The Synthetic Dollar Funding Channel of US Monetary Policy

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Motivation

Synthetic dollar funding: dollar funding through the FX swap market

1. Borrowing 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

- Synthetic dollar funding cost:

$$R_t^* \frac{S_t}{F_t} = \underbrace{R_t^\$}_{\text{direct funding cost}} - \underbrace{\left(R_t^\$ - R_t^* \frac{S_t}{F_t} \right)}_{\text{CIP deviation: gap}}$$

- Importance of synthetic dollar funding
  - Rising share of the synthetic dollar funding (Barajas et al., 2020) ‣ plot
  - Emergence of CIP deviations (*cid*) after the GFC (Du et al., 2018) ‣ plot

Research Question

Synthetic dollar funding channel of US monetary policy

- Related to credit channel of monetary policy (Bernanke & Gertler, 1995)
  - CIP deviations: wedge in the dollar funding market amplifying transmission channel

Roadmap:

1. Effect of US monetary policy on CIP deviations
   - High-frequency evidence
   - Theoretical explanation: 2-country NK model + FX swap market
2. Effect of CIP deviations on global capital flows
   - Mainly focus on the change in USD-denominated assets
3. Amplification of spillover and spillback effects
   - Comparing with counterfactual world without CIP deviations

Related Literature

Empirical: Keerati (2020), Viswanath-Naraj (2020), Cerutti et al. (2021), Jiang et al. (2021)

- High-frequency identification with more up-to-date dataset

Theoretical:

- CIP deviation and bank: Ivashina et al. (2015), Iida et al. (2018), Liao and Zhang (2020), Bahaj and Reis (2022)
  - Infinite horizon & GE model to analyze the transmission channel
- UIP deviation and macro model: 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
- 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

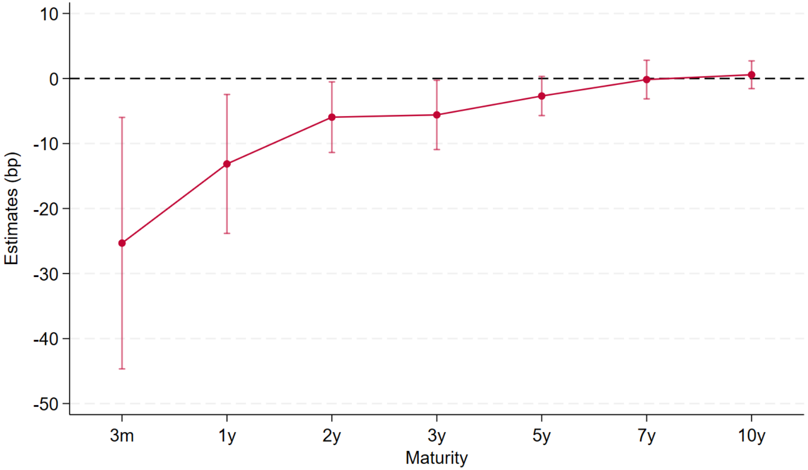
Empirical Strategy

OLS regression with currency fixed effects:

$$\Delta cid^{j}_{t,h} = \alpha_j + \beta_h \Delta mp_t + \epsilon^{j}_{t,h}$$

- $\Delta cid^{j,h}_t$: 2-day change in CIP deviations (currency j, maturity h) ▸ measure
  - $cid^{j,h}_t = r^{\$,h}_t - (r^{j,h}_t - \rho^{j,h}_t)$ for forward premium $\rho^{j,h}_t \equiv f^{j,h}_t - s^{j}_t$
  - Risk-free rate $r^{j,h}_t$: LIBOR
  - Unit: basis points
- Δmp_t: high-frequency identified US monetary policy shock ▸ identification
  - Baseline shock: Nakamura-Steinsson (2018)
  - Unit: % points
- Sample: G10 currencies / Jan 2008 - Apr 2021 (Post-GFC)
- Hypothesis: $\beta_h < 0$ ($\because$ $cid < 0$ on average) ▸ plot ▸ summary

Results



Note: An interval around each point estimate represents a 95% confidence interval with Driscoll-Kraay standard errors.

table term structure robust1 robust2

Model: FX Swap Market

Supply of US banks: obtain $-cid$ as arbitrage profits ‣ FX swap market ‣ details

$$\underbrace{E_t\left[\Omega_{t,t+1}\right]}_{\text{Bank SDF}}\underbrace{\left(R_t^*\frac{S_t}{F_t}-R_t\right)}_{=-cid_t\geq 0}=\underbrace{\mu_t}_{\text{shadow cost}}\left(\theta_{X1}+\theta_{X2}\frac{X_t}{P_t}\right)$$

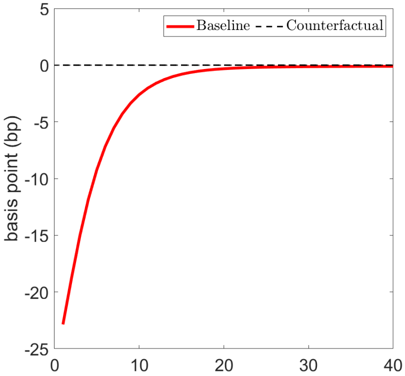
- Subject to limit on CIP arbitrage $(\theta_{X1},\theta_{X2})$

Demand of Non-US banks: pay $-cid$ as fees for currency matching ‣ details

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

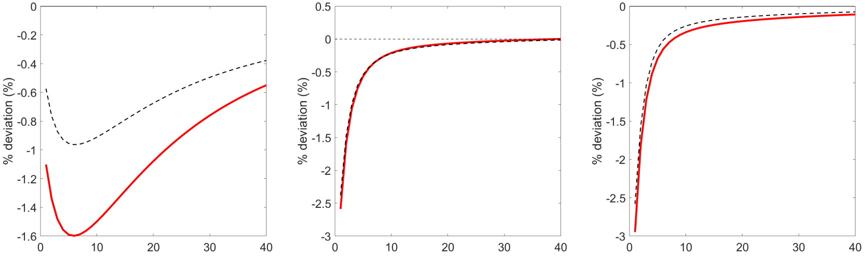
- Assumption: direct dollar funding not available
- Subject to (looser) regulation on hedged position $(\theta^*_{X1},\theta^*_{X2})$

Impulse Responses: CIP Deviations



- Matches the untargeted empirical estimate
- $R \uparrow \Rightarrow$ Net worth decreases $\Rightarrow$ Limit on CIP arbitrage becomes tightened $\Rightarrow$ Shadow cost of balance sheet inclines

Impulse Responses: Capital Flows and Outputs



(a) Cross-border Capital Flows (b) Non-US Output (c) US Output

- CIP deviations $\downarrow$ $\Rightarrow$ Demand for US assets $\downarrow$ $\Rightarrow$ US capital inflows $\downarrow$
- Amplification of spillover: higher costs of dollar funding
- Amplification of spillback: lower demand for US assets
- Amplification of about 10%-20%

Conclusion

Empirical findings: In response to 1%p contractionary shock

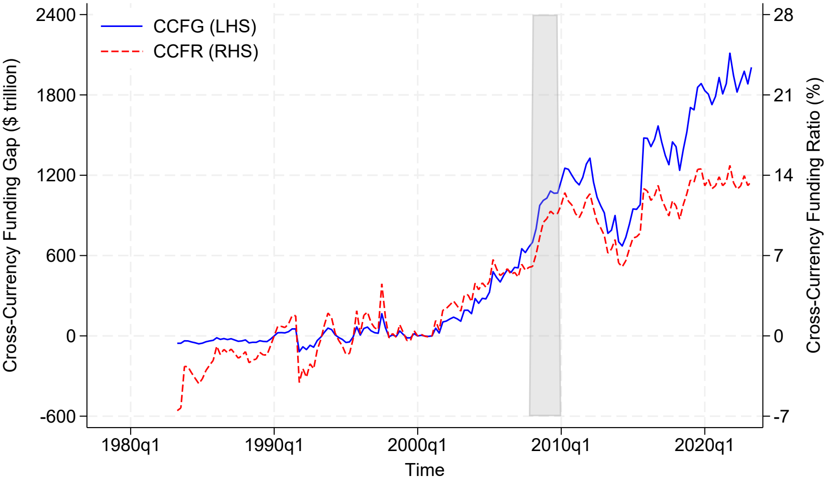
- Post-GFC: significant widening of *cid* (25.5bp for 3-month basis)

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

- *cid*: determined endogenously in the FX swap market
  - Supply: US banks with limit on CIP arbitrage
  - Demand: Non-US banks' currency matching for the USD assets
- *cid* widens since US banks' leverage constraints become tighter
- Amplification of spillover and spillback due to the widening of *cid*
  - Spillover ↑: higher dollar funding costs
  - Spillback ↑: decline in US capital holdings by non-US banks

Appendix

Share of Synthetic Dollar Funding



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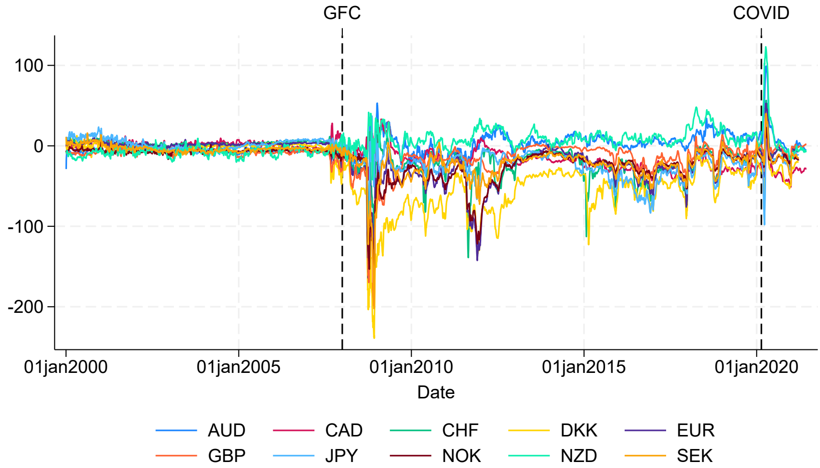
CIP Deviations



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Summary Statistics of CIP Deviations

	3M			1Y			2Y		
	90-99	00-07	08-	90-99	00-07	08-	90-99	00-07	08-
Mean	-3.75	-2.48	-20.93	-2.03	-0.45	-16.74	-2.14	-0.29	-15.63
Median	-2.68	-2.40	-17.87	-1.49	-0.52	-14.80	-2.09	-0.24	-14.21
S.D.	15.36	5.42	20.99	2.63	1.80	13.00	3.20	1.67	11.53
Autocorr.	0.39	0.52	0.75	0.33	0.64	0.71	0.39	0.64	0.71
	3Y			5Y			10Y		
	90-99	00-07	08-	90-99	00-07	08-	90-99	00-07	08-
Mean	-2.56	-0.25	-14.74	-2.46	0.76	-13.29	-4.05	-0.75	-10.63
Median	-2.53	-0.21	-13.55	-2.56	1.06	-12.08	-4.42	-0.45	-9.22
S.D.	3.20	1.76	11.21	4.31	2.51	12.63	3.22	2.64	12.19
Autocorr.	0.41	0.64	0.71	0.39	0.72	0.79	0.35	0.65	0.71

Note: This table presents summary statistics of CIP deviation for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. CIP deviation is measured as an average of cross-currency bases across G10 currencies. For each maturity, summary statistics for subperiods of 1990-1999, 2000-2007, and post-2008 are displayed. Row of this table refers to each summary statistic: mean, median, standard deviation, and autocorrelation. back

Measurement of CIP Deviations

CIP deviations: Cross-currency bases measured by ‣ summary

$$cid_t^{j,h} = r_t^{\$,h} - (r_t^{j,h} - \rho_t^{j,h})$$

- $r_t^{j,h}$: currency j risk-free rate with maturity h
  - Baseline: IBORs
  - Maturities from 3-month
    - ★ More related to business cycle frequency and not affected by quarter-end effects
- $\rho_t^{j,h}$: forward premium (adjusted for actual trading days)
  - Mid price of bid & ask using London closing rates
- Source: Updated dataset of Du, Im, and Schreger (2018) ‣ back

Identification of US Monetary Policy Shock

Identification problem: endogeneity of policy rate

- *cid*: market price of synthetic dollar funding
  - *cid* and monetary policy 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) back

Results: Pre-GFC vs Post-GFC

	3M			1Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	4.208**	-25.32**	-29.53**	0.683*	-13.14**	-13.82**
	(1.830)	(10.55)	(9.879)	(0.364)	(6.460)	(6.469)
R^2			0.019			0.065
Target	0.950	-36.63***	-37.58***	0.516**	-10.30**	-10.88**
	(1.805)	(7.779)	(7.906)	(0.248)	(2.250)	(2.399)
Path	3.232*	10.55**	7.314*	0.223	-3.548	-3.767
	(1.433)	(4.423)	(3.812)	(0.226)	(2.213)	(2.305)
R^2			0.083			0.088
N			1621			1557

Note: This table presents the regression results of cross-currency bases on 1%p contractionary US monetary policy shock for pre-GFC (00-07) and post-GFC (08-21) periods. Units of the estimates are in basis points. Driscoll-Kraay standard errors are reported in the parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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Cumulative Explained Variance of Δcid

	PC1		PC2		PC3	
Δcid	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
AUD	0.4776	0.6262	0.6285	0.7769	0.7692	0.8788
CAD	0.6065	0.7260	0.7660	0.8612	0.8906	0.9217
CHF	0.4252	0.7055	0.6245	0.8762	0.7698	0.9357
DKK	0.4423	0.5557	0.6418	0.7032	0.7786	0.8358
EUR	0.4251	0.7635	0.6133	0.9175	0.7438	0.9612
GBP	0.3635	0.6768	0.5480	0.8573	0.6885	0.9170
JPY	0.5010	0.7177	0.6479	0.8933	0.7825	0.9460
NOK	0.6525	0.5285	0.7951	0.6826	0.9189	0.7875
NZD	0.4287	0.6386	0.6297	0.7854	0.7725	0.8997
SEK	0.3925	0.6617	0.5986	0.8261	0.7445	0.9127

Note: This table presents cumulative explained variance in Δcid. 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 pre-GFC (00-07) and post-GFC (08-) periods separately. Three principal components are displayed in this table for simplicity.

Factor Loadings on PC1 and PC2

PC1	AUD		CAD		CHF		DKK		EUR	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	-0.0017	0.0471	0.0735	0.2177	-0.0079	0.2402	0.0875	0.1443	0.1004	0.2803
1y	0.1996	0.4132	0.3654	0.3669	0.1820	0.3563	0.3697	0.3855	0.2896	0.3626
2y	0.3827	0.4247	0.4162	0.4052	0.2995	0.4079	0.4173	0.4090	0.3708	0.4082
3y	0.4338	0.4562	0.4342	0.4173	0.3320	0.4287	0.4444	0.4099	0.3487	0.4136
5y	0.4556	0.4447	0.4348	0.4018	0.4999	0.4046	0.4327	0.4389	0.4561	0.4067
7y	0.4599	0.3638	0.4143	0.3967	0.5082	0.3973	0.4182	0.3899	0.4765	0.3909
10y	0.4542	0.3293	0.3723	0.4011	0.5086	0.3790	0.3491	0.3881	0.4604	0.3662
	GBP		JPY		NOK		NZD		SEK	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	0.0886	0.2455	0.0597	0.2387	-0.0266	0.2055	-0.0221	0.0867	-0.0225	0.1841
1y	0.2741	0.3344	0.3077	0.3707	0.3604	0.3424	0.3157	0.3454	0.2211	0.3609
2y	0.3992	0.4154	0.3939	0.4136	0.4028	0.4266	0.4591	0.4165	0.3647	0.3970
3y	0.4636	0.4303	0.4442	0.4298	0.4198	0.4565	0.3990	0.4431	0.3988	0.4204
5y	0.4695	0.4287	0.4500	0.4146	0.4255	0.4115	0.5167	0.4369	0.4461	0.4233
7y	0.3990	0.3884	0.4398	0.3886	0.4207	0.3975	0.4305	0.4071	0.4883	0.4122
10y	0.4039	0.3683	0.3916	0.3562	0.4157	0.3504	0.2785	0.3831	0.4703	0.3905

Factor Loadings on PC1 and PC2

PC2	AUD		CAD		CHF		DKK	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	0.5154	0.9041	0.6797	0.8265	0.1650	0.6450	0.2441	0.4190
1y	0.6870	0.1765	0.3540	0.3010	0.5585	0.4279	0.4763	0.3293
2y	0.3342	0.1354	0.3136	0.1178	0.5755	0.2218	0.4604	0.3660
3y	0.0664	0.0284	0.1289	-0.0650	0.3456	0.0080	0.1350	0.2945
5y	-0.1469	-0.0263	-0.1975	-0.1959	-0.1538	-0.2952	-0.2231	-0.1961
7y	-0.2146	-0.2133	-0.3207	-0.3020	-0.3009	-0.3507	-0.4229	-0.4676
10y	-0.2804	-0.2934	-0.3949	-0.2804	-0.3099	-0.3760	-0.5048	-0.4882
	GBP		JPY		NOK		NZD	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	0.1510	0.6473	0.7657	0.6554	0.9983	0.6550	-0.0082	0.8741
1y	0.4210	0.4962	0.4221	0.3732	0.0036	0.4091	-0.3567	0.3111
2y	0.4097	0.1363	0.2576	0.2219	-0.0237	0.1891	-0.2287	0.1277
3y	0.3840	-0.0350	0.0402	0.0295	-0.0094	0.0786	-0.4442	0.0114
5y	-0.1932	-0.2041	-0.1717	-0.2473	0.0313	-0.2486	0.0442	-0.1463
7y	-0.4639	-0.3493	-0.2496	-0.3776	0.0279	-0.3762	0.4410	-0.2162
10y	-0.4817	-0.3890	-0.2753	-0.4211	0.0327	-0.3979	0.6532	-0.2338

Note: This table presents factor loadings on the first two principal components for each currency and for pre-GFC (00-07) and 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. In a column, there are two subcolumns: left subcolumn is the factor loadings for pre-GFC periods while the right subcolumn is the ones for post-GFC periods. Elements of subcolumns are factor loadings for each maturity from 3-month to 10-year.

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Robustness Check 1: OIS Basis

Overnight Index Swap (OIS)

- Better proxy for risk-free rate due to the limited credit risk
- LIBOR-OIS spread: measure of credit risk (risk premium)

OIS Basis: cross-currency basis calculated using OIS rates as

$$
\begin{aligned}
cid_t^{ois,j,h} &= ois_t^{\$,h} - (ois_t^{j,h} - \rho_t^{j,h}) \\
&= \underbrace{libor_t^{\$,h} - (libor_t^{j,h} - \rho_t^{j,h})}_{cid_t^{libor,j,h}} + (libor_t^{j,h} - ois_t^{j,h}) - (libor_t^{\$,h} - ois_t^{\$,h})
\end{aligned}
$$

- Estimation results: larger effect of US mp shock results
- Due to higher US risk premium (Drechsler et al. 2017; Kekre and Lenel 2022)
  - Similar to Jiang et al. (2021) with Treasury basis decomposition

Estimation with OIS basis: Pre-GFC vs. Post-GFC

	3M			1Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	-9.335	-49.74**	-40.40*	7.126	-34.93***	-42.06**
	(6.527)	(13.34)	(13.70)	(10.31)	(4.914)	(11.62)
R^2			0.063			0.107
Target	-3.108	-53.82**	-50.71**	3.236	-20.53**	-23.76*
	(5.862)	(11.08)	(11.70)	(5.769)	(4.158)	(8.094)
Path	-5.840*	1.025	6.865	3.967	-14.72***	-18.68**
	(1.929)	(3.419)	(3.555)	(5.092)	(1.801)	(4.516)
R^2			0.133			0.118
N			1097			1026

Note: This table presents the regression results of OIS cross-currency bases on 1%p contractionary US monetary policy shock for pre-GFC (00-07) and post-GFC (08-21) periods. For 10-year maturity, only post-GFC estimates are provided since the series of OIS rates does not exist for pre-GFC periods in the data. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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Robustness Check 2: 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	-0.012	0.001	$i = -1$	-0.000	-0.009	0.006
	(0.004)	(0.007)	(0.006)		(0.008)	(0.010)	(0.010)
$i = 0$	0.014	0.015	0.014	$i = 0$	0.007	0.006	0.007
	(0.009)	(0.014)	(0.010)		(0.010)	(0.010)	(0.014)
$i = 1$	0.007	-0.010	0.017	$i = 1$	0.023	0.020	0.025
	(0.013)	(0.025)	(0.016)		(0.015)	(0.027)	(0.019)
$i = 2$	-0.005	0.027	-0.027	$i = 2$	0.008	-0.017	0.024
	(0.011)	(0.019)	(0.015)		(0.015)	(0.026)	(0.019)
Inflation forecasts				Δ Inflation forecasts			
$i = -1$	0.002	-0.024*	0.020*	$i = -1$	0.003	0.009	-0.000
	(0.007)	(0.012)	(0.008)		(0.011)	(0.024)	(0.011)
$i = 0$	0.018	0.033	0.007	$i = 0$	-0.002	-0.007	0.005
	(0.010)	(0.019)	(0.011)		(0.017)	(0.031)	(0.017)
$i = 1$	0.002	-0.031	0.027	$i = 1$	-0.012	0.040	-0.047
	(0.015)	(0.031)	(0.016)		(0.022)	(0.041)	(0.025)
$i = 2$	-0.013	0.023	-0.036	$i = 2$	0.043	0.010	0.064
	(0.022)	(0.037)	(0.029)		(0.030)	(0.045)	(0.035)
Unemployment forecasts				Constant			
$i = 0$	0.001	-0.001	0.002		-0.046	-0.046	-0.050
	(0.004)	(0.005)	(0.005)		(0.055)	(0.088)	(0.068)
R^2	0.224	0.139	0.218	F-statistic	2.67	0.94	3.61
N	184	184	184	p-value	0.001	0.533	0.000

Note: Robust standard errors are reported in the parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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Information-robust Monetary Policy Shock

Construction

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

Effects of MPI on CIP Deviation results

- Pre-GFC: more muted
- Post-GFC: larger for 3-month / more muted for longer maturities

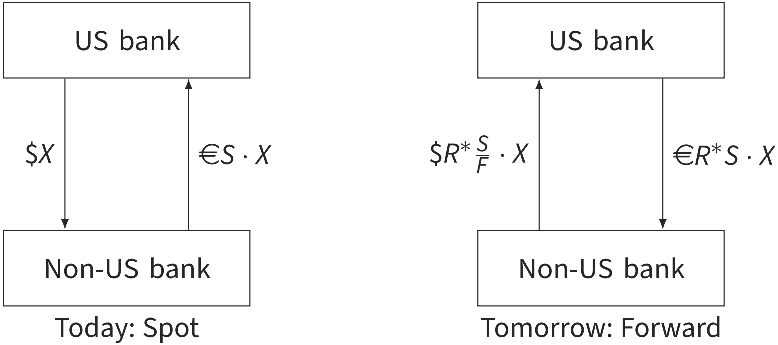
Estimation with *MPI*: Pre-GFC vs. Post-GFC

	3M			1Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.922	-33.86***	-34.78***	1.078*	-8.360**	-9.438**
	(2.035)	(5.283)	(4.507)	(0.393)	(2.422)	(2.672)
R^2			0.034			0.022
Target	-0.470	-49.90***	-49.43***	0.636*	-9.793***	-10.43***
	(1.768)	(7.136)	(7.353)	(0.233)	(1.894)	(2.015)
Path	2.527	13.03*	10.50*	0.360	1.035	0.675
	(1.278)	(4.105)	(3.827)	(0.173)	(2.007)	(2.099)
R^2			0.105			0.049
N			1377			1319

Note: This table presents the regression results of cross-currency bases on 1%p contractionary information-robust US monetary policy shock for pre-GFC (00-07) and post-GFC (08-21) periods. Information-robust US monetary policy shocks are estimated by residuals from the projection on Greenbook forecasts and removing serially correlated parts. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

back

Structure of a FX Swap Contract



▸ 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

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

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

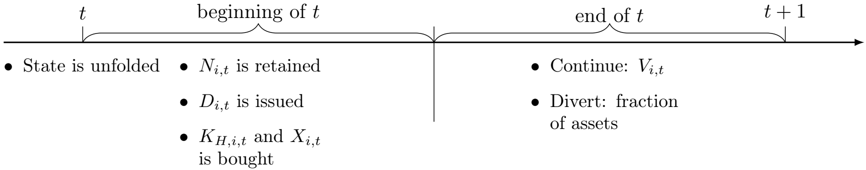
- $-cid_t$: fee for supplying synthetic dollar funding ($\because$ sell USD spot)

Balance Sheet and Flow of Funds

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

back

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
  - Exiting banks: pay out net worth to households
- $V_{i,t} = \nu_t N_{i,t}$: shown by guess and verify method proof
  - $\nu_t = E_t[\Lambda_{t,t+1}(1-\sigma+\sigma\nu_{t+1})(N_{i,t+1}/N_{i,t})] \equiv E_t[\Omega_{t,t+1}(N_{i,t+1}/N_{i,t})]$

Linearity of Bank Value Function

<u>Guess</u>: $V_{i,t} = \nu_t N_{i,t}$

$\Rightarrow$ 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:

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

- $\theta^*_{H1} > \theta^*_{X1}$: 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^*,

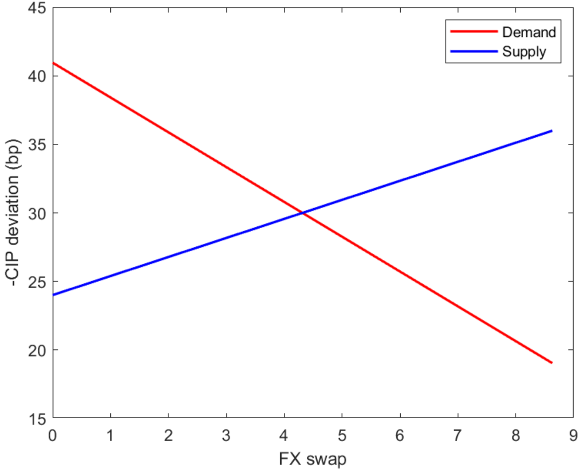
$$E_t\left[\Omega^*_{t,t+1}\frac{S_{t+1}}{S_t}\underbrace{\left(R_{K,t+1} - R_t^*\frac{S_t}{F_t}\right)}_{R_{K,t+1}-(R_t-cid_t)}\right] = \mu_t^*\left(\theta^*_{X1} + \theta^*_{X2}\frac{x_t^* S_t Q_t K^*_{H,t}}{P_t^*}\right)$$

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

back

Equilibrium for the 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

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

Capital adjustment cost

$$\Psi\left(\frac{I_t}{K_{t-1}}\right) \equiv \frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2$$

Tobin's Q

$$Q_t = P_t\left(1 + \psi_K\left(\frac{I_t}{K_{t-1}} - \delta\right)\right) - E_t\left[\Lambda_{t,t+1} P_{t+1} \psi_K \left(\frac{I_{t+1}}{K_t} - \delta\right)\frac{I_{t+1}}{K_t}\right]$$

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

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

where price indices for domestic and exported goods are given by

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

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: $I_t + K_{t-1}\frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 \equiv \left[\omega^{\frac{1}{\nu}} I_{H,t}^{\frac{\nu-1}{\nu}} + (1-\omega)^{\frac{1}{\nu}} I_{F,t}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}$

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

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

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

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

$$I_{F,t} = (1-\omega)(\frac{P_{F,t}}{P_t}\Big)^{-\nu}\left[I_t + K_{t-1}\frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2\right]$$

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

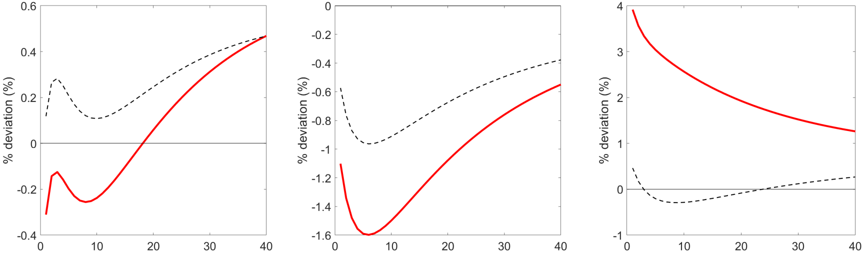
$$TR_t + s(P_{H,t}Y_{H,t} + S_t P^*_{H,t} Y^*_{H,t}) = 0$$

back

Calibration: Banking Sector

Parameter	Value	Target
β	0.995	US risk-free rate of 2%
σ	0.95	Average survival horizon of 5 years
θ_{H1}	0.604	US capital excess return of 200bp
θ_{X1}	0.121	RoW capital excess return of 200bp
θ^*_{F1}	0.304	US NFA-to-GDP ratio of -18.5%
θ^*_{H1}	0.304	Domesetic investment share of 54%
θ^*_{X1}	0.243	CIP deviation of -30bp
θ_{H2}	0.005	Devereux et al. (2023)
θ_{X2}	0.005	Devereux et al. (2023)
θ^*_{F2}	0.005	Devereux et al. (2023)
θ^*_{H2}	0.005	Devereux et al. (2023)
θ^*_{X2}	0.005	Devereux et al. (2023)

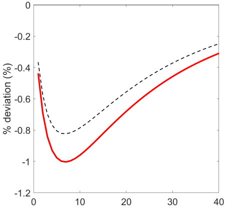
IRFs: Synthetic Dollar Funding



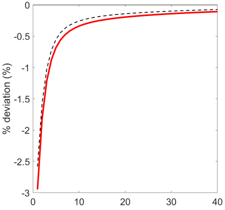
(a) Synthetic Dollar Funding (b) Cross-border Capital Flows (c) US's US Capital Holdings

- Decrease: due to the tightening of the leverage constraint
  - Increase in the counterfactual (substitution effect)
- Global retrenchment toward domestic assets
  - Capital inflows into the US: decreases
  - Domestic capital holdings (by the US): increases

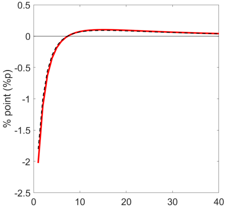
Amplification of Spillover and Spillback



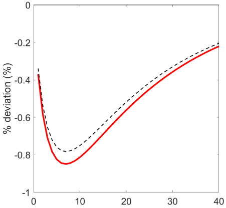
(a) US Capital



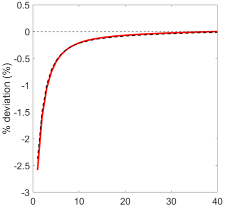
(b) US Output



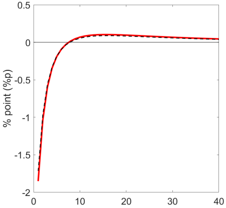
(c) US Inflation



(d) Non-US Capital

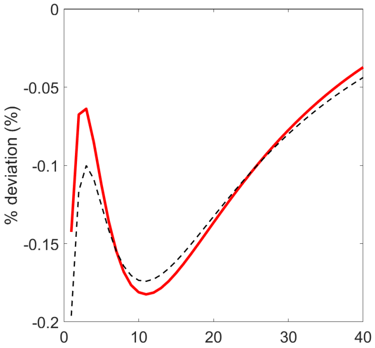


(e) Non-US Output

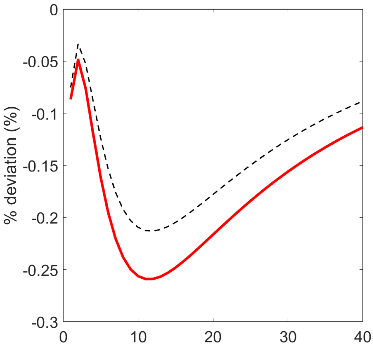


(f) Non-US Inflation

IRFs: Consumption



(a) US Consumption

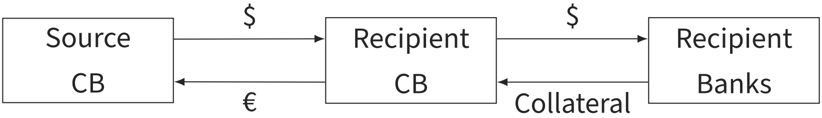


(b) Non-US Consumption

- CIP deviations: transfer of wealth from the Non-US to US
  - Intermediation fees that non-US banks pay for dollar funding

Central Bank Swap Lines

Lender of the last resort: collateralized public liquidity line



- Interest rate: swap spread ss_t over a risk-free rate
- $-cid_t \leq ss_t$: ceiling on CIP deviations (Bahaj and Reis, 2021)
  - Guaranteed by no arbitrage condition
  - International version of discount window policy

Implication for the monetary policy transmission channel:

- Synthetic dollar funding cost does not rise due to the upper bound
- May dampen the amplification!
- 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

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

- Complementary slackness condition:

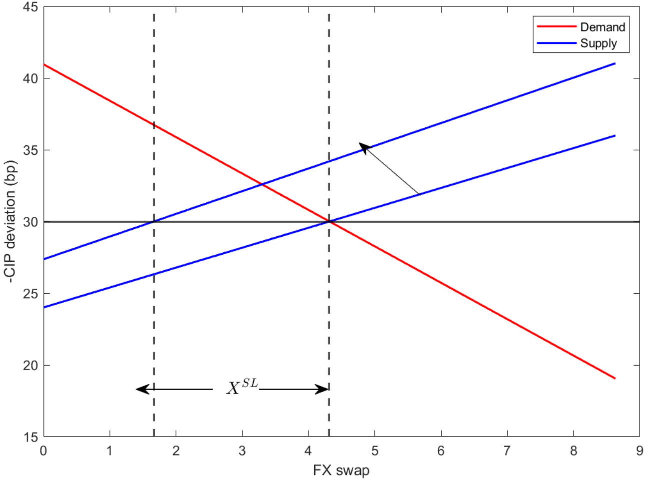
$$(cid_t - \overline{cid})X_t^{SL} = 0$$

- Government budget constraint

$$s\left(P_{H,t}Y_{H,t} + \frac{1}{S_t}P_{H,t}^*Y_{H,t}^*\right) + tr_t + X_t^{SL} = (R_{t-1} - cid_{t-1})\,X_{t-1}^{SL}$$

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

FX Swap Market with Swap Line Policy



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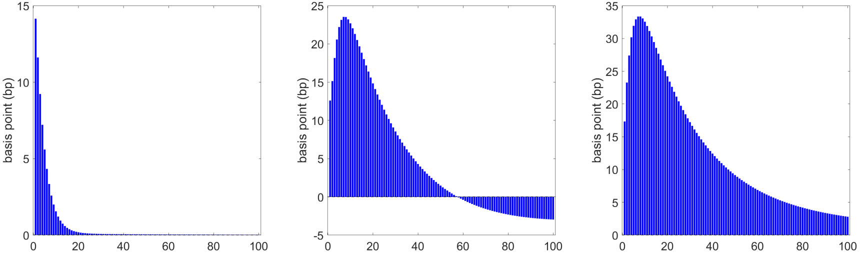
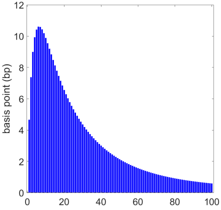
Transmission Channel: With v.s. Without Swap Lines



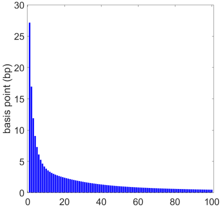
(a) CIP Deviations (b) Synthetic Dollar Funding (c) Cross-Border Holdings

- Upper bound binds due to the upward pressure on the size of CIP deviations
- Global retrenchment toward domestic assets is alleviated

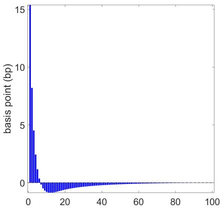
Transmission Channel: With v.s. Without Swap Lines



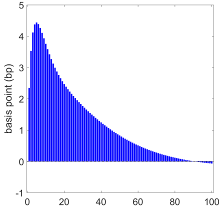
(a) US Capital



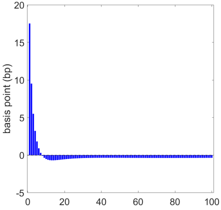
(b) US Output



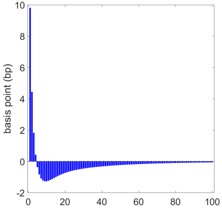
(c) US Inflation



(d) Non-US Capital



(e) Non-US Output



(f) Non-US Inflation