target		-36.63***		-10.00		-4.261		-3.902
		(7.775)		(6.278)		(3.094)		(2.821)
Path		10.54**		-3.174		-1.748		-1.765
		(4.422)		(2.214)		(1.627)		(1.271)
R^2	0.018	0.080	0.053	0.075	0.025	0.034	0.029	0.038
N	1047	1047	1018	1018	1027	1027	1027	1027

	5Y		7Y		10Y	
	(7)	(8)	(9)	(10)	(11)	(12)
NS	-2.686		-0.160		0.575	
	(1.500)		(1.799)		(1.292)	
Target		-1.442		-0.080		0.329
		(0.802)		(1.465)		(0.847)
Path		-1.303		-0.137		0.183
		(0.881)		(1.324)		(1.158)
R^2	0.009	0.010	0.000	0.000	0.001	0.001
N	1026	1026	1036	1036	1023	1023

Robustness Check: Absolute Value of CIP Deviations

	3M		1Y		2Y		3Y	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NS	18.78**		6.082*		2.104**		1.496	
	(7.399)		(3.233)		(0.793)		(1.059)	
Target		17.36**		4.047*		1.628*		1.743**
		(5.367)		(1.876)		(0.858)		(0.707)
Path		1.503		2.047		0.519		-0.202
		(3.302)		(1.688)		(0.679)		(0.640)
R^2	0.045	0.084	0.030	0.038	0.010	0.014	0.006	0.016
N	1047	1047	1022	1022	1028	1028	1030	1030

	5Y		7Y		10Y	
	(7)	(8)	(9)	(10)	(11)	(12)
NS	1.213		-0.054		0.339	
	(0.906)		(0.823)		(0.385)	
Target		1.580*		1.096		0.117
		(0.870)		(1.285)		(0.258)
Path		-0.345		-1.123		0.243
		(0.805)		(0.956)		(0.322)
R^2	0.004	0.013	0.000	0.008	0.000	0.001
N	1031	1031	1039	1039	1024	1024

Robustness Check: Information Effect

Signaling channel (Romer and Romer 2000; Nakamura and Steinsson 2018)

- Asymmetric information between the central bank and the market
- High-frequency surprises may reflect revision of market expectation

Slow absorption of information (Coibion and Gorodnichenko 2015)

- Market prices may not reflect fundamental shocks instantaneously
- High-frequency surprises may contain past fundamental shocks

Signalling Channel of Monetary Policy

Test for the signalling channel

- Greenbook forecasts: Fed's private information
- Project monetary policy indicators (NS, Target, Path) on Greenbook forecasts (Miranda-Agrippino and Rico, 2021) results

$$\Delta mp_t = \alpha + \sum_{i=-1}^{2} \beta_i' x_{t,i}^f + \sum_{i=-1}^{2} \gamma_i' (x_{t,i}^f - x_{t-1,i}^f) + \Delta \widetilde{mp}_t$$

  - Greenbook Sample: Feb 1984 - Dec 2017
  - $x_{t,i}^f$: vector of Greenbook forecasts of horizon i for GDP growth rate, inflation, and unemployment rate
    - ★ Unemployment rate: only contemporaneous forecast is included (Romer and Romer 2004)

Results: Signalling Channel of Monetary Policy

	NS	Target	Path		NS	Target	Path
GDP forecasts				Δ GDP forecasts			
i = –1	-0.004	-0.011*	0.001	i = –1	-0.000	-0.009	0.006
	(0.004)	(0.006)	(0.005)		(0.007)	(0.010)	(0.010)
i = 0	0.014	0.014	0.015	i = 0	0.007	0.006	0.007
	(0.009)	(0.014)	(0.010)		(0.010)	(0.015)	(0.014)
i = 1	0.007	-0.009	0.017	i = 1	0.022	0.021	0.024
	(0.013)	(0.024)	(0.015)		(0.015)	(0.027)	(0.019)
i = 2	-0.005	0.026	-0.027*	i = 2	0.008	-0.017	0.024
	(0.011)	(0.019)	(0.015)		(0.015)	(0.025)	(0.019)
Inflation forecasts				Δ Inflation forecasts			
i = –1	0.002	-0.023**	0.019**	i = –1	0.002	0.012	-0.002
	(0.007)	(0.011)	(0.008)		(0.011)	(0.023)	(0.011)
i = 0	0.018*	0.032*	0.007	i = 0	-0.002	-0.009	0.006
	(0.010)	(0.019)	(0.011)		(0.017)	(0.030)	(0.017)
i = 1	0.001	-0.031	0.026	i = 1	-0.011	0.037	-0.044*
	(0.015)	(0.031)	(0.016)		(0.021)	(0.040)	(0.024)
i = 2	-0.012	0.024	-0.035	i = 2	0.041	0.006	0.063*
	(0.022)	(0.036)	(0.029)		(0.029)	(0.045)	(0.035)
Unemployment forecasts				Constant			
i = 0	0.001	-0.002	0.002		-0.045	-0.042	-0.050
	(0.003)	(0.005)	(0.004)		(0.054)	(0.087)	(0.067)
R^2	0.223	0.133	0.215	p-value	0.001	0.569	0.000
F-statistic	2.71	0.91	3.67	N	192	192	192

Information-robust Monetary Policy Shock

<u>Construction</u>

1. $\Delta\widetilde{mp}$: robust to signaling effect
   - Orthogonal to the Fed's information set
2. Run AR(1) regression on $\Delta\widetilde{mp}$:

$$\Delta\widetilde{mp}_t = \alpha_0 + \alpha_1 \Delta\widetilde{mp}_{t-1} + \Delta mpi_t$$

   - Removing the serially correlated part in surprises
   - Δmpi_t: information-robust monetary policy shock

Estimation with *MPI*

	3M		1Y		2Y		3Y	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NS	-24.51**		-1.581		1.000		1.823*	
	(9.894)		(2.086)		(1.478)		(0.992)	
Target		-24.96***		-2.267*		-0.487		0.252
		(7.581)		(1.151)		(1.282)		(0.777)
Path		1.663		1.084		2.228*		1.909***
		(3.162)		(1.255)		(1.260)		(0.382)
R^2	0.045	0.098	0.001	0.007	0.002	0.012	0.006	0.011
N	879	879	862	862	869	869	871	871
	5Y		7Y		10Y			
	(7)	(8)	(9)	(10)	(11)	(12)		
NS	2.614*		2.441		0.680			
	(1.226)		(1.553)		(0.867)			
Target		1.068		1.779		-0.040		
		(1.123)		(1.352)		(0.431)		
Path		1.706***		0.877		0.966		
		(0.465)		(0.803)		(0.796)		
R^2	0.012	0.014	0.009	0.012	0.001	0.003		
N	873	873	879	879	866	866		

▸ back

Robustness Check: Fed Response to News Channel

Fed response to news channel: imperfect information for the Fed's monetary policy rule (Bauer & Swanson, 2023)

- Correlation between Δmp_t and macroeconomic and financial data available before FOMC announcements
- Orthogonalize Δmp_t with respect to available data:

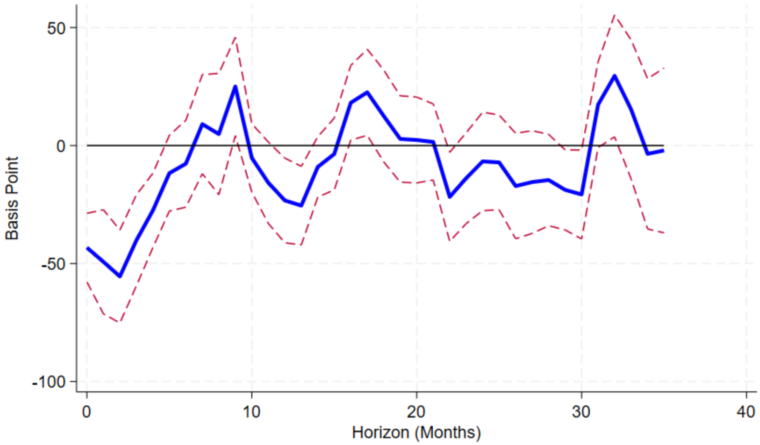
$$\Delta mp_t = \alpha + \gamma' X_t + \Delta mpn_t$$

  - X_t: vector of macroeconomic and financial data
  - Δmpn_t: monetary policy shock robust to the Fed Response to news channel

Results

	3M	1Y	2Y	3Y	5Y	7Y	10Y
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
NS	-34.06***	-6.300	-0.623	0.645	1.837	2.038	-0.247
	(12.20)	(4.238)	(1.631)	(0.663)	(1.285)	(1.162)	(0.877)
R^2	0.053	0.014	0.000	0.001	0.004	0.004	0.000
N	959	942	949	951	951	959	946

Local Projection



Note: 95% confidence interval

back

US Bank: Balance Sheet

Balance sheet ▸ chart

$$\underbrace{Q_t K_{H,i,t} + X_{i,t}}_{\text{Assets}} = \underbrace{D_{i,t} + N_{i,t}}_{\text{Liabilities}}$$

- $X_{i,t}$: risk-less lending to non-US banks (CIP arbitrage)
- Hedge exchange rate risks by FX swap contract (off-balance)

Budget constraint ▸ chart

$$Q_{t+1} K_{H,i,t+1} + X_{i,t+1} + R_t D_{i,t} = R_{K,t+1} Q_t K_{H,i,t} + R_t^* \frac{S_t}{F_t} X_{i,t} + D_{i,t+1}$$

$$\Rightarrow \frac{N_{i,t+1}}{N_{i,t}} = (R_{K,t+1} - R_t)\phi_{H,i.t} + \underbrace{\left(R_t^* \frac{S_t}{F_t} - R_t\right)}_{= -cid_t} \phi_{X,i.t} + R_t$$

- $-cid_t$: fee for supplying synthetic dollar funding ($\because$ sell USD spot)

Balance Sheet and Flow of Funds

Balance Sheet			Flow of Funds	
Asset	Liability		t	$t+1$
$Q_t K_{H,i,t}$	$D_{i,t}$		$-\$Q_t K_{H,i,t}$	$+\$R_{K,t+1} Q_t K_{H,i,t}$
$X_{i,t}$	$N_{i,t}$		$-\$X_{i,t}$	$+\$R_t^* (S_t/F_t) X_{i,t}$
			$+€S_t X_{i,t}$	$-€R_t^* S_t X_{i,t}$
			$-€S_t X_{i,t}$	$+€R_t^* S_t X_{i,t}$
			$+\$D_{i,t}$	$-\$R_t D_{i,t}$

back

Linearity of Bank Value Function

Guess: $V_{i,t} = \nu_t N_{i,t}$

$\Rightarrow$ Bellman equation:

$$\nu_t = \max_{\phi_{H,i,t},\phi_{X,i,t}} \nu_{H,t}\phi_{H,i,t} + \nu_{X,t}\phi_{X,i,t} + \nu_{N,t}$$

$$\text{s.t. } \nu_t \geq \left(\theta_{H1} + \theta_{H2}\frac{Q_t K_{H,t}}{P_t}\right)\phi_{H,i,t} + \left(\theta_{X1} + \theta_{X2}\frac{X_t}{P_t}\right)\phi_{X,i,t}$$

for

$$\nu_{H,t} \equiv E_t\left[\Omega_{t,t+1}\left(R_{K,t+1} - R_t\right)\right]$$

$$\nu_{X,t} \equiv E_t\left[\Omega_{t,t+1}\right]\left(R_t^*\frac{S_t}{F_t} - R_t\right)$$

$$\nu_{N,t} \equiv E_t\left[\Omega_{t,t+1}\right]R_t$$

Linearity of Bank Value Function

First-order conditions

$$\nu_{H,t} = \mu_t \left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right)$$
$$\nu_{X,t} = \mu_t \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right)$$

Verify:

$$\nu_t = \frac{\nu_{N,t}}{1 - \mu_t}$$

$\Rightarrow \nu_t$: same for all banks and not dependent on an individual bank's net worth back

US bank: Leverage Constraint

Key financial friction: limited commitment constraint (GK 2011)

$$V_{i,t} \geq \left(\theta_{H1} + \theta_{H2}\frac{Q_t K_{H,t}}{P_t}\right) Q_t K_{H,i,t} + \left(\theta_{X1} + \theta_{X2}\frac{X_t}{P_t}\right) X_{i,t}$$

- $\theta(\cdot)$: fraction of each asset that US banks can divert
  - Limited commitment constraint: induce self-enforcement
  - θ_{H2}, θ_{X2}: introduced for closing the model (Devereux et al., 2023)
    - ★ External stationarity device (Schmitt-Grohé and Uribe, 2003)
- Also interpreted as a leverage constraint ($\because V_{i,t}$ is linear in net worth)
  - θ_{H2}, θ_{X2}: state-dependent regulation
- θ: parameters for the degree of regulation on leverage
  - θ_{X1}, θ_{X2}: limit on CIP arbitrage (pre-GFC: $\theta_{X1} = \theta_{X2} = 0$)

US bank: Supply of FX Swap

Supply for FX swap: value func. opt. + LoM for net worth + leverage const.

$$\underbrace{E_t\left[\Omega_{t,t+1}\right]}_{\text{Bank SDF}}\underbrace{\left(R_t^*\frac{S_t}{F_t}-R_t\right)}_{=-cid_t}=\mu_t\left(\theta_{X1}+\theta_{X2}\frac{X_t}{P_t}\right)$$

- Upward-sloping inverse supply function in $-cid_t$ eqm
- μ_t: Lagrangian multiplier (tightness of the leverage constraint)
  - $\mu_t > 0$ guaranteed by the calibration
- cid_t: non-zero even up to first-order unless $\theta_{X1} = \theta_{X2} = 0$
  - Pre-GFC ($\theta_{X1} = \theta_{X2} = 0$): $cid_t = 0$ (perfectly elastic)
- As $\mu_t \uparrow$, CIP deviations widen, *i.e* $-cid_t \uparrow$

back

Non-US Bank: Balance Sheet

Balance sheet ‣ chart

$$Q_t^* K_{F,i,t}^* + S_t Q_t K_{H,i,t}^* = D_{i,t}^* + S_t \tilde{X}_{i,t}^* + N_{i,t}^*$$

- $Q_t X_{i,t}^*$ ($ value of US capital holdings): s.t. currency mismatch
  - $x_{i,t}^* Q_t K_{H,i,t}^*$ for $x_{i,t}^* \in [0,1]$: demand for *currency matching* (off-balance)
  - Motive for currency matching: regulation (leverage constraint)
  - Assumption: direct dollar funding *not available* to non-US banks

Budget constraint ‣ chart

$$Q_{t+1}^* K_{F,i,t+1}^* + S_{t+1} Q_{t+1} K_{H,i,t+1}^* + R_t^* (D_{i,t}^* + S_t \tilde{X}_{i,t}^*) + S_{t+1} R_t^* \frac{S_t}{F_t} x_{i,t}^* Q_t K_{H,i,t}^*$$

$$= R_{K,t+1}^* Q_t^* K_{F,i,t}^* + S_{t+1} R_{K,t+1} Q_t K_{H,i,t}^* + (D_{i,t+1}^* + S_{t+1} \tilde{X}_{i,t+1}^*) + R_t^* S_t x_{i,t}^* Q_t K_{H,i,t}^*$$

Balance Sheet and Flow of Funds

Balance Sheet		Flow of Funds	
Asset	Liability	t	$t+1$
$Q_t^* K_{F,i,t}^*$	$D_{i,t}^*$	$-€ Q_t^* K_{F,i,t}$	$+€ R_{K,t+1}^* Q_t^* K_{F,i,t}^*$
$S_t Q_t K_{H,i,t}^*$	$S_t \tilde{X}_t^*$	$-\$ Q_t K_{H,i,t}$	$+\$ R_{K,t+1} Q_t K_{H,i,t}^*$
	$N_{i,t}^*$	$+\$ x_{i,t}^* Q_t K_{H,i,t}^*$	$-\$ R_t^* (S_t/F_t) x_{i,t}^* Q_t K_{H,i,t}^*$
		$-€ S_t x_{i,t}^* Q_t K_{H,i,t}^*$	$+€ R_t^* S_t x_{i,t}^* Q_t K_{H,i,t}^*$
		$+€ S_t \tilde{X}_{i,t}^*$	$-€ R_t^* S_t \tilde{X}_{i,t}^*$
		$+€ D_{i,t}^*$	$-€ R_t^* D_{i,t}^*$

back

Non-US Bank: Law of Motion of Net Worth

Law of motion for net worth:

$$N^*_{i,t+1} = \Bigg[(R^*_{K,t+1} - R^*_t)\phi^*_{F,i,t} + \frac{S_{t+1}}{S_t}\left(R_{K,t+1} - R^*_t\frac{S_t}{S_{t+1}}\right)(1 - x^*_{i,t})\phi^*_{H,i,t} + \frac{S_{t+1}}{S_t}\left(R_{K,t+1} - R^*_t\frac{S_t}{F_t}\right)x^*_{i,t}\phi^*_{H,i,t} + R^*_t\Bigg]N^*_{i,t}$$

- Excess return on $x^*_{i,t}\phi^*_{H,i,t}$: $R_{K,t+1} - (R_t - cid_t)$
  - $-cid_t$: intermediation fee for currency matching

Non-US bank: Leverage Constraint

Leverage constraint:

$$V^*_{i,t} \geq \left[\left(\theta^*_{F1} + \theta^*_{F2} \frac{Q^*_t K^*_{F,t}}{P^*_t} \right) \phi^*_{F,i,t} + \left(\theta^*_{H1} + \theta^*_{H2} \frac{(1 - x^*_t) S_t Q_t K^*_{H,t}}{P^*_t} \right) (1 - x^*_{i,t}) \phi^*_{H,i,t} + \left(\theta^*_{X1} + \theta^*_{X2} \frac{x^*_t S_t Q_t K^*_{H,t}}{P^*_t} \right) x^*_{i,t} \phi^*_{H,i,t} \right] N^*_{i,t}$$

- $\theta^*_{H1} > \theta^*_{X1}$: stricter regulation on currency mismatch
  - Reflecting heavy penalty on currency mismatch in practice

Non-US Bank: Demand for FX Swap

Optimality condition for $X_{i,t}$:: For the Lagrangian multiplier μ_t^*,

$$E_t\left[\Omega^*_{t,t+1}\frac{S_{t+1}}{S_t}\underbrace{\left(R_{K,t+1}-R_t^*\frac{S_t}{F_t}\right)}_{R_{K,t+1}-(R_t-cid_t)}\right]=\mu_t^*\left(\theta^*_{X1}+\theta^*_{X2}\frac{x_t^*S_tQ_tK^*_{H,t}}{P_t^*}\right)$$

- Downward-sloping inverse demand function in $-cid_t$ eqm

back

Household

Optimization Problem

$$\max_{\{C_t, L_t, D_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma} - 1}{1-\gamma} - \kappa \frac{L_t^{1+\varphi}}{1+\varphi} \right]$$

$$\text{s.t. } P_t C_t + D_t = W_t L_t + R_{t-1} D_{t-1} + TR_t + \Pi_t$$

First-order conditions

$$\kappa C_t^{\gamma} L_t^{\varphi} = \frac{W_t}{P_t}$$

$$E_t[\Lambda_{t,t+1}] R_t = 1$$

for the SDF given by $\Lambda_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left(\frac{P_t}{P_{t+1}} \right)$ back

Capital-good Producer

Perfectly competitive capital-good producers purchasing investment goods at P_t and selling to banks at Q_t

Investment adjustment cost

$$\Psi\left(\frac{I_t}{I_{t-1}}\right) \equiv \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$$

Tobin's Q

$$Q_t = P_t\left[1 + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 + \psi_I \frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}} - 1\right)\right] - E_t\left[\Lambda_{t,t+1} P_{t+1} \psi_I \left(\frac{I_{t+1}}{I_t}\right)^2 \left(\frac{I_{t+1}}{I_t} - 1\right)\right]$$

Law of motion for the capital

$$K_t = I_t + (1 - \delta)K_{t-1}$$

back

Firm

Monopolistic competitive firm $j \in [0, 1]$: $Y_t(j) = Z_t L_t(j)^{1-\alpha} K_{t-1}(j)^{\alpha}$

Cost minimization

$$W_t = (1-\alpha) MC_t \frac{Y_t(j)}{L_t(j)}$$

$$\tilde{R}_{K,t} = \alpha MC_t \frac{Y_t(j)}{K_{t-1}(j)}$$

$$MC_t = \frac{1}{Z_t} \frac{W_t^{1-\alpha} \tilde{R}_{K,t}^{\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}}$$

Price rigidity: Following Rotemberg (1982), for price adjustment cost ψ_P,

$$(1+s)(\epsilon - 1) = \epsilon \frac{MC_t}{P_{H,t}} - \psi_P \left(\frac{P_{H,t}}{P_{H,t-1}} - 1 \right) \frac{P_{H,t}}{P_{H,t-1}} + E_t \left[\Lambda_{t,t+1} \psi_P \left(\frac{P_{H,t+1}}{P_{H,t}} - 1 \right) \left(\frac{P_{H,t+1}}{P_{H,t}} \right)^2 \left(\frac{Y_{H,t+1}}{Y_{H,t}} \right) \right]$$

back

Wholesaler

Perfectly competitive wholesalers aggregating varieties into a single good

- Domestic wholesalers: $Y_{H,t} \equiv \left[\int_{0,1} Y_{H,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$
- Export wholesalers: $Y^*_{H,t} \equiv \left[\int_{0,1} Y^*_{H,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$

Demand functions for each variety

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} Y_{H,t}, \quad Y^*_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} Y^*_{H,t}$$

where price indices for domestic and exported goods are given by

$$P_{H,t} = \left[\int_0^1 P_{H,t}^{1-\epsilon}(j) dj \right]^{\frac{1}{1-\epsilon}}, \quad P^*_{H,t} = \left[\int_0^1 P^{*1-\epsilon}_{H,t}(j) dj \right]^{\frac{1}{1-\epsilon}}$$

back

Retailer

Perfectly competitive retailer aggregating domestic and foreign goods

- Consumption: $C_t \equiv \left[\omega^{\frac{1}{\nu}} C_{H,t}^{\frac{\nu-1}{\nu}} + (1-\omega)^{\frac{1}{\nu}} C_{F,t}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}$
- Investment: $I_t\left(1 + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) \equiv \left[\omega^{\frac{1}{\nu}} I_{H,t}^{\frac{\nu-1}{\nu}} + (1-\omega)^{\frac{1}{\nu}} I_{F,t}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}$

Demand functions: For $P_t = \left[\omega P_{H,t}^{1-\nu} + (1-\omega) P_{F,t}^{1-\nu}\right]^{\frac{1}{1-\nu}}$

$$C_{H,t} = \omega\left(\frac{P_{H,t}}{P_t}\right)^{-\nu} C_t$$

$$C_{F,t} = (1-\omega)\left(\frac{P_{F,t}}{P_t}\right)^{-\nu} C_t$$

$$I_{H,t} = \omega\left(\frac{P_{H,t}}{P_t}\right)^{-\nu} I_t\left(1 + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right)$$

$$I_{F,t} = (1-\omega)\left(\frac{P_{F,t}}{P_t}\right)^{-\nu} I_t\left(1 + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right)$$

back

Monetary and Fiscal Policy

Monetary Policy

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{P_t}{P_{t-1}}\right)^{\phi_\pi(1-\rho_R)} \epsilon_{R,t}$$

where $\bar{R}$ is the steady-state value for R_t, ρ_R is the interest rate smoothing parameter, and

$$\log \epsilon_{R,t} = \rho_m \log \epsilon_{R,t-1} + \sigma_m \epsilon_{m,t}$$

for the monetary policy shock $\epsilon_{m,t} \sim N(0,1)$.

Fiscal Policy

$$TR_t + s(P_{H,t}Y_{H,t} + S_t P^*_{H,t} Y^*_{H,t}) = 0$$

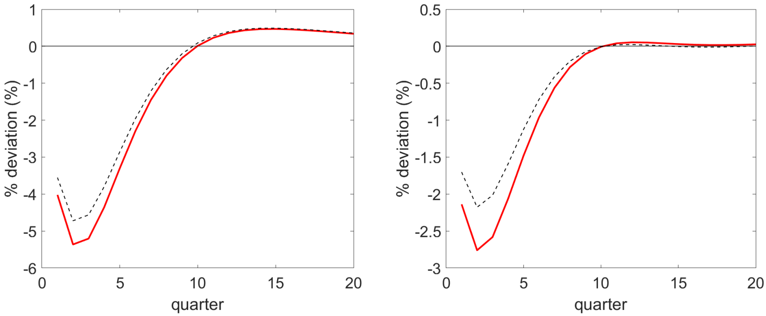
back

Calibration

Parameter	Value	Description	Source or Target
γ	2	Inverse of intertemporal elasticity of substitution	Standard literature
ω	0.8	Home bias	Standard literature
ν	3.8	Elasticity of substitution across country	Bajzik et al. (2020)
ϵ	6	Elasticity of substitution within country	Standard literature
φ	1	Inverse of Frisch elasticity	Standard literature
$s = s^*$	0.2	Subsidy to firms	$s = 1/(\epsilon - 1)$
κ	13.97	Disutility of labor (US)	Steady-state L of 1/3
κ^*	11.83	Disutility of labor (Non-US)	Steady-state L^* of 1/3
α	1/3	Capital share	Standard literature
ψ_P	155.88	Rotemberg price adjustment cost	Calvo parameter of 0.84
δ	0.04	Capital depreciation rate	Standard literature
ψ_I	0.7	Investment adjustment cost	Standard literature
ξ	0.12	Transfer to new US banks	Steady-state leverage of 6
ξ^*	0.09	Transfer to new non-US banks	Steady-state leverage of 6
ϕ_π	1.5	Taylor coefficient on inflation	Standard literature
ρ_r	0.7	Interest rate smoothing parameter	Standard literature
ρ_m	0.25	Persistence of US MP shock	Standard literature

back

Investments

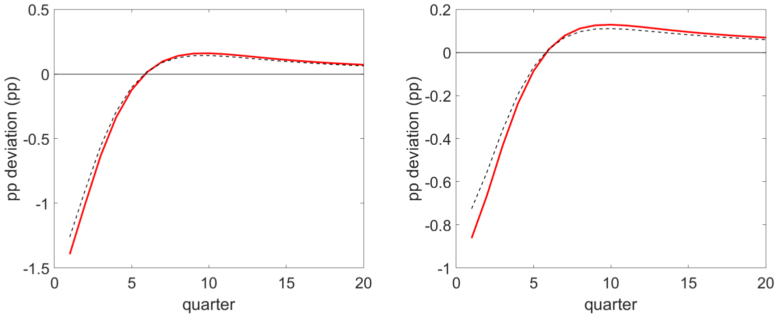


(a) US Investment

(b) Non-US Investment

back

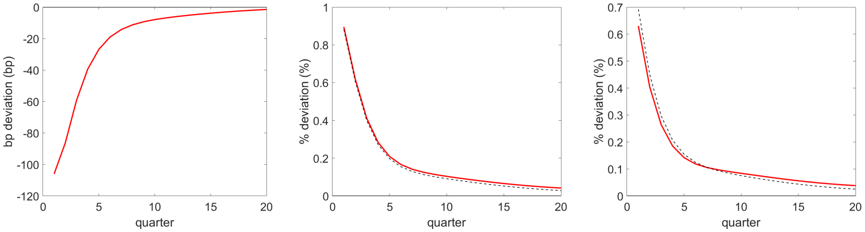
Inflation Rates



(a) US Inflation Rate (b) Non-US Inflation Rate

back

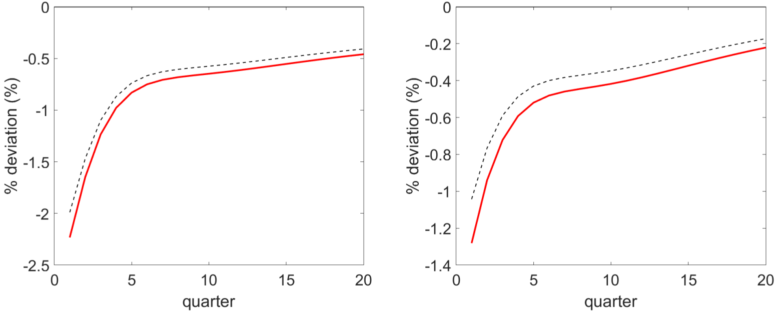
Exchange Rates



(a) Forward Premium (b) Real Exchange Rate (c) Real Forward Rate

back

Capital Asset Prices

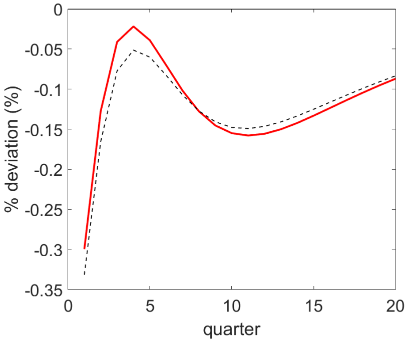


(a) US Price of Capital

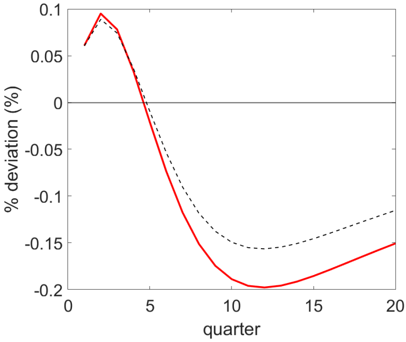
(b) Non-US Price of Capital

back

Consumption



(a) US Consumption



(b) Non-US Consumption

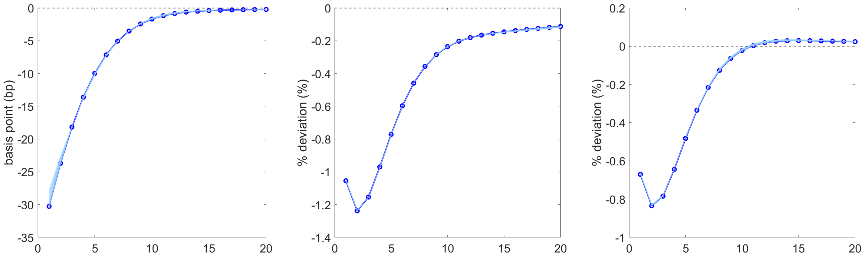
- Smaller decrease in US consumption: due to the transfer of wealth as *cid* (1% of steady-state consumption)

back

Sensitivity Analysis

Choice of θ_{X2}: do impulse responses for each θ_{X2} vary substantially?

- Pick 100 number of $\theta_{X2} \in (0.0001, \theta_{X1}/\bar{x})$
  - To guarantee positive value of leverage constraint $\theta_{X1} + \theta_{X2}(x_t - \bar{x})$
  - $\theta_{H2}, \theta^*_{F2}, \theta^*_{H2}, \theta^*_{X2}$: fixed



(a) CIP Deviations (b) US Output (c) Non-US Output

back