

The Synthetic Dollar Funding Channel of US Monetary Policy^{*}

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This version: March 6, 2024

Abstract

This paper studies a novel transmission channel of US monetary policy through the FX swap market: the *synthetic dollar funding channel*. First, I show empirically that a contractionary US monetary policy shock widens deviations from covered interest rate parity (CIP) significantly in the post-GFC period. Then, I construct a two-country New Keynesian model with financially-constrained banks and a FX swap market. In the FX swap market, US banks are suppliers of synthetic dollar funding and obtain CIP deviations as intermediation fees arising from the limit to arbitrage while non-US banks are demanders for matching currencies in holding US capital. In equilibrium, CIP deviations are endogenously determined so that the FX swap market clears. From the calibrated model, a contractionary US monetary policy shock widens CIP deviations because it tightens the leverage constraint of US bank. This implies that the gap between cost of synthetic dollar funding and direct dollar funding becomes larger. Then, spillover to non-US and spillback to US output, investment, and inflation are amplified compared to the counterfactual case in which CIP holds. Finally, I show that central bank swap lines attenuate the synthetic dollar funding channel of US monetary policy.

JEL Codes: E52, F41, G15

Keywords: CIP deviations; Synthetic dollar funding; Monetary policy; Transmission channel

^{*}I am greatly indebted to my advisors, Stephanie Schmitt-Grohé, Martin Uribe, and Jesse Schreger, for their guidance and support in my dissertation. I would also like to thank Richard Clarida, Wenxin Du, and seminar participants at Columbia University for helpful comments.

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1 Introduction

There is an extensive literature on the transmission of US monetary policy to the global economy as the US plays a central and asymmetric role in the world (Miranda-Agrippino and Rey, 2020). This strand of literature has focused on the direct dollar funding market as the transmission mechanism whereby non-US countries can borrow directly from the pool of US dollar (USD) (see Bräuning and Ivashina (2020) for example). Since the direct dollar funding cost, such as the London Inter-Bank Offered Rate (LIBOR), tracks closely the policy rate of the Federal Reserve, US monetary policy can be transmitted to foreign countries through capital flows determined by this cost.

However, as Du and Schreger (2022) point out, many market participants of non-US countries, including banks, lack access to the direct dollar funding market and instead have to rely on foreign exchange (FX) swap market for dollar funding. Dollar funding through the FX swap market is referred to as synthetic dollar funding since it is generated by swapping local currency into US dollars. The share of synthetic dollar funding in the total dollar funding has been rising rapidly since 2000's, implying the importance of investigating synthetic dollar funding (Barajas et al., 2020). The cost of synthetic dollar funding is generically different from the direct dollar funding cost, and the gap between these two costs is equivalent to deviations from Covered Interest Rate Parity (CIP).¹

The emergence of CIP deviations after the global financial crisis (GFC) made it necessary to distinguish synthetic dollar funding costs from direct dollar funding costs. Before the GFC, covered interest rate parity held well in the sense that the magnitude of CIP deviations was negligible. However, during the GFC, there were substantial deviations from the parity (see Baba et al. (2008) for instance). What is more striking is that CIP deviations did not disappear and stayed at negative value on average persistently even after the GFC. The negative value of CIP deviations implies that synthetic dollar funding costs are higher than direct dollar funding costs. There exists an extensive literature on the sources of CIP deviations after the GFC, and the regulation on riskless arbitrage has been identified as one of the main reasons (Du et al., 2018a).

Motivated from the rising importance of synthetic dollar funding and the divergence between synthetic and direct dollar funding costs, this paper investigates a novel transmission channel of US monetary policy: the synthetic dollar funding channel. It refers to the transmission of US monetary policy through capital flows mediated by the FX swap market. Flows of synthetic dollar funding are determined by synthetic dollar funding costs whereby CIP deviations work as wedges between synthetic and direct dollar funding costs. Hence, this paper analyzes effects of US monetary policy shocks on CIP deviations and their implications for macroeconomic variables.

First, this paper estimates the responses of CIP deviations to US monetary policy shocks using high-frequency identification. It is shown that for the whole sample period from January 2000 to

¹Following the convention of measuring cross-currency bases, this paper defines CIP deviations as direct dollar funding costs – synthetic dollar funding costs.

April 2021, responses of 3-month CIP deviations are insignificant, with the effects decreasing as maturities become longer. Next, I investigate the structural break in the effect of US monetary policy on CIP deviations around the GFC considering that CIP deviations have emerged since the GFC. The estimation result shows that US monetary policy has large and significant effects on CIP deviations in the post-GFC (2008-) periods, whereas the pre-GFC (2000-2007) effects are insignificant. For instance, 3-month CIP deviations widen by 25.5bp in response to a 100bp contractionary shock in the post-GFC period, which is substantial considering that the post-GFC average of CIP deviations for G10 currencies is about 20bp. The results are shown to be robust to the choice of risk-free rate in measuring CIP deviations and to the information effect of US monetary policy.

Given the above empirical results, I then construct a two-country New Keynesian model with financially-constrained banks and a FX swap market to investigate why this happens and what this implies for the transmission of US monetary policy to the world. The novel part of this model is embedding the FX swap market into a general equilibrium model. Then, CIP deviations are endogenously determined as an equilibrium object in the FX swap market where the participants are US and non-US banks. US banks are suppliers while non-US banks are demanders in the FX swap market. They exchange their currencies at the FX swap market to exploit arbitrage profits or to avoid currency mismatch problem.

US banks are suppliers of synthetic dollar funding since they can access USD deposits whereas non-US banks cannot by the assumption. The process of supplying synthetic dollar funding is equivalent to the CIP arbitrage because US banks borrow in USD and lend in foreign currency while covering the currency risk. In other words, they sell USD spot and buy USD forward, supplying the USD synthetically. One of the key financial frictions of the model is that US banks are subject to a limit on arbitrage reflecting the strengthened regulation after the GFC. Then, CIP deviations emerge as shadow costs of bank balance sheet space. Since the size of CIP deviations is the arbitrage profit, they are intermediation fees that US banks can obtain by supplying synthetic dollar funding. Hence, the model predicts upward-sloping supply of synthetic dollar funding in the size of CIP deviations.

Non-US banks comprise the demand side of the synthetic dollar funding market for matching currencies of US capital holdings. They demand currency matching since US capital holdings with currency risks are subject to tighter regulation. Since this model assumes that direct dollar funding is not available to non-US banks, they have to rely on synthetic dollar funding in order to avoid currency mismatch. Then, the excess return on US capital held by non-US banks is the difference between the rate of return on US capital and the synthetic dollar funding cost. As CIP deviations become more negative, the synthetic dollar funding cost rises and the excess return on USD-denominated capital declines; non-US banks need to pay CIP deviations as intermediation fees to US banks. Thus, the demand function for synthetic dollar funding is decreasing in the size of CIP deviations.

The model is calibrated targeting long-run first moments of the US and non-US economy. Based

on the calibrated model, impulse responses to a 100bp contractionary US monetary policy shock are derived. In order to investigate the amplification of transmission through synthetic dollar funding, these impulse responses are compared with the counterfactual ones where there is no limit to CIP arbitrage. CIP deviations widen since the leverage constraint of US banks become tighter. This is due to the lower price of capital and the following lower net worth of US banks, leading to higher shadow costs of balance sheet space. Notably, this model produces the impact response of CIP deviations similar to the empirical estimate as an untargeted moment. In the counterfactual case, CIP deviations stay at zero.

The widening of CIP deviations implies amplified transmission of US monetary policy to macroeconomic aggregates since synthetic dollar funding costs rise more than direct dollar funding costs. First, the quantity of synthetic dollar funding decreases and non-US banks' holdings for US capital drop more than the counterfactual case. Consequently, both the US and the non-US aggregate capital stock are reduced. Note that the amplified decrease in US capital stock implies the spillback effect originating from the decline in US capital holdings by non-US banks. Aggregate output, investment, and inflation show similar patterns of amplified spillover and spillback. Interestingly, US consumption is higher while non-US consumption is lower under the baseline case. This is because CIP deviations are intermediation fees that US banks collect from non-US banks, resulting in the transfer of wealth from the non-US to the US. Nominal and real appreciation are also amplified due to the lower supply of the US dollar through the FX swap market.

Finally, I investigate the effect of central bank swap lines on the synthetic dollar funding channel of US monetary policy. The swap line policy is known to impose an upper bound on CIP deviations, stabilizing the FX swap market during financial distress periods ([Bahaj and Reis, 2022](#)). When there is a contractionary US monetary policy shock, the swap line policy can prevent the widening of CIP deviations and affect the following spillover to the world. In order to investigate the effect on the transmission channel, the swap line policy is modeled as an occasionally binding upper bound on CIP deviations. Then, I compare impulse responses under the existence of the swap line policy to those without the swap line policy. In response to the same shock as the baseline model, the widening of CIP deviations becomes smaller due to the binding upper bound. Thus, the decline in synthetic dollar funding is dampened, leading to higher US capital holdings by non-US banks compared to the baseline model. Hence, the transmission to capital, output, investment, and inflation is attenuated.

Related Literature

After the onset of the GFC, there has been extensive literature on the emergence of CIP deviations (see [Baba et al. \(2008\)](#), [Du and Schreger \(2016\)](#), [Du et al. \(2018a\)](#), [Du et al. \(2018b\)](#)). [Du et al. \(2018a\)](#) and [Cerutti et al. \(2021\)](#) regress CIP deviations on interest rate differentials and suggest the role of monetary policy, though they do not estimate the causal effects. [Jiang et al. \(2021\)](#) estimate

the causal effect of high-frequency identified US monetary policy shocks on Treasury basis. This paper uses LIBOR basis instead since it gauges frictions in interbank dollar funding markets, which are the main focus of this paper, while Treasury basis is more related to convenience yields.

[Keerati \(2020\)](#) and [Viswanath-Natraj \(2020\)](#) take the similar approach as this paper for the empirical estimation part. They use high-frequency identified monetary policy shocks and LIBOR basis as the measure for CIP deviations. In [Keerati \(2020\)](#), US monetary policy is estimated to have insignificant effect on CIP deviations of G10 currencies even for post-GFC periods. [Viswanath-Natraj \(2020\)](#) uses sample consisting of Euro Area, Japan, and Switzerland, and the effect is also estimated to be insignificant. This is in contrast to the results of this paper; this paper uses more up-to-date dataset until April 2021 and also shows robustness of the results to using OIS rates as risk-free rates and to information effect of monetary policy.

Regarding the theoretical explanation for CIP deviations based on financial intermediaries, [Ivashina et al. \(2015\)](#) derives CIP deviations from margin requirement for the arbitrage. [Iida et al. \(2018\)](#) extend [Ivashina et al. \(2015\)](#) by microfounding the investment decisions of arbitrageurs and argue that interest rate differentials are also important for determining CIP deviations. In addition, [Liao and Zhang \(2020\)](#) model currency hedging of net foreign asset position based on mean-variance utility, and show that the sign of CIP deviations is determined by the sign of the net foreign asset position. However, these papers are partial equilibrium model with static or finite horizon, so it is hard to analyze general equilibrium effects or conduct policy analysis. I extend the literature to infinite horizon and general equilibrium model and investigate the transmission channel of monetary policy to global economies.

This paper is also related to research on the (failure of) interest rate parity and its implication for the macroeconomy. [Kollmann \(2005\)](#) introduces exogenous shocks to UIP deviations into a two-country model and shows that UIP shocks are main sources of exchange rate fluctuations. In [Gabaix and Maggiori \(2015\)](#), UIP deviations are generated endogenously by segmented international financial markets and global financiers. [Itskhoki and Mukhin \(2021\)](#) extend this framework by incorporating into the conventional business cycle model and explain several puzzles in international macroeconomics. [Kalemli-Özcan \(2019\)](#), [di Giovanni et al. \(2022\)](#), and [Varela and Kalemli-Özcan \(2022\)](#) relate UIP deviations to global risk appetite or global financial cycle and discuss the spillover effect through UIP deviations. [Schmitt-Grohé and Uribe \(2022\)](#) distinguish transitory and permanent US monetary policy shock and analyze the effect of each shock on UIP deviations and exchange rate based on small open New Keynesian model with portfolio adjustment costs. Notably, [Akinci et al. \(2022\)](#) and [Devereux et al. \(2023\)](#) have methodological similarities to this paper. [Akinci et al. \(2022\)](#) investigate the effect of uncertainty shock while [Devereux et al. \(2023\)](#) focus on the effect of first-order shocks in the presence of collateral advantage of US government bond.

However, all the above papers work on UIP deviations rather than CIP deviations. Even though

UIP deviation is usually higher than CIP deviation, CIP deviation is crucial for banks since they are usually required to hedge currency risks. Said differently, CIP deviation is a pivotal barometer for gauging the cost of dollar funding in the international financial market. This paper contributes to the literature on interest rate parity and its implication for global economies by shedding light on CIP deviations and the synthetic dollar funding channel.

This paper is also closely related to recent papers on convenience yields. In [Jiang et al. \(2020\)](#) and [Kekre and Lenel \(2021\)](#), convenience yields are determined from the demand for safety that USD provides: exogenously given demand function for US government bonds ([Jiang et al., 2020](#)) or money-in-the-utility function ([Kekre and Lenel, 2021](#)). [Bianchi et al. \(2022\)](#) argue that settlement risk in interbank markets creates the precautionary demand for US dollar and CIP deviations appear as dollar liquidity premium. Unlike these papers, I derive CIP deviations from the limit to arbitrage and demand for currency matching, unrelated to the safety or the liquidity that USD provides.

With some earlier papers ([Baba and Packer \(2009a,b\)](#)), there are recent research on the effects of central bank swap lines on CIP deviations and asset prices such as [Bahaj and Reis \(2022\)](#) and [Kekre and Lenel \(2021\)](#). However, these papers look at high-frequency changes, which is often impossible for macroeconomic aggregates. This paper supplements the literature by analyzing the effect of the swap line policy on transmission channel of US monetary policy.

This paper is organized as follows. In section 2, I present empirical evidence on the effect of US monetary policy on CIP deviations. Section 3 presents a two-country New Keynesian model with banks and the FX swap market. In section 4, I calibrate the model and present impulse responses to contractionary US monetary policy shock. Section 5 concludes.

2 Empirical Evidence

In this section, I estimate the effect of US monetary policy on CIP deviations in order to provide evidence on the transmission of US monetary policy to synthetic dollar funding cost. For this purpose, I construct panel dataset consisting of CIP deviations of G10 currencies and high-frequency identified US monetary policy shocks from January 2000 to April 2021. Then, effects of US monetary policy on CIP deviations are estimated by OLS regression with currency fixed effects for pre-GFC and post-GFC periods. The estimation results are insignificant for pre-GFC periods while they are large and significant for post-GFC periods. Moreover, the results are robust to using the overnight index swap (OIS) rate as the risk-free rate and to the information effect of US monetary policy.

2.1 Empirical Strategy

Following the literature such as [Nakamura and Steinsson \(2018\)](#), the effect of US monetary policy on CIP deviation can be estimated by the following OLS regression with currency fixed effects:

$$\Delta cid_{t,h}^j = \alpha_j + \beta_h \Delta mp_t + \epsilon_{t,h}^j \quad (2.1)$$

The dependent variable $\Delta cid_{t,h}^j$ is the change in CIP deviation between currency j and USD with maturity h . In the right-hand side, α_j is the currency fixed effect, Δmp_t is the change in US monetary policy indicator, and $\epsilon_{t,h}^j$ is the disturbance term. Then, for each maturity h , (2.1) is estimated from the currency panel. β_h is the effect of US monetary policy on CIP deviation for each h , implying that we obtain the term structure of the estimated effects. The currencies used in this regression are G10 currencies while the maturities span from 3-month to 10-year.^{2,3} Maturities longer than or equal to 3-month are chosen since they are more related to business cycle frequency, and also not affected by quarter-end effects (see [Du et al., 2018a](#)). The sample period starts from February 2000 and ends at April 2021.⁴

However, the above fixed effect regression cannot identify the causal link between the US monetary policy and CIP deviation. This is due to the endogeneity of policy rates, which can bring about inconsistent and biased estimates of the estimates. Since CIP deviations are the market price of the synthetic dollar funding through the FX swap market, it is determined in the general equilibrium. This means that CIP deviations are affected by not only monetary policy stance but also other macroeconomic variables that are related to the demand for US dollar or financing conditions of intermediaries. Since those macroeconomic variables are also correlated with US monetary policy, a simple OLS regression is susceptible to the endogeneity problem.

Regarding the identification of exogenous monetary policy shock, there has been an extensive literature on using high-frequency surprises in interest rate futures as monetary policy shocks (see [Gürkaynak et al., 2005](#); [Nakamura and Steinsson, 2018](#) for example). Those papers measure surprises in the interest rate futures over narrow window, for instance 30 minutes, around each FOMC announcement. Then, they extract one or multiple principal components from the high-frequency surprises and regard those components as direct measures for US monetary policy shocks. The key identifying assumption is that all the information on fundamentals related to monetary policy are priced before the FOMC announcement. This assumption is satisfied since we take the window narrow enough that the monetary policy cannot respond to the changes in fundamentals over that

²G10 currencies other than the USD are Australian Dollar (AUD), Canadian Dollar (CAD), Swiss Franc (CHF), Danish Krone (DKK), Euro (EUR), British Pound (GBP), Japanese Yen (JPY), Norwegian Krone (NOK), New Zealand Dollar (NZD), and Swedish Krona (SEK).

³CIP deviations have maturities of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year.

⁴February 2000 is the first month of 2000 with the FOMC meeting, and April 2021 is the last period that I have the US monetary policy shock data for.

window, implying that the surprises in the interest rate futures are only due to unsystematic part of monetary policy. Hence, the surprises in the interest rate futures only reflect unexpected changes in monetary policy. Following this literature, Δmp_t in this model is identified by high-frequency method. The detailed method and data for this identification will be covered in Section 2.2.

2.2 Measurement and Data

CIP deviations of G10 currencies are measured by the cross-currency bases defined as the following:

$$cid_{t,h}^j \equiv r_{t,h}^{\$} - (r_{t,h}^j - \rho_{t,h}^j)$$

where $r_{t,h}^{\$}$ and $r_{t,h}^j$ are the risk-free rate of the USD and currency j respectively that matures h periods after the time t . $\rho_{t,h}^j$ is the forward premium of currency j against the USD with maturity h , defined as the difference between the log of forward and spot exchange rate. The spot and the forward exchange rate are defined in units of currency j per USD, so the increase in those exchange rates means the appreciation of the USD.

For 3-month maturity, cross-currency basis is directly calculated by the above equation. First, the interbank offered rate (IBOR) is used as the proxy for the risk-free rate $r_{t,h}^{\$}$ and $r_{t,h}^j$.⁵ Daily data of IBORs for each currency can be obtained from Bloomberg.⁶ Next, $\rho_{t,h}^j$ is measured as the mid price of bid and ask for the forward premium using London closing rates, and is adjusted for the actual trading days.

For maturities longer than or equal to 1-year, the forward premium is inaccurate since the forward market is relatively illiquid. Instead, following Du et al. (2018a), cross-currency basis is directly measured from the cross-currency swap traded in the over-the-counter (OTC) market. Similar to the forward premium above, the mid price of bid and ask for the cross-currency basis is used. As in Du et al. (2018a), we can back out the forward premium by replicating the fixed-for-fixed currency swap. First, an investor pays the fixed-for-floating interest rate swap $r_{t,h}^{irs,j}$ in order to exchange fixed payments into floating payments. Then, she pays cross-currency basis to exchange the floating payments in currency j into those in the USD since the cross-currency swap exchanges floating interest payments. Finally, floating payments in the USD is exchanged into fixed payments by paying the USD interest rate swap $r_{t,h}^{irs,\$}$. Since this investment strategy replicates the fixed-for-fixed

⁵IBORs have been replaced by the Secured Overnight Financing Rate (SOFR) since December 31 2021. Since the data end at April 2021, the replacement of the IBORs does not matter in this paper. Also, there is a concern that IBOR is an imperfect benchmark for risk-free rate since it is unsecured, especially during financial distress periods. For this reason, I conduct a robustness check in Section 2.3.3 and show that using the overnight index swap (OIS) rates does not change the results of my analysis qualitatively.

⁶For USD, GBP, JPY, and CHF, we use LIBOR as the benchmark rate. EURIBOR is used for the case of EUR. For other currencies, their own benchmark rates are used. See Du et al. (2018b) for details.

currency swap with the return rate of the forward premium, it can be calculated as

$$\rho_{t,h}^j = r_{t,h}^{irs,j} + cid_{t,h}^j - r_{t,h}^{irs,\$}$$

Daily data for interest rate swaps and cross-currency bases are available at Bloomberg, and Jesse Schreger kindly shared the data with me.

After calculating CIP deviations, I take two-day difference in CIP deviations as $\Delta cid_{t,h}^j$. For each period t , this two-day window spans from one day before t to one day after t , meaning that $\Delta cid_{t,h}^j = cid_{t+1,h}^j - cid_{t-1,h}^j$. If t corresponds to the date of the FOMC meeting, $\Delta cid_{t,h}^j$ measures the change between CIP deviations one day before and after the FOMC meeting. The reason for taking the two-day window, instead of the one-day window, is that there is time zone difference in the currency market. When there is a US monetary policy shock, some currency markets may be closed and not respond to the shock. Hence, similar to some literature on currency markets, I take two-day difference in CIP deviations.

CIP deviations measured as the cross-currency basis can take both positive and negative value. For example, cross-currency bases of Australian Dollar (AUD) and New Zealand Dollar (NZD) are positive on average while those of other currencies are negative on average.⁷ Then, the change in CIP deviations has completely different meaning depending on the sign of CIP deviations. For example, when CIP deviations are negative, then the decline in CIP deviations means that CIP deviations widen from zero. On the contrary, if CIP deviations are positive, then the rise in CIP deviations implies the narrowing of CIP deviations. Table 1 displays summary statistics of CIP deviations for each maturity and for three different subperiods. CIP deviation is measured as an average of cross-currency bases across G10 currencies. According to Table 1, mean and median of CIP deviations are mostly negative for every maturity. In particular, the mean of 3-month CIP deviation is about -21bp for post-GFC periods. Thus, the decline in CIP deviations can be interpreted as the widening of CIP deviations, and this paper will use the decline and the widening interchangeably. We can also see that the size of mean, median, and standard deviation of CIP deviations became substantially larger after 2008, implying that there is a structural break around the GFC on the size and the volatility of CIP deviations.

In order to identify the US monetary policy shocks, five interest rate futures are used: federal funds futures immediately following the FOMC announcement (FF1), federal funds futures immediately following the next FOMC announcement (FF4), and 3-month Eurodollar futures at horizons of

⁷Liao and Zhang (2020) show that cross-currency basis is negative (positive) when net foreign asset position of a country is positive (negative). This is because arbitrageurs take the opposite position of the counterparty countries whose hedging demand comes from their net foreign asset position denominated in US dollar. If a country has positive net foreign asset position, then arbitrageurs should take negative position of US dollar, implying that cross-currency basis should be negative for positive arbitrage profits. In light of this argument, cross-currency bases of AUD and NZD are positive since these countries have negative net foreign asset position.

Table 1: 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.

two, three, four quarters ahead (ED2, ED3, and ED4 respectively). Note that interest rate futures other than FF1 contain information on forward guidance which has become a crucial policy tool since the global financial crisis and the following zero lower bound periods. Then, surprises in these interest rate futures are measured over 30-minute window around each FOMC announcement: changes from 10 minutes before to 20 minutes after the FOMC announcement.

Following Nakamura and Steinsson (2018), one principal component is extracted from surprises in five interest rate futures. This factor is denoted as *NS* in this paper, and it contains information on not only overnight federal funds rate target but also forward guidance. Alternatively, we can extract two orthogonal principal components, target factor and path factor, following Gürkaynak et al. (2005). Here, the target factor indicates the shock on federal funds target while the path factor can be interpreted as the forward guidance shock. The target and the path factor are denoted as *Target* and *Path* respectively. All three series of monetary policy shocks are normalized such that a 1%p increase in the shock raises the 1-year US treasury rate by 1%p. For high-frequency identification, tick-by-tick data for FF1, FF4, ED2, ED3, and ED4 are needed. This paper uses US monetary policy shocks estimated by Acosta (2023) which contains the series of *NS*, *Target*, and *Path*.

2.3 Results

2.3.1 Baseline Estimation

Table 2 shows the estimated effect β_h of US monetary policy shock on CIP deviations from the baseline regression (2.1). β_h measures the basis point change in CIP deviations in response to one unit of contractionary shock. Since US monetary policy shocks are normalized to have 1-1 relationship with 1-year US treasury rate, we can treat the one unit of shock as a 1%p or 100bp contractionary shock.

Since CIP deviations are the gap between the synthetic dollar funding costs and the direct dollar funding costs, $-\beta_h$ can be interpreted as an additional cost (in bp) to pay for the synthetic dollar funding in response to the 100bp US monetary policy shock.⁸ For example, if β_h is estimated as -5, then the synthetic dollar funding rises 5bp more than the direct dollar funding cost.⁹ Therefore, the estimates of β_h can be understood to measure the amplification of the US monetary policy through the FX swap market.

In Table 2, we have results for seven maturities which are denoted as 3M, 1Y, 2Y, 3Y, 5Y, 7Y, and 10Y. For each maturity, 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 reported in the parentheses are clustered at the currency level since the data are subject to serial correlation within each currency in general. R^2 and N are the R^2 and the number of observations of this baseline estimation respectively.

In response to a 1%p contractionary NS shock, 3-month CIP deviation is estimated to decline by 7.779bp, which is statistically insignificant. The effects are significant for 1Y, 2Y, and 3Y maturities with the estimates of about 2-5bp. For maturities 5Y to 10Y, the effects become more muted and insignificant. It is hard to say that these estimated effects of *NS* shock are significant in statistical and economic way. On the other hand, when we decompose the monetary policy shock into target and path factors, we can see that most of the effect comes from the federal funds target rather than the forward guidance. The target factor has significant effect on CIP deviations for most of the maturities, and it leads to a decrease in the 3-month CIP deviation by 12.26bp. Considering that 1-year US treasury rate increases by 100bp, this estimate of 12.26bp cannot be said to be trivial economically.

Moreover, we can see that β_h declines in absolute value as maturities get longer, implying that the US monetary policy has less effect on longer-term CIP deviations. This term structure of β_h can be explained by the expectation hypothesis on the relationship between short-term and long-term

⁸In Section 2.2, we have seen that the average CIP deviation is negative, implying that negative β_h corresponds to the widening of CIP deviations.

⁹Direct dollar funding cost, for example LIBOR, does not move 1-1 with 1-year US treasury rate as it will be shown later. For this reason, we cannot interpret β_h as an additional *percentage* increase in the synthetic dollar funding cost.

cross-currency bases. According to the expectation hypothesis, long-term cross-currency bases are the sum of expected future short-term bases (up to first-order). Then, the term structure of β_h implies that the effect of monetary policy shock on expected future short-term bases is decaying over time.

Table 2: Effect of US Monetary Policy Shock on CIP deviations

	Full Sample							
	3M		1Y		2Y		3Y	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NS	-7.779 (4.826)		-5.223** (1.487)		-2.177* (0.833)		-2.264* (0.751)	
Target		-12.26** (3.131)		-3.705** (0.795)		-1.541* (0.509)		-1.513** (0.394)
Path		3.570 (2.471)		-1.807 (0.810)		-0.785 (0.439)		-0.886 (0.445)
R^2	0.012	0.032	0.026	0.034	0.013	0.016	0.018	0.021
N	1621	1621	1557	1557	1580	1580	1573	1573
	5Y		7Y		10Y			
	(7)	(8)	(9)	(10)	(11)	(12)		
NS	-1.092 (0.570)		-0.102 (0.574)		0.310 (0.576)			
Target		-0.758* (0.295)		-0.171 (0.251)		0.049 (0.252)		
Path		-0.412 (0.356)		0.030 (0.376)		0.230 (0.371)		
R^2	0.013	0.014	0.004	0.004	0.013	0.013		
N	1578	1578	1584	1584	1572	1572		

Note. This table presents the regression results of cross-currency bases on 1%p contractionary US monetary policy shock for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. For each maturity, 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. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. R^2 and N denote the R^2 and the number of observations of the regression respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In Online Appendix A.1, I decompose β_h into the effect on the US LIBOR, on the (negative of) the currency j 's risk-free rate, and on the forward premium. From the decomposition, we can see that the change in the synthetic dollar funding cost mostly comes from the forward premium. In addition, Online Appendix A.2 analyzes the term structure of β_h by conducting principal component analysis on CIP deviations across maturities. The first principal component is the level factor while the second principal component is the slope factor with factor loadings decreasing over maturities. Hence, the term structure of β_h comes from this slope factor.

2.3.2 Structural Break

Next, we look at whether there is a structural break in the effect of the US monetary policy on CIP deviations since the GFC. There has been tighter leverage constraints and macroprudential regulations

on riskless arbitrage after the GFC. Before the GFC, assets were measured on a risk-weighted basis, so riskless arbitrage was not subject to the regulation on leverage. Since there was little limit on the arbitrage activity, CIP deviations were nearly zero for pre-GFC periods. If Covered Interest Rate Parity holds, then CIP deviations are naturally disconnected from the monetary policy. However, the regulation on leverage changed to non-risk-weighted basis after the GFC and accordingly there has been limit on the CIP arbitrage as well (see [Basel Committee on Banking Supervision \(2014\)](#) and [Du et al. \(2018a\)](#)). In turn, CIP deviations have emerged and reflected the shadow cost of balance sheets of CIP arbitrageurs, usually global banks, since the balance sheet space became scarce resources for the banks. If the US monetary policy affects CIP deviations through the balance sheets of global banks, then this channel should be viable after the GFC while it is absent before the GFC.

Thus, what we are expecting to find is that the effect of US monetary policy on CIP deviations is insignificant for pre-GFC periods while it emerges after the global financial crisis. For this purpose, I define a dummy variable $PostGFC_t$ that takes 1 for the periods from the year of 2008 and 0 otherwise. Then, the structural break in β_h is estimated by the following regression:

$$\Delta cid_{t,h}^j = \alpha_j + (\beta_h^0 + \beta_h^1 PostGFC_t) \Delta mp_t + \epsilon_{t,h}^j \quad (2.2)$$

In this regression, β_h^0 , which is the coefficient on Δmp_t , is the pre-GFC effect on CIP deviations. On the other hand, β_h^1 , the coefficient on the interaction term between the post-GFC dummy and the US monetary policy shock, captures the difference in the pre-GFC and post-GFC effects on CIP deviations. If β_h^1 is estimated as negative, it means that the effect of US monetary policy on CIP deviations becomes more negative for post-GFC periods. The total post-GFC effect is then given by the sum of the two coefficients $\beta_h^0 + \beta_h^1$.

The estimation results of (2.2) are shown in Table 3. For each maturity from 3-month to 10-year, we have three columns reporting estimates of β_h for pre-GFC and post-GFC periods, and their difference. Also, for each maturity, the top row is the estimation results when NS is used as the proxy for US monetary policy shock. On the other hand, the bottom rows are the results from using $Target$ and $Path$ as monetary policy shocks. Standard errors clustered at the currency level are reported in the parentheses.

For the pre-GFC periods, β_h of the NS shock is insignificant across all maturities, supporting the hypothesis that the US monetary policy cannot affect CIP deviations when the Covered Interest Rate Parity holds. The $Target$ shock also has insignificant effect on CIP deviations except for 1-year of which the estimate 0.586 is trivial economically. Similar to the estimation from the whole sample periods, $Path$ shocks do not have significant effect on CIP deviations.

On the other hand, β_h 's with maturities 3-month, 1-year, 2-year, and 3-year are estimated to be significant for post-GFC periods. Post-GFC effects are much larger than the effects estimated from the whole sample periods due to the insignificant and negligible effects for pre-GFC periods. In

particular, 3-month CIP deviation declines by 25.51bp in response to a contractionary *NS* shock corresponding to the 100bp rise in 1-year US treasury rate. This estimate of 25.51bp is significant not only statistically but also economically; the synthetic dollar funding cost increases 25.51bp more than the direct dollar funding cost does when the US policy rate rises. This implies profound amplification of the effect of US monetary policy on the dollar funding cost through the FX swap market. Comparing with the pre-GFC periods, the differential effects are estimated to be significant for maturities from 3-month to 3-year. *Target* factor also has a similar effect on CIP deviations, with larger effect on 3-month CIP deviation than the *NS* shock has. *Path* factor is mostly insignificant except for 3-month, and the effect on 3-month CIP deviation is 10.69bp. This positive estimate can be due to the intertemporal substitution of the synthetic dollar supply by financial intermediaries. Expecting future rise in policy rates and future decrease in the supply of synthetic dollar funding, banks can substitute the present supply for the future supply.

2.3.3 Robustness Check

In this section, I investigate whether the above results are robust to the following points. First, the results do not change qualitatively if the OIS rate, instead of IBOR, is used as the proxy for risk-free rate. OIS rate is known to be a better proxy for risk-free rate due to the limited credit risk compared to IBOR, especially during the financial distress periods. For this reason, LIBOR-OIS spread is often used as a measure for credit risk or risk premium. OIS rates are collected from Bloomberg, but there were no data for DKK and NOK, so OIS rates of those two currencies are omitted. Also, 7-year and 10-year OIS rates are not available for the pre-GFC periods.

CIP deviations calculated using the OIS rate as the risk-free rate is given by

$$cid_{t,h}^{j,ois} \equiv ois_{t,h}^{\$} - (ois_{t,h}^j - \rho_{t,h}^j) = \underbrace{libor_{t,h}^{\$} - (libor_{t,h}^j - \rho_{t,h}^j)}_{cid_{t,h}^{j,libor}} + (libor_{t,h}^j - ois_{t,h}^j) - (libor_{t,h}^{\$} - ois_{t,h}^{\$})$$

Here, $cid_{t,h}^{j,libor}$ is the CIP deviation used in the baseline estimation. For distinguishing two different measures of CIP deviation, I will refer to $cid_{t,h}^{j,ois}$ and $cid_{t,h}^{j,libor}$ as OIS-basis and LIBOR-basis respectively. Then, the above equation says that the OIS-basis can be decomposed into the LIBOR-basis and the difference between LIBOR-OIS spreads of currency j and USD.

Table 4 reports the effect of US monetary policy on the OIS-basis for pre-GFC and post-GFC periods. The estimation method is the same as (2.1) except that the OIS-basis is used as the dependent variable. Similar to the case of LIBOR-basis, US monetary policy shocks do not have significant effects on OIS-basis before the GFC, while contractionary shocks are estimated to decrease the OIS-basis.¹⁰ Note that there are only post-GFC estimates for 7-year and 10-year maturity due

¹⁰Effects on the 7-year OIS basis are estimated as positive, which does not align with the previous baseline results.

Table 3: Effect of US Monetary Policy Shock on CIP deviations: Pre-GFC v.s. Post-GFC

	3M			1Y			2Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	3.997 (2.040)	-25.51* (10.56)	-29.50* (9.965)	0.740 (0.353)	-13.86** (4.014)	-14.60** (4.241)	0.533 (0.317)	-5.958* (1.864)	-6.491** (1.745)
R^2			0.026			0.065			0.030
Target	0.957 (1.796)	-37.34** (7.896)	-38.29*** (8.005)	0.586* (0.247)	-10.30** (2.250)	-10.88** (2.399)	0.309 (0.203)	-4.273** (1.282)	-4.581** (1.265)
Path	3.138 (1.509)	10.69* (4.230)	7.549 (3.683)	0.218 (0.150)	-3.548 (2.213)	-3.767 (2.305)	0.233 (0.161)	-1.731 (1.086)	-1.964 (1.049)
R^2			0.083			0.088			0.038
N			1621			1557			1580
	3Y			5Y			7Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.118 (0.303)	-5.626* (1.937)	-5.744* (2.032)	0.041 (0.181)	-2.708 (1.510)	-2.749 (1.599)	0.156 (0.216)	0.540 (1.344)	0.384 (1.358)
R^2			0.036			0.021			0.014
Target	0.095 (0.182)	-3.900** (1.080)	-3.995** (1.158)	-0.175 (0.169)	-1.529 (0.774)	-1.354 (0.847)	-0.083 (0.175)	0.260 (0.697)	0.343 (0.804)
Path	0.030 (0.161)	-1.787 (1.184)	-1.818 (1.218)	0.178 (0.095)	-1.233 (0.925)	-1.411 (0.928)	0.211 (0.192)	0.219 (0.699)	0.008 (0.635)
R^2			0.045			0.022			0.014
N			1573			1578			1572
	10Y								
	Pre-GFC	Post-GFC	Diff						
NS	0.156 (0.216)	0.540 (1.344)	0.384 (1.358)						
R^2			0.014						
Target	-0.083 (0.175)	0.260 (0.697)	0.343 (0.804)						
Path	0.211 (0.192)	0.219 (0.699)	0.008 (0.635)						
R^2			0.014						
N			1572						

Note. This table presents the regression results of cross-currency bases on 1%p contractionary US monetary policy shock with structural break around the GFC for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. For each maturity, there are three columns: estimation results for pre-GFC periods (00-07), post-GFC periods (08-), and their differences. The top row is the estimation results when *NS* is used as the proxy for US monetary policy shock while the bottom rows are the results from using *Target* and *Path* as monetary policy shocks. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. R^2 and N denote the R^2 and the number of observations of the regression respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

to the data availability issue.

The effects are larger (in absolute value) than the baseline estimation. We will see where the difference comes from by decomposing these estimates. This reinforces the argument of this paper that the effect of US monetary policy on CIP deviations works through the balance sheet of banks intermediating the CIP arbitrage.

Next, I show that the baseline estimation results are robust to the information effect of monetary policy. As in [Miranda-Agrippino and Ricco \(2021\)](#), there are two sources of the information

This may be due to limitations of data since there are not enough data on 7-year OIS rates compared to other maturities.

Table 4: Effect of US Monetary Policy Shock on the OIS-basis: Pre-GFC v.s. Post-GFC

	3M			1Y			2Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	-9.335 (6.527)	-49.74** (13.34)	-40.40* (13.70)	7.126 (10.31)	-34.93*** (4.914)	-42.06** (11.62)	1.709 (4.442)	-29.28*** (3.712)	-30.99*** (5.568)
R^2			0.063			0.107			0.100
Target	-3.108 (5.862)	-53.82** (11.08)	-50.71** (11.70)	3.236 (5.769)	-20.53** (4.158)	-23.76* (8.094)	-7.124 (4.328)	-17.99*** (2.126)	-10.86 (5.938)
Path	-5.840* (1.929)	1.025 (3.419)	6.865 (3.555)	3.967 (5.092)	-14.72*** (1.801)	-18.68** (4.516)	6.208 (2.722)	-12.16*** (1.499)	-18.37*** (2.660)
R^2			0.133			0.118			0.124
N			1097			1026			803
	3Y			5Y			7Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	10.28 (4.607)	-15.10 (6.543)	-25.38** (6.461)	15.72 (10.14)	-0.122 (6.179)	-15.85* (5.595)	- (4.197)	10.09* (4.197)	- (4.197)
R^2			0.039			0.024			0.059
Target	-0.188 (1.960)	-4.754 (6.773)	-4.566 (8.046)	5.083 (2.513)	0.745 (3.920)	-4.338 (2.523)	- (2.911)	7.244* (2.911)	- (2.911)
Path	11.87 (6.322)	-9.891** (2.116)	-21.76* (6.902)	12.80 (8.495)	-0.702 (3.192)	-13.51 (5.963)	- (2.350)	5.110 (2.350)	- (2.350)
R^2			0.042			0.025			0.061
N			781			760			517
	10Y								
	Pre-GFC	Post-GFC	Diff						
NS	- (3.443)	1.041 (3.443)	- (3.443)						
R^2			0.018						
Target	- (3.206)	4.373 (3.206)	- (3.206)						
Path	- (1.718)	-0.746 (1.718)	- (1.718)						
R^2			0.021						
N			622						

Note. This table presents the regression results of OIS cross-currency bases on 1%p contractionary US monetary policy shock with structural break around the GFC for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. For each maturity, there are three columns: estimation results for pre-GFC periods (00-07), post-GFC periods (08-), and their differences. The top row is the estimation results when *NS* is used as the proxy for US monetary policy shock while the bottom rows are the results from using *Target* and *Path* as monetary policy shocks. For 7-year and 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. R^2 and N denote the R^2 and the number of observations of the regression respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

effect: signaling channel and the slow absorption of information. First, monetary policy can signal fundamentals on which the policy rate is based to private decision makers (see [Romer and Romer, 2000](#); [Nakamura and Steinsson, 2018](#) for example). This signaling channel comes from the asymmetric information between the central bank and the market. Observing the policy rate which works as the signal, the private sector extract information on the fundamentals that the central bank may have more information on. For example, if the policy rate rises, then the private sector (households or firms for instance) may think that the economy is stronger than they expect. Then, a high-frequency

surprise may not be shock; instead, it can reflect the revision of private sector's expectation on fundamentals. Second, [Coibion and Gorodnichenko \(2015\)](#) show that expectations respond gradually, rather than instantaneously, to fundamental shocks. This implies that fundamental shocks may not be instantaneously reflected to market prices, even prices in financial markets. In this case, high-frequency surprises may contain information on past fundamental shocks to which an exogenous shock should be orthogonal. In these two cases, Δmp may not be an exogenous "shock", confounding the estimation for β_h . In order to produce estimates robust to the information effect, information-robust monetary policy shocks are constructed and used as the proxy for the monetary policy shock.

As the first step, I test for the signalling channel of the US monetary policy following [Miranda-Agrippino and Ricco \(2021\)](#). They use Greenbook forecasts as proxies for the Fed's private information since the forecasts contain information on fundamentals for determining the monetary policy but are not open to the public. The forecasts are made for GDP growth rate, inflation, and unemployment rate which determine the systematic part of the monetary policy. These forecasts are published with 5 years of lag, implying that they are the private information of the Fed. In order to control for the Fed's private information, three monetary policy indicators (*NS*, *Target*, and *Path*) are projected on Greenbook forecasts as

$$\Delta mp_t = \alpha + \sum_{i=-1}^2 \beta'_i x_{t,i}^f + \sum_{i=-1}^2 \gamma'_i (x_{t,i}^f - x_{t-1,i}^f) + \Delta \widetilde{mp}_t \quad (2.3)$$

where $x_{t,i}^f$ is the vector of Greenbook forecasts for GDP growth rate, inflation, and unemployment rate. Subscript t is the date of FOMC announcement while subscript i is the forecast horizon: -1 for previous quarter, 0 for current quarter, 1 and 2 for next one and two quarters.¹¹ For the case of unemployment rate, only contemporaneous forecast is included as in [Romer and Romer \(2004\)](#) due to the multicollinearity. We also have the first-difference term $x_{t,i}^f - x_{t-1,i}^f$ which is the difference between forecasts published in current meeting and previous meeting. The results of (2.3) are reported in Table A.9 of Online Appendix A.3.

In the next step, we take the residual term $\Delta \widetilde{mp}$ from (2.3). $\Delta \widetilde{mp}$ is robust to the signalling effect since it is orthogonal to the Fed's information set. Controlling the Fed's information set, we can extract components from surprises in the interest rate futures that are orthogonal to the signalling channel. However, $\Delta \widetilde{mp}$ may still be subject to the imperfect information problem which brings about the slow absorption of information.

In order to resolve the imperfect information, I run the following AR(1) regression on $\Delta \widetilde{mp}$ and

¹¹Greenbook forecasts are made 6 days before the FOMC meeting, but they are not open to the public, so it is still private information at the time of the FOMC meeting.

take the autoregressive part away:

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

By removing the serially correlated part in futures surprises, we can obtain the residual Δmpi_t for each series of *NS*, *Target*, and *Path*. This Δmpi_t is used as the information-robust monetary policy shock to estimate the robust effect of US monetary policy shock on CIP deviations:

$$\Delta cid_{t,h}^j = \alpha_j + \beta_h \Delta mpi_t + \epsilon_{t,h}^j \quad (2.4)$$

Table 5 shows the information-robust effect of the US monetary policy shock on CIP deviations for pre-GFC and post-GFC periods. Similar to the results in Table 3, effects of monetary policy are insignificant for pre-GFC periods while the effects on short-term basis are large and significant for post-GFC periods.¹² Broadly speaking, estimating information-robust effect does not produce qualitatively different estimates, which implies that the potential information effects may not be crucial problems in this analysis. Obviously estimates of the baseline and the information-robust effects are different quantitatively. Figure 1 compares the effects for pre-GFC and post-GFC periods. In each panel (1a) and (1b), red triangles are estimates of β_h from the baseline model. They are displayed across maturities from 3-month to 10-year. On the other hand, blue circles are information-robust effects while the blue line around each circle is the 95% confidence interval. We can see that information-robust effects are more muted for pre-GFC periods. For post-GFC periods, information-robust effects are larger for 3-month maturity while they are more muted for other maturities. However, all differences are not large in the sense that all baseline estimates are within the 95% confidence interval of the information-robust estimates.

3 The Model

Following Devereux et al. (2023), we study a two-country production economy with nominal price rigidity and limited commitment constraints of financial intermediaries. The two countries are the US and the non-US. Through this model, we can analyze effects of US monetary policy on CIP deviations, synthetic dollar funding, and implications for global economies.¹³ The novel contribution of this model is the determination of CIP deviations as general equilibrium objects. As CIP deviations are prices of synthetic dollar funding through the FX swap market, it is determined by the supply and demand for the synthetic dollar funding. For this purpose, I embed the FX swap market in the general equilibrium model with banks subject to leverage constraints.

¹²Pre-GFC effect on 1-year CIP deviation is significant, but the estimate of 1bp is negligible economically.

¹³Although the effect of US monetary policy is the main focus of this paper, we can also analyze the effects of other shocks including monetary policy shocks of the non-US, financial friction shocks, and productivity shocks.

Table 5: Effect of Information-robust US Monetary Policy Shock on CIP deviations

	3M			1Y			2Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.922 (2.035)	-33.86*** (5.283)	-34.78*** (4.507)	1.078* (0.393)	-8.360** (2.422)	-9.438** (2.672)	0.820 (0.399)	-3.442* (1.337)	-4.262** (1.259)
R^2			0.034			0.022			0.011
Target	-0.470 (1.768)	-49.90*** (7.136)	-49.43*** (7.353)	0.636* (0.233)	-9.793*** (1.894)	-10.43*** (2.015)	0.415 (0.221)	-4.433** (1.107)	-4.848** (1.199)
Path	2.527 (1.278)	13.03* (4.105)	10.50* (3.827)	0.360 (0.173)	1.035 (2.007)	0.675 (2.099)	0.377 (0.180)	1.499 (1.216)	1.123 (1.221)
R^2			0.105			0.049			0.025
N			1377			1319			1345
	3Y			5Y			7Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.168 (0.335)	-2.642 (1.347)	-2.809 (1.477)	0.148 (0.223)	-1.416 (1.334)	-1.564 (1.401)	-0.005 (0.348)	-0.234 (1.207)	-0.229 (1.250)
R^2			0.010			0.011			0.005
Target	0.196 (0.163)	-3.389** (0.781)	-3.585** (0.862)	-0.122 (0.193)	-1.312 (0.584)	-1.190 (0.640)	-0.181 (0.224)	-0.652 (0.401)	-0.470 (0.415)
Path	0.003 (0.163)	1.125 (1.123)	1.122 (1.200)	0.301* (0.126)	0.553 (0.920)	0.252 (0.948)	0.192 (0.155)	1.111 (1.124)	0.919 (1.148)
R^2			0.021			0.013			0.007
N			1335			1348			1347
	10Y								
	Pre-GFC	Post-GFC	Diff						
NS	0.306 (0.227)	-0.026 (1.008)	-0.332 (1.083)						
R^2			0.015						
Target	-0.041 (0.217)	-0.058 (0.562)	-0.017 (0.682)						
Path	0.309 (0.201)	0.527 (0.791)	0.219 (0.832)						
R^2			0.016						
N			1334						

Note. This table presents the regression results of cross-currency bases on 1%p contractionary information-robust US monetary policy shock with structural break around the GFC for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. Information-robust US monetary policy shocks are estimated by residuals from the projection on Greenbook forecasts and removing serially correlated parts. For each maturity, there are three columns: estimation results for pre-GFC periods (00-07), post-GFC periods (08-), and their differences. The top row is the estimation results when *NS* is used as the proxy for US monetary policy shock while the bottom rows are the results from using *Target* and *Path* as monetary policy shocks. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. R^2 and N denote the R^2 and the number of observations of the regression respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3.1 Structure of FX Swap Market

Before moving on to the theoretical analysis, I describe the basic and simplified structure of FX swap contract and FX swap market. US banks and non-US banks are participants and counterparties of each other in the FX swap market, but this simplification summarizes the real world well. Large global banks who can borrow USD from USD-rich households or US MMFs and lend the USD to ultimate borrowers by selling USD in the spot market. This transaction is usually mediated by broker-dealers, but they are mostly part of global banks in the form of subsidiaries for instance. These

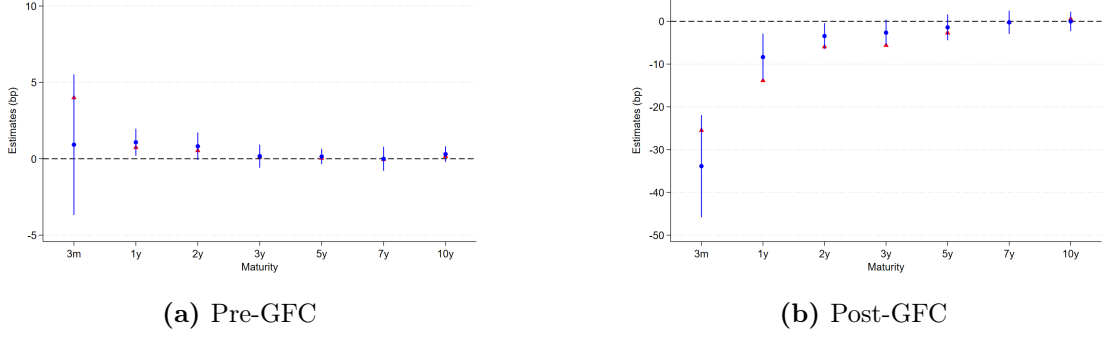


Figure 1: Baseline v.s. Information-robust Effects

Note. This figure presents baseline and information-robust effects of US monetary policy on CIP deviations across maturities from 3-month to 10-year. Blue circles are the information-robust estimates while the blue line around each circle is the 95% confidence interval. Red triangles are estimates from the baseline model.

top-tier global banks are usually US banks, though not always. On the other hand, banks, non-bank financial institutions (such as insurance companies, pension funds, hedge funds), and non-financial firms of non-US countries are main users of FX swap. This paper assumes demand-side of the FX swap market as the banking sector in non-US countries since I focus on the transmission of US monetary policy through interbank markets. When non-US banks hold USD-denominated assets, they are subject to a currency mismatch problem and following currency risks since they usually lack USD-denominated funding. Since banks are heavily penalized on currency mismatches, they buy USD spot and sell USD forward in the FX swap market in order to hedge currency risks. For this reason, it is without loss of generality to set the main players of the FX swap market as US banks and non-US banks. From now on, the currency of the US is denoted as USD (\$) while the non-US currency is denoted as EUR (€) for notational convenience.

Figure 2 summarizes cash flows of a FX swap contract. FX swap contract consists of two legs: spot leg and forward leg. Today, both parties of the FX swap exchange their currencies at the spot exchange rate S which is expressed in unit of EUR per USD. US bank exchanges $\$X$ into $\text{€}S \cdot X$, so it obtains $\text{€}S \cdot X$ while the non-US bank obtains $\$X$. At the same time, they enter into a forward contract at the forward exchange rate F . This forward leg locks in the exchange rate of tomorrow by the forward exchange rate which is predetermined today. The notional value of the FX swap is assumed to be $\$R^*(S/F)X$ where R^* is a non-US risk-free rate. This means that US bank hedges all of its risk-free return on $\text{€}S \cdot X$. Indeed, US bank gets $\$R^*(S/F)X$ while paying $\text{€}R^*S \cdot X$ to the non-US bank, which are the proceeds from investing $\text{€}S \cdot X$ into non-US risk-free assets.

In this sense, FX swap is similar to collateralized borrowing where the currency of each party works as the collateral. Here, US bank is the lender of the USD with EUR as collateral since it sells USD and buys EUR in the spot market. The rate of return on this lending is R^*S/F since

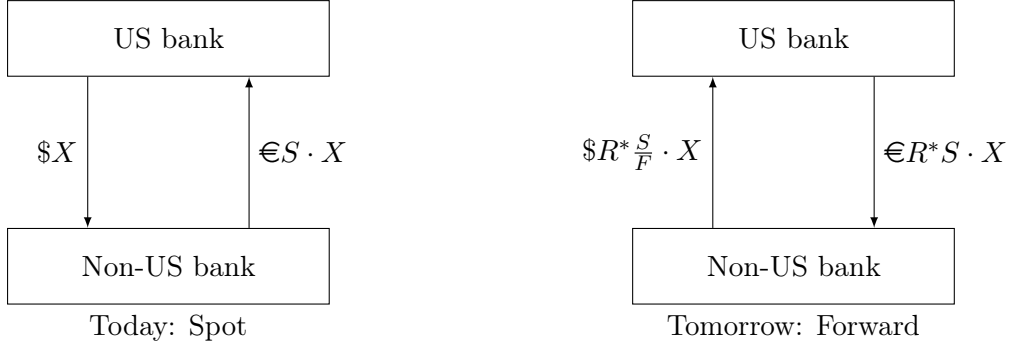


Figure 2: Structure of a FX Swap Contract

the forward contract exchanges proceeds R^*S from the EUR-denominated assets into USD at the predetermined forward rate. Thus, $R^*S/F - R$, an excess return on USD lending, is the profit that US banks obtain from supplying the USD in the FX swap market. In the next section, we will see the endogenous determination of $R^*S/F - R$ in the FX swap market with maintaining this simple structure of the FX swap market.

3.2 US Economy

3.2.1 Household

The life-time utility function of the representative US household is

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

where C_t is the aggregate consumption and L_t is the aggregate labor supply. $1/\gamma$ is the the elasticity of intertemporal substitution, $1/\varphi$ is the Frisch elasticity, and κ is the parameter for disutility of labor supply.

The household buys aggregate consumption goods of which price is P_t and deposits D_t to financial intermediaries at gross deposit rate R_t . On the other hand, the household obtains labor income $W_t L_t$ from supplying labor to domestic firms, net profits Π_t from all firms and financial intermediaries, and net transfer TR_t from the US government. Then, the sequential budget constraint of the household is given by

$$P_t C_t + D_t = W_t L_t + R_{t-1} D_{t-1} + \Pi_t + TR_t \quad (3.1)$$

The first-order conditions of the household's utility maximization problem with respect to C_t ,

L_t , and D_t are

$$\kappa C_t^\gamma L_t^\varphi = \frac{W_t}{P_t} \quad (3.2)$$

$$E_t [\Lambda_{t,t+1}] R_t = 1 \quad (3.3)$$

for the stochastic discount factor (SDF) of the representative household

$$\Lambda_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left(\frac{P_t}{P_{t+1}} \right) \quad (3.4)$$

(3.2) is the intratemporal condition between consumption and labor supply while (3.3) is the Euler equation for the deposits.

3.2.2 Capital Good Producers

There are perfectly competitive capital good producers who purchase aggregate investment goods at P_t , installing them, and sell to households at Q_t . The law of motion for the aggregate capital stock is then

$$K_t = I_t + (1 - \delta)K_{t-1} \quad (3.5)$$

When installing investment goods, there is an investment adjustment cost $\frac{\psi_K}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2$. Then, the per-period profit function of capital good producers is given by

$$\Pi_t^K \equiv Q_t I_t - P_t \left(I_t + K_{t-1} \frac{\psi_K}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 \right)$$

Consequently, the following life-time profit maximization problem

$$\max_{\{I_{t+s}\}_{s=0}^{\infty}} E_t \left[\sum_{s=0}^{\infty} \Lambda_{t,t+s} \Pi_{t+s}^K \right]$$

yields the first-order condition for Q_t as

$$Q_t = P_t \left(1 + \psi_K \left(\frac{I_t}{K_{t-1}} - \delta \right) \right) - E_t \left[\Lambda_{t,t+1} P_{t+1} \psi_K \left(\frac{I_{t+1}}{K_t} - \delta \right) \frac{I_{t+1}}{K_t} \right] \quad (3.6)$$

3.2.3 Retailers

The composite consumption good C_t is aggregated by perfectly competitive consumption good retailers who assemble composite consumption of domestically-produced US goods $C_{H,t}$ and composite consumption of imported non-US goods $C_{F,t}$. The aggregation technology is given by the following

constant elasticity of substitution (CES) function:

$$C_t \equiv \left[\omega^{\frac{1}{\nu}} C_{H,t}^{\frac{\nu-1}{\nu}} + (1-\omega)^{\frac{1}{\nu}} C_{F,t}^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}$$

where ω is the home-bias parameter and ν is the elasticity of substitution between domestic and imported consumption.

From the profit maximization problem, we can obtain the demand functions as

$$C_{H,t} = \omega \left(\frac{P_{H,t}}{P_t} \right)^{-\nu} C_t \quad (3.7)$$

$$C_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t} \right)^{-\nu} C_t \quad (3.8)$$

and the aggregate price index as

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

where $P_{H,t}$ is the price of domestic consumption while $P_{F,t}$ is the price of imported consumption.

Let us define the terms-of-trade T_t faced by the US as the ratio of imported good price to domestic good price $P_{F,t}/P_{H,t}$. From the above equation for the aggregate price of domestic economy, $P_{H,t}$ and $P_{F,t}$ can be expressed as functions of the terms-of-trade as

$$P_{H,t} = P_t \left[\omega + (1-\omega) T_t^{1-\nu} \right]^{-\frac{1}{1-\nu}} \quad (3.9)$$

$$P_{F,t} = P_t \left[\omega T_t^{-(1-\nu)} + 1 - \omega \right]^{-\frac{1}{1-\nu}} \quad (3.10)$$

Similar to the aggregate consumption, perfectly competitive investment goods retailers assemble domestically-produced investment good $I_{H,t}$ and imported investment good $I_{F,t}$ as

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

for the aggregate investment I_t . Note that the aggregated product contains not only the aggregate investment I_t but also the investment adjustment cost because it is paid by capital producers. Then, the demand functions for investment goods are

$$I_{H,t} = \omega \left(\frac{P_{H,t}}{P_t} \right)^{-\nu} \left[I_t + K_{t-1} \frac{\psi_K}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 \right] \quad (3.11)$$

$$I_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t} \right)^{-\nu} \left[I_t + K_{t-1} \frac{\psi_K}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 \right] \quad (3.12)$$

3.2.4 Wholesalers

As we will see in Section 3.2.5, there is a continuum of firms in $[0, 1]$ producing each variety. Perfectly competitive wholesalers aggregate these varieties into a single good and sell to retailers. There are two sets of wholesalers: domestic and export wholesalers. Domestic wholesalers assemble $Y_{H,t}(j)$ into domestically-spent output $Y_{H,t}$ while export wholesalers assemble $Y_{H,t}^*(j)$ into exported output $Y_{H,t}^*$. The aggregation technology of them are given by

$$Y_{H,t} \equiv \left[\int_0^1 Y_{H,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$$

$$Y_{H,t}^* \equiv \left[\int_0^1 Y_{H,t}^*(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$$

where ϵ is the elasticity of substitution between varieties.

These wholesalers purchase $Y_{H,t}(j)$ and $Y_{H,t}^*(j)$ from firms at the price of $P_{H,t}(j)$ and $P_{H,t}^*(j)$, and sell to retailers at $P_{H,t}$ and $P_{H,t}^*$ respectively. Then, the demand functions are

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} Y_{H,t} \quad (3.13)$$

$$Y_{H,t}^*(j) = \left(\frac{P_{H,t}^*(j)}{P_{H,t}^*} \right)^{-\epsilon} Y_{H,t}^* \quad (3.14)$$

with the price indices of domestic and exported goods

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

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

Note that the law of one price does not generally hold due to the assumption of local currency pricing (LCP) described in the next section.¹⁴

3.2.5 Firm

A monopolistically competitive firm $j \in [0, 1]$ produces each variety from the production function:¹⁵

$$Y_t(j) = Z_t K_{t-1}(j)^\alpha L_t(j)^{1-\alpha}$$

¹⁴In the Online Appendix F, I investigate alternative currency pricing paradigms such as producer currency pricing (PCP) and dominant currency pricing (DCP), and show that the results of the model do not change qualitatively. Quantitative differences come from the exchange rate pass-through to the import price.

¹⁵I will use the firm and the variety interchangeably in this paper since each firm produces only one variety.

where the total factor productivity (TFP) Z_t follows an exogenous AR(1) process as

$$\log Z_t = \rho_z \log Z_{t-1} + \sigma_z \epsilon_{z,t} \quad (3.15)$$

for an *i.i.d* productivity shock $\epsilon_{z,t} \sim N(0, 1)$.

Each firm j minimizes its total cost $W_t L_t(j) + \tilde{R}_{K,t} K_{t-1}(j)$ for the nominal wage W_t and the nominal rental rate of capital $\tilde{R}_{K,t}$ taking its output $Y_t(j)$ as given. The first-order conditions from the cost minimization problem are then

$$W_t = (1 - \alpha) MC_t \frac{Y_t(j)}{L_t(j)} \quad (3.16)$$

$$\tilde{R}_{K,t} = \alpha MC_t \frac{Y_t(j)}{K_{t-1}(j)} \quad (3.17)$$

where the nominal marginal cost MC_t is

$$MC_t = \frac{1}{Z_t} \frac{W_t^{1-\alpha} \tilde{R}_{K,t}^\alpha}{(1 - \alpha)^{1-\alpha} \alpha^\alpha} \quad (3.18)$$

Note that the marginal cost is common across varieties j .

Now, we discuss the pricing decision of firm j . We assume LCP, *i.e.*, prices of domestically-sold goods and exported goods are determined and sticky in the currency of the destination market. Hence, domestically-sold goods are sticky in USD while exported goods are sticky in EUR. Also, we model price rigidity à la [Rotemberg \(1982\)](#) such that there is a price adjustment cost proportional to the nominal aggregate sales. Finally, there is subsidy s on sales to get rid of the pricing distortion from the monopolistic competition in the steady-state. Then, firm j 's periodic profit $\Pi_t^P(j)$ denominated in USD is

$$\begin{aligned} \Pi_t^P(j) = & (1 + s) \left(P_{H,t}(j) Y_{H,t}(j) + \frac{1}{S_t} P_{H,t}^*(j) Y_{H,t}^*(j) \right) - TC_t(j) \\ & - \frac{\psi_P}{2} \left[\left(\frac{P_{H,t}(j)}{P_{H,t-1}(j)} - 1 \right)^2 P_{H,t} Y_{H,t} + \left(\frac{P_{H,t}^*(j)}{P_{H,t-1}^*(j)} - 1 \right)^2 \frac{1}{S_t} P_{H,t}^* Y_{H,t}^* \right] \end{aligned}$$

where ψ_P is the parameter for price adjustment cost. The spot exchange rate S_t is expressed in units of EUR per USD, so a rise in S_t means the appreciation of the USD. Then, the firm j 's life-time profit maximization problem from period t defined as

$$\max_{\{P_{H,t+s}(j), P_{H,t+s}^*(j)\}_{s=0}^\infty} E_t \sum_{s=0}^\infty \Lambda_{t,t+s} \Pi_{t+s}^P(j)$$

yields the following first-order conditions as

$$(1+s)(\epsilon-1) = \epsilon \frac{MC_t}{P_{H,t}} - \psi_P \left(\frac{P_{H,t}}{P_{H,t-1}} - 1 \right) \frac{P_{H,t}}{P_{H,t-1}} + E_t \left[\Lambda_{t,t+1} \psi_P \left(\frac{P_{H,t+1}}{P_{H,t}} - 1 \right) \left(\frac{P_{H,t+1}}{P_{H,t}} \right)^2 \frac{Y_{H,t+1}}{Y_{H,t}} \right] \quad (3.19)$$

$$(1+s)(\epsilon-1) = \epsilon \frac{S_t MC_t}{P_{H,t}^*} - \psi_P \left(\frac{P_{H,t}^*}{P_{H,t-1}^*} - 1 \right) \frac{P_{H,t}^*}{P_{H,t-1}^*} + E_t \left[\Lambda_{t,t+1} \psi_P \left(\frac{P_{H,t+1}^*}{P_{H,t}^*} - 1 \right) \left(\frac{P_{H,t+1}^*}{P_{H,t}^*} \right)^2 \frac{S_t}{S_{t+1}} \frac{Y_{H,t+1}^*}{Y_{H,t}^*} \right] \quad (3.20)$$

3.2.6 Financial Intermediary

The financial intermediary side is modeled à la [Gertler and Kiyotaki \(2010\)](#). There is a continuum of perfectly competitive financial intermediaries (“banks” for short) with measure one. US banks can source their funds from their retained net worth as well as issuing deposits to US households. From this funding, they can purchase US capitals or arbitrage CIP deviations by lending to non-US banks in the cash market.¹⁶ The detailed intermediation process of US banks is explained below.

Figure 3 displays the timeline of the bank decision problem. At the *beginning* of each period t , the state of time t which includes all shocks as well as stay/exit status of banks is unfolded. Banks exit with probability $1 - \sigma$ while they stay as bankers with probability σ .¹⁷ Exiting banks pay out all of their net worth to households as dividends while they are filled with new banks with initial net worth as transfers of ξ fraction of banks’ total asset value from the household.

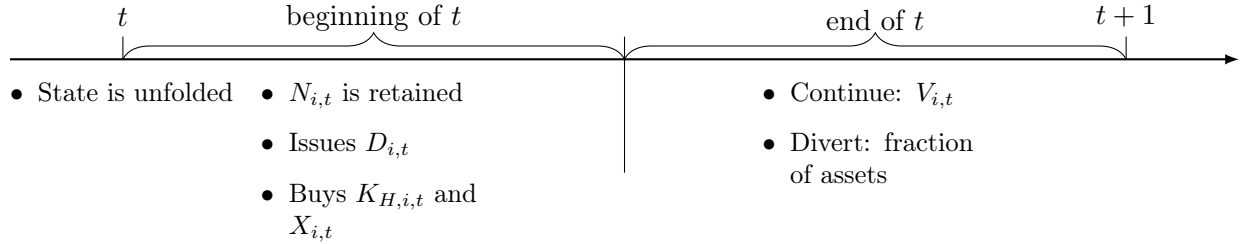


Figure 3: Timeline of Bank i 's Decision

After observing the state and conditional on that bank i stays, it retains its net worth $N_{i,t}$ and issues deposits $D_{i,t}$ at gross interest rate R_t .¹⁸ Regarding the asset side, the bank can purchase US

¹⁶In reality, banks can also arbitrage CIP deviation by taking long and short positions in Treasuries. This “real money investor”-like behavior is excluded in this paper since we are focusing on the interbank flow of funds and LIBOR-basis rather than Treasury-basis.

¹⁷Without this assumption, banks would retain all of their earnings to the future in order to escape from the leverage constraint. In this case, financial intermediaries are just a veil.

¹⁸In this model, there is no difference between wholesale funding and retail funding. Thus, R_t can be understood as

capital $K_{H,i,t}$ at price Q_t while it can engage in CIP arbitrage $X_{i,t}$ in the FX swap market.^{19,20} $\$X_{i,t}$ is exchanged for $\text{€}S_t X_{i,t}$ and lent to non-US banks in the cash market with non-US interest rate of R_t^* while the exchange rate risk is hedged by the swap contract. The balance sheet identity of bank i in terms of USD is then given by

$$Q_t K_{H,i,t} + X_{i,t} = D_{i,t} + N_{i,t}$$

Note that exchanging $\$X_{i,t}$ for $\text{€}S_t X_{i,t}$ does not appear in the period t -balance sheet evaluated in terms of USD.

From holding $K_{H,i,t}$ from t to $t+1$, bank i earns rental rate of capital $\tilde{R}_{K,t+1}$ while the capital depreciation rate is δ . We can define the gross return rate $R_{K,t+1}$ on holding capital from t to $t+1$ as $R_{K,t+1} \equiv (\tilde{R}_{K,t+1} + (1-\delta)Q_{t+1})/Q_t$. On the other hand, the gross return rate on $X_{i,t}$ is $R_t^* S_t / F_t$. Since $\text{€}S_t X_{i,t}$ is lent to non-US banks at period t , $\text{€}R_t^* S_t X_{i,t}$ accrues to the US bank at $t+1$. As the currency risk is hedged at the forward exchange rate F_t , which is determined at period t , US bank exchanges $\text{€}R_t^* S_t X_{i,t}$ for $\$R_t^* (S_t / F_t) X_{i,t}$. With these gross returns from assets and newly issued deposits $D_{i,t+1}$, the bank can purchase US capital $K_{H,i,t+1}$ and engage in CIP arbitrage $X_{i,t+1}$ while repaying deposits $R_t D_{i,t}$. To sum up, we can describe bank i 's budget constraint at $t+1$ as

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

The above discussion on the balance sheet and the flow of funds of US bank i is described in Figure 4. The red box presents the cash flows from the FX swap contract.

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

Figure 4: Balance Sheet and Flow of Funds of the US Bank

Combining the balance sheet identity and the budget constraint, we can obtain the law of

either the deposit rate or the interbank lending rate such as LIBOR, SOFR, or federal funds rate.

¹⁹We exclude the possibility of purchasing non-US capital assets for simplicity.

²⁰Trades in the FX swap market are usually mediated by broker-dealers. Since many broker-dealers are part of investment banks, in the form of subsidiaries for instance, we can think of the bank in this paper as consolidated base.

motion for bank i 's net worth as

$$N_{i,t+1} = \left[(R_{K,t+1} - R_t) \phi_{H,i,t} + \underbrace{\left(R_t^* \frac{S_t}{F_t} - R_t \right)}_{\textcircled{A}} \phi_{X,i,t} + R_t \right] N_{i,t} \quad (3.21)$$

where $\phi_{H,i,t}$ and $\phi_{X,i,t}$ are defined as

$$\begin{aligned} \phi_{H,i,t} &= \frac{Q_t K_{H,i,t}}{N_{i,t}} \\ \phi_{X,i,t} &= \frac{X_{i,t}}{N_{i,t}} \end{aligned}$$

In (3.21), $R_{K,t+1} - R_t$ is the excess return on US capital bond while \textcircled{A} is the excess return on the CIP arbitrage. Indeed, \textcircled{A} is the negative of CIP deviations, *i.e.* $-cid_t$ where cid_t is defined as^{21,22}

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

Hence, the US bank earns arbitrage profit of $-cid_t$ by playing a role as CIP arbitrageurs. At the same time, $-cid_t$ can be interpreted as the fee that the US bank obtains from supplying USD through the FX swap market, *i.e.* synthetic dollar funding since it sells USD in the spot leg of the FX swap market. In other words, CIP arbitrageurs are suppliers of synthetic dollar funding in this model.

Let $V_{i,t}$ be continuing bank i 's objective function at the *end* of the period t after the bank made decisions for $K_{H,i,t}$, $X_{i,t}$, and $D_{i,t}$. Then, $V_{i,t}$ is defined as

$$V_{i,t} = E_t \sum_{s=1}^{\infty} (1 - \sigma) \sigma^{s-1} \Lambda_{t,t+s} N_{i,t+s} = E_t [\Lambda_{t,t+1} \{ (1 - \sigma) N_{i,t+1} + \sigma V_{i,t+1} \}]$$

for the US household's SDF $\Lambda_{t,t+s} = \beta^s (C_{t+s}/C_t)^{-\gamma} (P_t/P_{t+s})$. Note that $V_{i,t}$ is the function of $K_{H,i,t}$, $X_{i,t}$, and $D_{i,t}$.

Each bank is subject to a leverage constraint

$$V_{i,t} \geq \Theta_t \left[\left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right) Q_t K_{H,i,t} + \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right) X_{i,t} \right] \quad (3.22)$$

where θ_{H1} , θ_{H2} , θ_{X1} , θ_{X2} are parameters for the tightness of the constraint. Θ_t is a global financial friction shock following

$$\log \Theta_t = \rho_{\theta} \log \Theta_{t-1} + \sigma_{\theta} \epsilon_{\theta,t} \quad (3.23)$$

²¹CIP deviations are defined following the tradition of cross-currency basis.

²²In this model, cid_t is negative in the steady-state. Hence, $-cid_t$ can be considered as positive near the steady-state.

This constraint is usually motivated from the limited commitment; banks can divert certain fraction of their asset at the end of each period and thus franchise value of banks should be larger than the diverted asset to induce self-enforcement (see [Gertler and Kiyotaki, 2010](#)). However, it can also be interpreted as a leverage constraint imposed by a financial regulatory authority since $V_{i,t}$ is later shown to be linear in net worth. Then, θ 's are parameters for the degree of regulation on leverage.

Importantly, the leverage constraint is imposed not only on capital but also on CIP arbitrage $X_{i,t}$. This is in line with the change in regulatory framework after the GFC; the calculation of leverage ratio changed from non-risk-weighted basis to risk-weighted basis. Arbitrage contains little risk, so the size of arbitrage was not subject to regulation based on risk-weighted leverage ratio. On the other hand, the regulation on non-risk-weighted leverage ratio puts limit on arbitrage activity. This regulatory reform can be parameterized by non-zero θ_{X1} and θ_{X2} while they have been zero before the GFC. Following [Devereux et al. \(2023\)](#), the quadratic parameters θ_{H2} and θ_{X2} are introduced to induce stationarity. This can be understood as monitoring cost proportional to the scale of asset, making banks easier to divert when they hold larger amount of assets. Note that the quadratic parts depend on the aggregate asset rather than individual bank's asset, so they are exogenous to bank i .

Then, continuing bank i 's optimization problem at the *beginning* of period t is

$$V_{i,t} = \max_{K_{H,i,t}, X_{i,t}, D_{i,t}} E_t [\Lambda_{t,t+1} \{(1 - \sigma)N_{i,t+1} + \sigma V_{i,t+1}\}]$$

subject to the law of motion of net worth (3.21) and the leverage constraint (3.22). In Online Appendix B, I show that the value function is linear in net worth such that $V_{i,t} = \nu_t N_{i,t}$ by guess and verify method. Let us define the expected discounted returns on assets and net worth as

$$\nu_{H,t} \equiv E_t [\Omega_{t,t+1} (R_{K,t+1} - R_t)] \quad (3.24)$$

$$\nu_{X,t} \equiv E_t [\Omega_{t,t+1}] \left(R_t^* \frac{S_t}{F_t} - R_t \right) \quad (3.25)$$

$$\nu_{N,t} \equiv E_t [\Omega_{t,t+1}] R_t \quad (3.26)$$

for the stochastic discount factor of bank $\Omega_{t,t+1} \equiv \Lambda_{t,t+1}(1 - \sigma + \sigma\nu_{t+1})$.²³ Then, the Bellman equation is simplified as

$$\begin{aligned} \nu_t = \max_{\phi_{H,i,t}, \phi_{X,i,t}} & \nu_{H,t} \phi_{H,i,t} + \nu_{X,t} \phi_{X,i,t} + \nu_{N,t} \\ \text{s.t. } \nu_t \geq & \Theta_t \left[\left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right) \phi_{H,i,t} + \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right) \phi_{X,i,t} \right] \end{aligned}$$

²³When there is a limit on leverage, the marginal net worth loosens the leverage constraint and provides additional value, creating a wedge between the SDF of households and the SDF of banks.

The first-order conditions of the above Bellman equation are

$$\nu_{H,t} = \mu_t \Theta_t \left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right) \quad (3.27)$$

$$\nu_{X,t} = \mu_t \Theta_t \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right) \quad (3.28)$$

where μ_t is the Lagrangian multiplier of the leverage constraint. As long as $\mu_t > 0$, $\nu_{H,t}$ and $\nu_{X,t}$ are non-zero even up to first-order in contrast to frictionless asset pricing models.

Let us focus on (3.28) which is the FOC for the CIP arbitrage. Combining (3.25) and (3.28), we can obtain the relationship between CIP deviations and synthetic dollar funding as

$$-cid_t = \frac{\mu_t \Theta_t}{E_t[\Omega_{t,t+1}]} \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right)$$

This equation is the upward-sloping inverse supply function of synthetic dollar funding. When the leverage constraint does not bind such that $\mu_t = 0$ or there is no limit on the arbitrage such that $\theta_{X1} = \theta_{X2} = 0$, the supply function is perfectly elastic at zero CIP deviations. This is the case before regulations on non-risk-weighted assets were introduced. Otherwise, the elasticity of the supply function is finite and positive. As the leverage constraint becomes tighter and thus μ_t rises, the supply function becomes more inelastic. In this model, the leverage constraint always binds as it is guaranteed by the calibration discussed later. Figure 6 shows the upward-sloping supply curve of the synthetic dollar funding evaluated near the steady-state.

For each period, with probability σ , banks continue operating with net worth evolving according to (3.21). Meanwhile, exiting banks are filled with new banks with endowments transferred from households. Hence, the law of motion for the aggregate net worth is given by

$$N_{t+1} = \sigma \left[(R_{K,t+1} - R_t) \phi_{H,t} + \left(R_t^* \frac{S_t}{F_t} - R_t \right) \phi_{X,t} + R_t \right] N_t + (1 - \sigma) \xi (\phi_{H,t} + \phi_{X,t}) N_t \quad (3.29)$$

3.2.7 Monetary Policy

We assume the following Taylor rule type US monetary policy as

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}} \right)^{\rho_R} \left(\frac{P_t}{P_{t-1}} \right)^{\phi_\pi (1 - \rho_R)} \epsilon_{R,t} \quad (3.30)$$

where \bar{R} is the steady-state value for R_t , ρ_R is the interest rate smoothing parameter, and ϕ_π is the Taylor rule coefficient on inflation rate. Log of the disturbance term $\epsilon_{R,t}$ follows an AR(1) process

$$\log \epsilon_{R,t} = \rho_m \log \epsilon_{R,t-1} + \sigma_m \epsilon_{m,t} \quad (3.31)$$

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

3.2.8 Fiscal Policy

The US government transfers TR_t to households and subsidizes firms to get rid of market power. This fiscal policy is described as the following:

$$TR_t + s \left(P_{H,t} Y_{H,t} + \frac{1}{S_t} P_{H,t}^* Y_{H,t}^* \right) = 0 \quad (3.32)$$

3.3 Non-US Economy

For the non-US economy, all sectors other than financial intermediaries are assumed to be identical to the US economy. See Online Appendix C for details. In this section, we focus on financial intermediaries.

3.3.1 Financial Intermediary

As the US, there is a continuum of banks with total measure one while they exit with probability $1 - \sigma$ in each period. Given its net worth $N_{i,t}^*$, bank i takes deposits $D_{i,t}^*$ from non-US households. Also, there are additional amount of lending $S_t X_t$ from US banks.²⁴ This suggests that the total amount of deposits is $D_{i,t}^* + S_t X_t$. From these sources of funding, bank i can purchase the non-US capital $K_{F,i,t}^*$ at its price Q_t^* and the US capital $K_{H,i,t}^*$ at Q_t . Then, the balance sheet identity of bank i is given by

$$Q_t^* K_{F,i,t}^* + S_t Q_t K_{H,i,t}^* = D_{i,t}^* + S_t X_t + N_{i,t}^*$$

At period $t + 1$, bank i earns gross return rate of $R_{K,t+1}^* \equiv (\tilde{R}_{K,t+1}^* + (1 - \delta)Q_{t+1}^*)/Q_t^*$ from the non-US capital and $R_{K,t+1}$ from the US capital. With these returns and newly issued deposits $D_{i,t+1}^* + S_{t+1} X_{t+1}$, it can purchase $K_{F,i,t+1}^*$ and $K_{H,i,t+1}^*$. Since $\epsilon R_t^* S_t X_t$ is exchanged into $\$R_t^* (S_t/F_t) X_t$ by the forward leg of the FX swap contract, the repayment of deposits in EUR is $R_t^* D_{i,t}^* + S_{t+1} R_t^* (S_t/F_t) X_t$. Then, the budget constraint is

$$\begin{aligned} Q_{t+1}^* K_{F,i,t+1}^* + S_{t+1} Q_{t+1} K_{H,i,t+1}^* + R_t^* D_{i,t}^* + S_{t+1} R_t^* \frac{S_t}{F_t} X_t \\ = R_{K,t+1}^* Q_t^* K_{F,i,t}^* + S_{t+1} R_{K,t+1} Q_t K_{H,i,t}^* + (D_{i,t+1}^* + S_{t+1} X_{t+1}) \end{aligned}$$

Figure 5 summarizes the balance sheet and the flow of funds of non-US bank. Cash flows from the FX swap contract is described in the red box.

²⁴It is without loss of generality that non-US banks receive X_t uniformly from US banks.

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

Figure 5: Balance Sheet and Flow of Funds of the Non-US Bank

Since the value of US capital holding $Q_t K_{H,i,t}^*$ is denominated in USD, there is a currency mismatch between the return and the funding cost. In this model, the motive for *currency matching* arises because non-US banks are subject to tighter limit on asset holdings of which currency risks are not hedged, reflected in the leverage constraint (3.34). Unlike the mean-variance framework, we can still use the first-order perturbation method, simplifying the analysis.²⁵ Let bank i fund $x_t^* \in [0, 1]$ share of $Q_t K_{H,i,t}^*$ through the FX swap market, which represents the demand for synthetic dollar funding. Since X_t is the amount of USD that is exchanged in the FX swap market, the demand for synthetic dollar funding should satisfy $x_{i,t}^* Q_t K_{H,i,t}^* = X_t$.

There is an implicit assumption that non-US banks cannot approach direct dollar funding market where they can borrow USD at interest rate R_t . Instead, currency matching is only available through the FX swap market. This is the important and distinguishing feature of this model that creates the channel through which CIP deviations can affect cross-border capital flows and asset prices. This assumption is not unrealistic since non-US banks, except for some big global banks, usually lack access to the direct dollar funding market or they need to pay high premium for the dollar funding (see Ivashina et al., 2015; Du and Schreger, 2022 for instance).²⁶

Combining the balance sheet identity and the budget constraint with $X_t = x_{i,t}^* Q_t K_{H,i,t}^*$, we can obtain the law of motion for net worth as

$$\begin{aligned}
N_{i,t+1}^* = & \left[(R_{K,t+1}^* - R_t^*) \phi_{F,i,t}^* + \underbrace{\frac{S_{t+1}}{S_t} \left(R_{K,t+1} - R_t^* \frac{S_t}{S_{t+1}} \right)}_{\textcircled{B}} (1 - x_{i,t}^*) \phi_{H,i,t}^* \right. \\
& \left. + \underbrace{\frac{S_{t+1}}{S_t} \left(R_{K,t+1} - R_t^* \frac{S_t}{F_t} \right)}_{\textcircled{C}} x_{i,t}^* \phi_{H,i,t}^* + R_t^* \right] N_{i,t}^* \quad (3.33)
\end{aligned}$$

²⁵Liao and Zhang (2020) derives the demand for currency hedging from mean-variance utility function in a two-period partial equilibrium framework.

²⁶Non-US banks cannot usually tap US dollar from deposits. Wholesale dollar funding is also available for top-tier global banks. Hence, non-US banks with low credit quality have to rely on synthetic dollar funding. See Rime et al. (2022) for detailed explanation.

for the ratio of each asset to net worth

$$\phi_{F,i,t}^* = \frac{Q_t^* K_{F,i,t}^*}{N_{i,t}^*}$$

$$\phi_{H,i,t}^* = \frac{S_t Q_t K_{H,i,t}^*}{N_{i,t}^*}$$

We can see that each asset-to-net-worth ratio is multiplied by the excess return of the asset. ③ is the dollar return on $K_{H,i,t}^*$ in excess of EUR borrowing. Since the currency of return, USD, is not matched with the currency of cost which is EUR, the excess return in USD is subject to the exchange rate risk. On the other hand, ④ is the dollar return in excess of the synthetic dollar funding cost, implying that the currency of return and cost are matched.²⁷ It can be expressed as $R_{K,t+1} - (R_t - cid_t)$, so $-cid_t$ is an intermediation fee that the non-US bank has to pay for the synthetic dollar funding.

Let us denote continuing bank i 's objective function as $V_{i,t}^*$. Then, $V_{i,t}^*$ is defined recursively as

$$V_{i,t}^* = E_t \sum_{s=1}^{\infty} (1 - \sigma) \sigma^{s-1} \Lambda_{t,t+s}^* N_{i,t+s}^* = E_t [\Lambda_{t,t+1}^* \{(1 - \sigma) N_{i,t+1}^* + \sigma V_{i,t+1}^*\}]$$

Similar to the US, each bank is subject to a leverage constraint

$$V_{i,t}^* \geq \Theta_t \left[\left(\theta_{F1}^* + \theta_{F2}^* \frac{Q_t^* K_{F,t}^*}{P_t^*} \right) Q_t^* K_{F,i,t}^* + \left(\theta_{H1}^* + \theta_{H2}^* \frac{(1 - x_t^*) S_t Q_t K_{H,t}^*}{P_t^*} \right) (1 - x_{i,t}^*) S_t Q_t K_{H,i,t}^* \right. \\ \left. + \left(\theta_{X1}^* + \theta_{X2}^* \frac{x_t^* S_t Q_t K_{H,t}^*}{P_t^*} \right) x_{i,t}^* S_t Q_t K_{H,i,t}^* \right] \quad (3.34)$$

where Θ_t is the global financial friction shock. Here, θ_{H1}^* and θ_{X1}^* are parameters for the limit on unhedged and hedged US capital holdings. In our calibration, $\theta_{H1}^* > \theta_{X1}^*$, so unhedged US capital holdings are subject to tighter regulation.

²⁷One may argue that the return rate in EUR is still subject to exchange rate risk as ④ is multiplied by the USD appreciation rate, and it needs to be fully hedged. However, this is infeasible since $R_{K,t+1}$ is unknown at period t . Thus, we cannot hedge $R_{K,t+1}$, and instead use return rate without uncertainty when deciding the amount of hedging. In this paper, risk-free rate R_t^* is used, and there is an hedging error $((F_t - S_{t+1})/S_t)(R_{K,t+1} - R_t^* S_t/F_t)$. This hedging error is small, about -0.013bp in the steady-state, and thus creates little problem since we are analyzing near the steady-state.

Under the conjecture that $V_{i,t}^* = \nu_t^* N_{i,t}^*$, the optimization problem of continuing bank i is

$$\begin{aligned} \nu_t^* &= \max_{\phi_{F,i,t}^*, \phi_{H,i,t}^*, x_{i,t}^*} \nu_{F,t}^* \phi_{F,i,t}^* + \nu_{H,t}^* (1 - x_{i,t}^*) \phi_{H,i,t}^* + \nu_{X,t}^* x_{i,t}^* \phi_{H,i,t}^* + \nu_{N,t}^* \\ \text{s.t. } \nu_t^* &\geq \Theta_t \left[\left(\theta_{F1}^* + \theta_{F2}^* \frac{Q_t^* K_{F,t}^*}{P_t^*} \right) \phi_{F,i,t}^* + \left(\theta_{H1}^* + \theta_{H2}^* \frac{(1 - x_t^*) S_t Q_t K_{H,t}^*}{P_t^*} \right) (1 - x_{i,t}^*) \phi_{H,i,t}^* \right. \\ &\quad \left. + \left(\theta_{X1}^* + \theta_{X2}^* \frac{x_t^* S_t Q_t K_{H,t}^*}{P_t^*} \right) x_{i,t}^* \phi_{H,i,t}^* \right] \end{aligned}$$

for the stochastic discount factor of bank $\Omega_{t,t+1}^* \equiv \Lambda_{t,t+1}^* (1 - \sigma + \sigma \nu_{t+1}^*)$ and the expected discounted returns on assets and net worth as

$$\nu_{F,t}^* \equiv E_t \left[\Omega_{t,t+1}^* (R_{K,t+1}^* - R_t^*) \right] \quad (3.35)$$

$$\nu_{H,t}^* \equiv E_t \left[\Omega_{t,t+1}^* \frac{S_{t+1}}{S_t} \left(R_{K,t+1}^* - R_t^* \frac{S_t}{S_{t+1}} \right) \right] \quad (3.36)$$

$$\nu_{X,t}^* \equiv E_t \left[\Omega_{t,t+1}^* \frac{S_{t+1}}{S_t} \left(R_{K,t+1}^* - R_t^* \frac{S_t}{F_t} \right) \right] \quad (3.37)$$

$$\nu_{N,t}^* \equiv E_t \left[\Omega_{t,t+1}^* \right] R_t^* \quad (3.38)$$

The first-order conditions for the above problem are

$$\nu_{F,t}^* = \mu_t^* \Theta_t \left(\theta_{F1}^* + \theta_{F2}^* \frac{Q_t^* K_{F,t}^*}{P_t^*} \right) \quad (3.39)$$

$$\nu_{H,t}^* = \mu_t^* \Theta_t \left(\theta_{H1}^* + \theta_{H2}^* \frac{(1 - x_t^*) S_t Q_t K_{H,t}^*}{P_t^*} \right) \quad (3.40)$$

$$\nu_{X,t}^* = \mu_t^* \Theta_t \left(\theta_{X1}^* + \theta_{X2}^* \frac{x_t^* S_t Q_t K_{H,t}^*}{P_t^*} \right) \quad (3.41)$$

where μ_t^* is the Lagrangian multiplier of the leverage constraint. In particular, (3.37) and (3.41) yield the inverse demand function for the synthetic dollar funding as

$$-cid_t = \frac{E_t \left[\Omega_{t,t+1}^* \frac{S_{t+1}}{S_t} (R_{K,t+1}^* - R_t^*) \right]}{E_t \left[\Omega_{t,t+1}^* \frac{S_{t+1}}{S_t} \right]} - \frac{\mu_t^* \Theta_t}{E_t \left[\Omega_{t,t+1}^* \frac{S_{t+1}}{S_t} \right]} \left(\theta_{X1}^* + \theta_{X2}^* \frac{x_t^* S_t Q_t K_{H,t}^*}{P_t^*} \right)$$

The demand for synthetic dollar funding $x_t^* Q_t K_{H,t}^*$ is decreasing in $-cid_t$ unless $\mu_t^* = \theta_{X1}^* = \theta_{X2}^* = 0$, and it is displayed as the downward-sloping red line in Figure 6.

The law of motion for the aggregate net worth is

$$N_{t+1}^* = \sigma \left[(R_{K,t+1}^* - R_t^*) \phi_{F,t}^* + \frac{S_{t+1}}{S_t} \left(R_{K,t+1}^* - R_t^* \frac{S_t}{S_{t+1}} \right) (1 - x_t^*) \phi_{H,t}^* \right. \\ \left. + \frac{S_{t+1}}{S_t} \left(R_{K,t+1}^* - R_t^* \frac{S_t}{F_t} \right) x_t^* \phi_{H,t}^* + R_t^* \right] N_t^* + (1 - \sigma) \xi^* (\phi_{F,t}^* + \phi_{H,t}^*) N_t^* \quad (3.42)$$

where ξ^* is the fraction of total assets provided as endowment for entrant banks.

3.4 Equilibrium

The market clearing condition for the FX swap market equates the demand and supply for synthetic dollar funding. US banks supply X_t as CIP arbitrageurs while non-US banks demand $x_t^* Q_t K_{H,t}^*$ for currency matching. Hence, the equilibrium condition is

$$X_t = x_t^* Q_t K_{H,t}^* \quad (3.43)$$

Figure 6 plots the demand and supply of synthetic dollar funding around the steady-state.

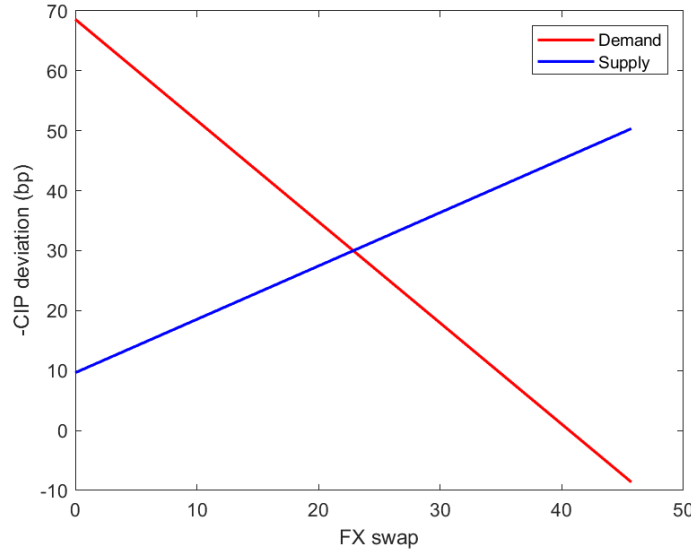


Figure 6: Demand and Supply Function of the FX Swap Market

Note. This figure shows the demand and supply functions for the synthetic dollar funding in the FX swap market. These functions are evaluated around the steady-state.

Combining the household and bank budget constraint with the profit functions of the firms, we

can obtain the US balance of payment as

$$\begin{aligned}
& \left(1 - \frac{\psi_P}{2} \left(\frac{P_{H,t}}{P_{H,t-1}} - 1\right)^2\right) P_{H,t} Y_{H,t} + \left(1 - \frac{\psi_P}{2} \left(\frac{P_{H,t}^*}{P_{H,t-1}^*} - 1\right)^2\right) \frac{1}{S_t} P_{H,t}^* Y_{H,t}^* \\
& - P_t \left(C_t + I_t + K_{t-1} \frac{\psi_K}{2} \left(\frac{I_t}{K_{t-1}} - \delta\right)^2\right) \\
& - (R_{K,t} - 1)(1 - x_{t-1}^*) Q_{t-1} K_{H,t-1}^* - \underbrace{\left(R_{K,t} - R_{t-1}^* \frac{S_{t-1}}{F_{t-1}}\right)}_{\textcircled{D}} X_{t-1} \\
& = - \left[(1 - x_t^*) Q_t K_{H,t}^* - (1 - x_{t-1}^*) Q_{t-1} K_{H,t-1}^*\right]
\end{aligned} \tag{3.44}$$

The LHS of the above equation is the current account of the US, which consists of the trade balance and the income balance. Trade balance is the difference between the output and the domestic absorption. For the income balance, $R_{K,t} - 1$ is the net interest payment on $(1 - x_{t-1}^*) Q_{t-1} K_{H,t-1}^*$ held by non-US banks whereas \textcircled{D} , the difference between the return rate on US capital and the synthetic dollar funding cost, is the net interest payment on X_{t-1} . Since $X_{t-1} = x_{t-1}^* Q_{t-1} K_{H,t-1}^*$ is held by non-US banks and invested into US capital, US needs to pay $R_{K,t}$ as an interest. However, US receives synthetic dollar funding cost since it supplies USD through the FX swap market, so the net interest income is $R_{K,t} - R_{t-1}^* S_{t-1}/F_{t-1}$. On the other hand, the RHS of (3.44) is the change in the net foreign asset position (NFA) of the US since $-(1 - x_t^*) Q_t K_{H,t}^*$ is the NFA position at period t . Note that X_t does not affect the NFA position due to the nature of the FX swap.

All equations characterizing the equilibrium are summarized in Online Appendix D.

4 Results

4.1 Calibration

Table 6 presents calibrated parameters in this model. Note that this model is in quarterly frequency. First, in the household side, the discount factor β is given by 0.995 to produce 2% annual risk-free rate while the inverse of intertemporal elasticity of substitution γ is 2 following the standard literature. The elasticity of substitution ν between domestic and imported goods is calibrated as 3.8 following [Devereux et al. \(2023\)](#).²⁸ On the other hand, the elasticity of substitution ϵ between varieties within each country is 6 following the standard literature. Since developed countries show strong home bias, ω is calibrated as 0.8 following [Devereux et al. \(2023\)](#). φ , which is the inverse of Frisch elasticity, is set to be 1, and disutility of labor κ and κ^* are calibrated to match the steady-state labor 1/3.

For the firm parameters, subsidy s and s^* are set at 0.2 to eliminate the steady-state price distortion while the capital share α is given by a standard value of 1/3. The Rotemberg price

²⁸This value comes from [Bajzik et al. \(2020\)](#) as the median of the meta-analysis considering the publication bias.

adjustment cost ψ_P is calibrated as 159.87 in order to match the Calvo parameter of 0.84.²⁹ Capital depreciation rate δ is set at 0.04 while the investment adjustment cost ψ_K is set at 4.

Parameters of the financial intermediaries are calibrated to match several long-run first moments of the US and the non-US. First, σ , which is the survival rate of banks, is given by 0.95 to match the average survival horizon of 5 years. ξ and ξ^* are calibrated as 0.128 and 0.085 respectively to match the steady-state US and non-US banks' leverage of 6. The main financial friction parameters θ_{H1} , θ_{X1} , θ_{F1}^* , θ_{H1}^* , and θ_{X1}^* are calibrated by targeting the following five empirical moments at annual frequency simultaneously: excess return on US capital of 200bp, excess return on non-US capital of 200bp, US NFA-to-GDP ratio of -18.5%, non-US banks' domestic investment share of 54%, and post-GFC CIP deviations of -30bp. Excess returns on capital $R_K - R$ and $R_K^* - R^*$ are long-run average credit spreads, which include not only equity returns but also corporate bond yields and commercial paper rates. The steady-state value of this excess return on bank assets is set at 200bp following Philippon (2015). Net foreign asset position in this model is $-Q(1 - x^*)K_H^*$, so the third empirical moment targets $-Q(1 - x^*)K_H^*/(4 * Y)$. As non-US banks' asset portfolios consist of US and non-US capital, its domestic investment share is $Q^*K_F^*/(Q^*K_F^* + SQK_H^*)$. The steady-state domestic investment share of 54% is from Camanho et al. (2022) who analyzed fund-level data from FactSet for the period 1999-2015. Post-GFC CIP deviation of -30bp comes from the average of 3-month LIBOR basis of G10 currencies except AUD and NZD for the period 1/1/2008 to 6/10/2021.

The quadratic parameters θ_{H2} , θ_{X2} , θ_{F2}^* , θ_{H2}^* , θ_{X2}^* are introduced to solve the indeterminacy problem in a portfolio balance model with incomplete markets. This is similar to the external debt-elastic interest rate in Schmitt-Grohé and Uribe (2003) to solve the indeterminacy problem in a small open economy model with incomplete markets. Following Devereux et al. (2023), all parameters θ_{H2} , θ_{X2} , θ_{F2}^* , θ_{H2}^* , and θ_{X2}^* are set at a low value 0.005. In Online Appendix G, I conduct a sensitivity analysis showing that the results of the baseline model are not driven by the choice of these quadratic parameters.

In the government side, ϕ_π is set as 1.5 following the standard New Keynesian literature such as Galí (2015). Interest rate smoothing parameters ρ_r and ρ_r^* are assumed to be 0.5.

Regarding the shock variables, the persistence of TFP and financial friction shocks ρ_z , ρ_z^* , ρ_θ , ρ_θ^* are assumed to be 0.7 while the persistence of monetary policy shocks ρ_m and ρ_m^* are 0.5. The standard deviations σ_m and σ_m^* of monetary policy shocks are given by 0.25% to produce 1% annual standard deviation. Following Devereux et al. (2023), ρ_{m,m^*} and σ_θ are calibrated as 0.656 and 1.111 respectively targeting $\rho(\Delta c_t, \Delta c_t^*) = 0.9$ and $\rho(\Delta \mathcal{E}_t, \Delta c_t - \Delta c_t^*) = -0.05$. Notably, σ_θ is calibrated to resolve the Backus-Smith puzzle (see Backus and Smith (1993)). When calibrating the model, only monetary shocks and the global financial friction shock are considered while technology shocks

²⁹Corsetti et al. (2008) show that the Rotemberg parameter ψ_P corresponds to $(\epsilon - 1)\lambda/(1 - \lambda)(1 - \beta\lambda)$ for the Calvo parameter λ .

are excluded.

The detailed explanation for the calibration and steady-state of the baseline model are derived in Online Appendix E.

Table 6: Parameter Values

Parameter	Value	Description	Source or Target
β	0.995	Discount factor	2% risk-free rate
γ	2	Inverse of intertemporal elasticity of substitution	Devereux et al. (2023)
ω	0.8	Home bias	Devereux et al. (2023)
ν	3.8	Elasticity of substitution across country	Devereux et al. (2023)
ϵ	6	Elasticity of substitution within country	Devereux et al. (2023)
φ	1	Inverse of Frisch elasticity	Devereux et al. (2023)
κ	13.915	US Disutility of labor	Steady-state L of 1/3
κ^*	12.253	Non-US Disutility of labor	Steady-state L^* of 1/3
$s = s^*$	0.2	Subsidy to firms	$s = 1/(\epsilon - 1)$
α	1/3	Capital share	Capital share of 1/3
ψ_P	159.87	Rotemberg price adjustment cost	Calvo parameter of 0.84
δ	0.04	Capital depreciation rate	Devereux et al. (2023)
ψ_K	4	Investment adjustment cost	Devereux et al. (2023)
σ	0.95	Survival rate of banks	Average survival horizon of 5 years
ξ	0.128	Transfer to new US banks	Steady-state bank leverage of 6
ξ^*	0.085	Transfer to new Non-US banks	Steady-state bank leverage of 6
θ_{H1}	0.604	US bank friction on US capital	Excess return on US capital of 200bp
θ_{X1}	0.121	US bank friction on FX swap	Excess return on non-US capital of 200bp
θ_{F1}^*	0.304	Non-US bank friction on non-US capital	US NFA-to-GDP ratio of -18.5%
θ_{H1}^*	0.304	Non-US bank friction on unhedged US capital	Domestic investment share of 54%
θ_{X1}^*	0.243	Non-US bank friction on hedged US capital	Post-GFC CIP deviation of -30bp
θ_{H2}	0.005	Quadratic term corresponding to θ_{H1}	Devereux et al. (2023)
θ_{X2}	0.005	Quadratic term corresponding to θ_{X1}	Devereux et al. (2023)
θ_{F2}^*	0.005	Quadratic term corresponding to θ_{F1}^*	Devereux et al. (2023)
θ_{H2}^*	0.005	Quadratic term corresponding to θ_{H1}^*	Devereux et al. (2023)
θ_{X2}^*	0.005	Quadratic term corresponding to θ_{X1}^*	Devereux et al. (2023)
ϕ_π	1.5	Taylor coefficient on inflation	Galí (2015)
ρ_θ	0.7	Persistence of US leverage constraint shock	Standard literature
σ_θ	1.111	S.D. of global leverage constraint shock	$\rho(\Delta \mathcal{E}_t, \Delta c_t - \Delta c_t^*) = -0.05$
ρ_r	0.5	US interest rate smoothing parameter	Standard literature
ρ_m	0.5	Persistence of US MP shock	Standard literature
σ_m	0.01/4	S.D. of US MP shock	
ρ_r^*	0.5	Non-US interest rate smoothing parameter	Standard literature
ρ_m^*	0.5	Persistence of non-US MP shock	Standard literature
σ_m^*	0.01/4	S.D. of non-US MP shock	
ρ_{m,m^*}	0.656	Correlation coefficient between ϵ_m and ϵ_m^*	$\rho(\Delta c_t, \Delta c_t^*) = 0.9$

4.2 Impulse Responses

Based on the calibrated model, I produce impulse responses to 100bp contractionary US monetary policy shock. In particular, impulse responses from the baseline model are compared with the counterfactual economy where there is no limit on CIP arbitrage, *i.e.* $\theta_{X1} = \theta_{X2} = 0$. This counterfactual setting models the economy during the pre-GFC periods while the baseline economy is the case for the post-GFC periods. All other parameters of the counterfactual economy are set to be the same as the baseline model in order to focus only on differences in impulse responses due to the limit on CIP arbitrage.

Figure 7 displays impulse responses to 100bp tightening of US monetary policy. Blue solid line is the baseline impulse response while the green dotted line is the counterfactual one. Time periods in the x-axis are in quarterly frequency, so the impulse responses are shown up to 10 years.

The main mechanism of the synthetic dollar funding channel works through the effect of US monetary policy on CIP deviations (price) and synthetic dollar funding (quantity). First, panel (7b) shows that CIP deviations decline about 23bp from their steady-state in the baseline economy. This matches the empirical estimate of 25.5bp in Table 3 as an untargeted moment. Since CIP deviations are negative in the steady-state, the decline in CIP deviations is equivalent to the widening of CIP deviations. After about 14 quarters, CIP deviations return to their steady-state level of -30bp. On the other hand, CIP deviations do not respond in the counterfactual economy since the CIP always holds in the absence of regulation on CIP arbitrage.

CIP deviations widen because net worth of banks decreases and their leverage constraints become more tightened accordingly. In panel (7c) and (7d), net worth of both banks decreases in response to the contractionary US monetary policy shock. If the US policy rate rises, the aggregate demand of the US is reduced, exerting downward pressure on the price of the US capital. As US capitals are held by US and non-US banks, the asset values of their balance sheets decline, which leads to lower net worth. Compared to the counterfactual economy, the decrease in the net worth is smaller for US banks whereas it is larger for non-US banks. This is due to the two offsetting factors determining the real value of net worth: price of capital and inflation. As we will see later, inflation rate goes down more in the baseline economy, which pushes the real value of net worth upward. Even though the decline in the price of capital is larger for the baseline economy, the lower inflation makes the net worth of US banks decreases less. This is the opposite for non-US banks.

In panel (7e) and (7f), the Lagrangian multipliers of US and non-US banks rise about 0.8 log points. This means that the leverage constraints of both US and non-US banks are tightened due to their lower net worth. As implied by the supply function of FX swap (3.28), the increase in the Lagrangian multiplier of the US bank leads to the widening of CIP deviations in panel (7b). US banks reduce supply of synthetic dollar funding through the FX swap market, so CIP deviations as the price of the synthetic dollar funding widen in the equilibrium. Note that the tightening of

the non-US banks' leverage constraint brings about the decrease in the demand for FX swap and upward pressure for CIP deviations. In the general equilibrium, the supply-side effect is larger than the demand-side effect so that CIP deviations widen. Comparing with the counterfactual case, the increases in Lagrangian multipliers are larger in the baseline case even though the net worth of the US bank declines less. This difference comes from the additional constraint that US banks face in the baseline economy: leverage constraint on FX swap. Even though the net worth of the US bank decreases more in the counterfactual economy, its leverage is less constrained since it faces no limit on FX swap activity.

Along with CIP deviations as price variables, panel (7g) displays the impulse response of the quantity variable: synthetic dollar funding. Since a contractionary US monetary policy shock reduces the supply (more than the demand) of FX swap, the synthetic dollar funding decreases in the baseline economy. Interestingly, there is a stark difference in the counterfactual impulse response which shows an increase in the synthetic dollar funding. This is due to the change in the composition of assets held by US banks. Since there is no regulation on FX swap, US banks substitute FX swap for US capital holdings, which results in the increasing synthetic dollar funding in the counterfactual economy.

These effects on CIP deviations and synthetic dollar funding transmit to real economies of the US and the non-US through changes in capital holdings by banks. US capital holdings by non-US banks decline by about 1.10% as shown in panel (7h). In other words, cross-border positions on US capitals are reduced significantly since part of the positions are funded through the FX swap market and the cost of this funding becomes higher due to the widening of CIP deviations. Instead, in panel (7i), domestic capital holdings by US banks increase. This is in line with the role of US monetary policy in the global retrenchment toward domestic assets (Miranda-Agrippino and Rey, 2020). In this model, the FX swap market friction, reflected in CIP deviations, plays a major role in generating the global retrenchment. Note that the response of non-US banks' US capital holdings is much larger than the counterfactual with 0.64% decline, which reflects the stark difference in the response of the synthetic dollar funding as discussed above.

Panel (7j) and (7k) show the impulse responses of aggregate US and non-US capital. US capital decreases by 0.44%, and this is in part due to the spillback of US monetary policy to the US through the change in CIP deviations. The reduction of cross-border asset holdings and the lower demand for the US capital by non-US banks yield the spillback which takes place in the presence of the friction in the FX swap market.³⁰ This spillback is amplified by 0.07%p comparing with the counterfactual response. One may argue that this amplification is quantitatively negligible, but the difference between the baseline and the counterfactual model implies the amplification is nearly 20% and therefore nontrivial. Non-US capital goes down by 0.37% and shows amplification of 0.02%p.

³⁰Breitenlechner et al. (2022) find non-trivial spillback effect of US monetary policy shocks. Also, Fischer (2015) implies that the Federal Reserve considers, at least implicitly, the spillback effect when implementing the monetary policy.

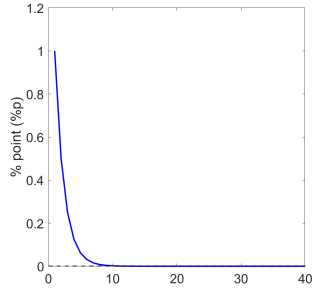
Since CIP deviations are the wedge between the synthetic and the direct dollar funding cost, the synthetic dollar funding cost rises more than the direct cost when CIP deviations widen. Hence, the intermediation by non-US banks is hampered more, reducing not only the US capital holdings but also the non-US capital holdings. This spillover effect is amplified relative to the counterfactual world where the CIP always holds and the synthetic dollar funding cost is equivalent to the direct funding cost.

Impulse responses of output (7l) and (7m) are affected by the movements of capital stock shown previously. Obviously, outputs of both the US and the non-US decrease as the conventional model, but these impulse responses are amplified in the existence of the limit on CIP arbitrage. US output decreases by 2.95%, which is 0.34%p larger decrease than the counterfactual case, while non-US output decreases by 2.59% with the amplification of 0.17%p. Investment expenditure of both countries also shows similar patterns. In panel (7n) and (7o), US investment is reduced by 10.93% while non-US investment is reduced by 9.26%. These baseline impulse responses of the US and the non-US are amplified by 1.64%p and 0.64%p respectively.

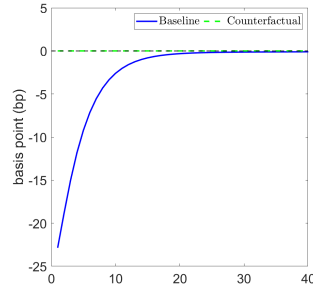
Panel (7p) and (7q) display impulse responses of consumption. Interestingly, US consumption is higher while non-US consumption is lower in the baseline economy than the counterfactual economy. This can be explained by CIP deviations as intermediation fees that US banks obtain from supplying the USD in the FX swap market. Since non-US banks demand USD to hold US capital but they cannot access direct dollar funding market, there is an excess demand for the USD. This excess demand is cleared by the synthetic dollar funding, but this requires paying CIP deviations for using the USD liquidity through the FX swap market. Hence, there is a transfer of wealth from the non-US to the US as the form of CIP deviations.

From panel (7r) and (7s), decreases in US and non-US inflation rates are also amplified. This is due to the lower aggregate demand arising from the limit on CIP arbitrage. Since the synthetic dollar funding cost goes up, intermediation by non-US banks is hampered and thus non-US aggregate demand is also reduced. Moreover, since non-US banks hold less amount of US capital, the demand for the US capital decreases and the total US investment shrinks accordingly. As a result, US inflation rate declines by 2.03% with amplification of 0.21%p while non-US inflation rate goes down by 1.85% with amplification of 0.10%p.

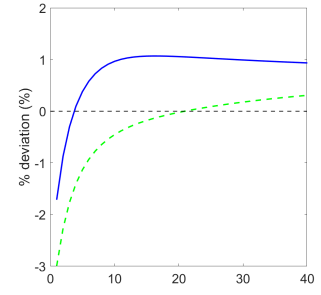
As the conventional theory predicts, USD appreciates in both nominal and real value as in panel (7t) and (7u). This model predicts the amplification of this effect: nominal appreciation rate rises by 1.29%p with amplification of 0.84%p and real appreciation of 0.28% with amplification of 0.19%p. It is due to the lower supply of the USD through the FX swap market as it is shown in the response of the synthetic dollar funding. Also, the real forward exchange rate rises more in the baseline economy by the same reason. Note that the forward exchange rate rises less than the spot exchange rate, implying the decline in the forward premium as observed in the data.



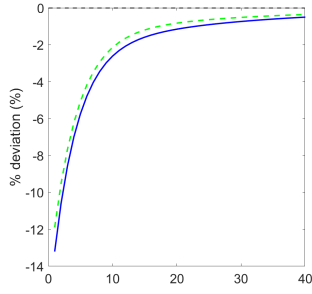
(a) US MP Shock



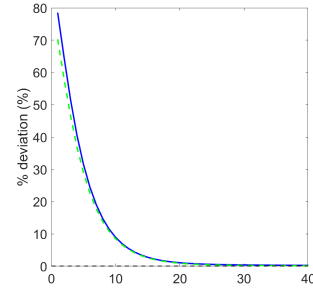
(b) CIP Deviation



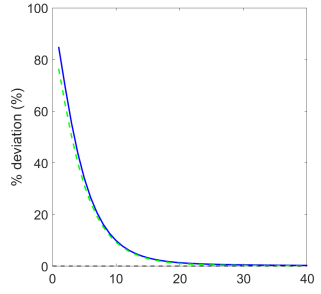
(c) US Bank Net Worth



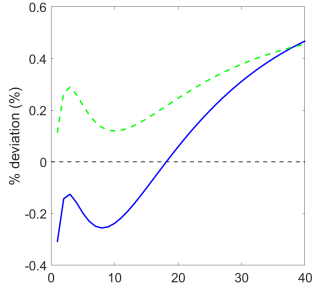
(d) Non-US Bank Net Worth



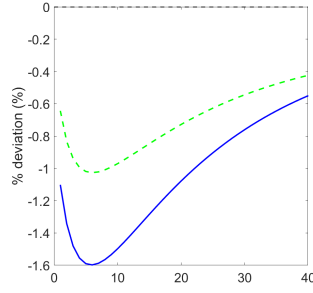
(e) US Lagrangian Multiplier



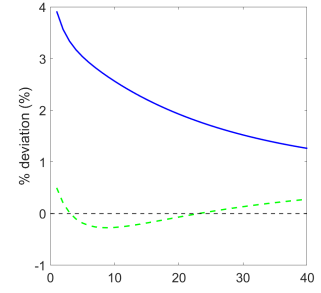
(f) Non-US Lagrangian Multiplier



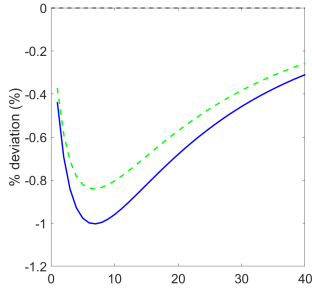
(g) Synthetic Dollar Funding



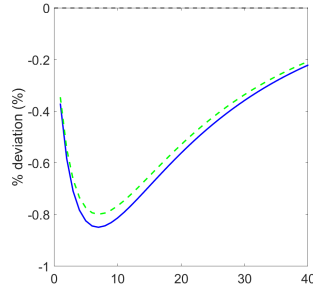
(h) Non-US's US Capital Holding



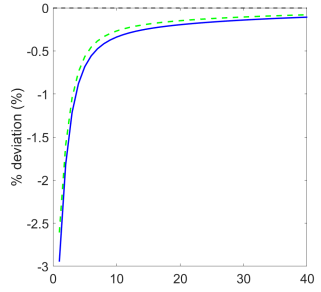
(i) US's US Capital Holding



(j) US Aggregate Capital

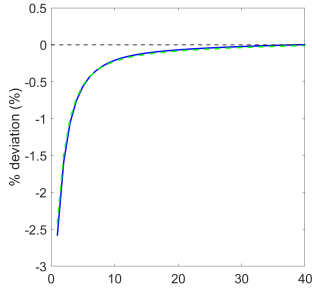


(k) Non-US Aggregate Capital

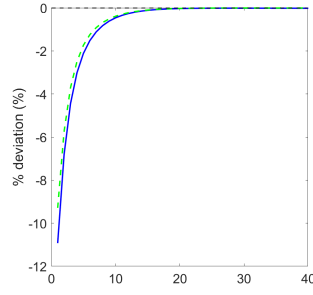


(l) US Output

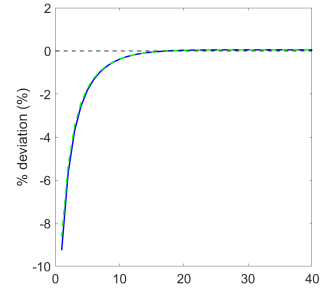
Figure 7: Impulse Responses to Contractionary US Monetary Policy Shock



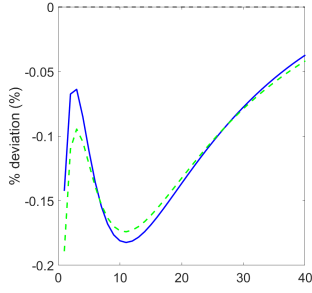
(m) Non-US Output



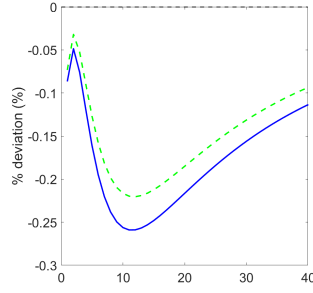
(n) US Investment



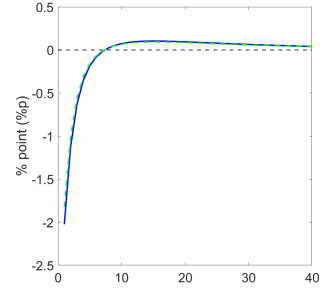
(o) Non-US Investment



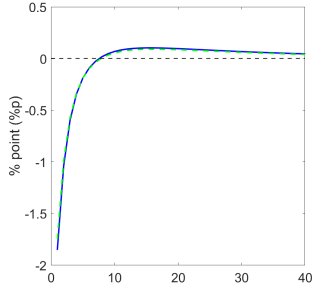
(p) US Consumption



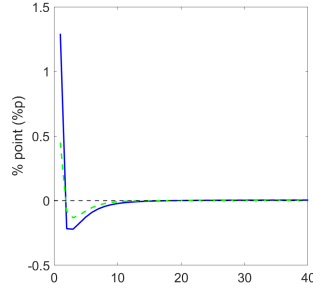
(q) Non-US Consumption



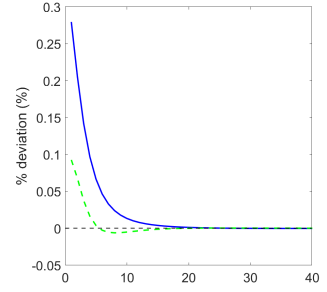
(r) US Inflation



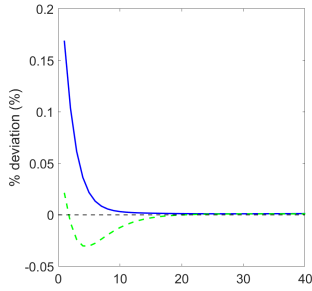
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

Figure 7: Impulse Responses to Contractionary US Monetary Policy Shock (Continued)

Note. This figure shows impulse responses to 100bp contractionary US monetary policy shock. Time periods of the impulse responses are in quarterly frequency. For each panel, blue solid line is the baseline impulse response where US banks are subject to the leverage constraint on FX swap. Impulse responses from the counterfactual economy where there is no leverage constraint on FX swap are displayed in green dotted lines.

4.3 US Monetary Policy and Central Bank Swap Lines

In this section, we analyze how central bank swap liens affect the transmission channel of US monetary policy.³¹ Central bank swap line policy is an international liquidity facility in the sense that a source central bank lends its currency to a recipient central bank while it pledges its currency as a collateral. Figure 8 describes the basic structure of central bank swap lines. The source central bank provides its currency to the recipient central bank while the currency of the recipient central bank is used as collateral.³² Then, the recipient central bank lends the source currency to the banks in its jurisdiction with collateral pledged, usually at similar terms as domestic discount window lending. The interest rate that the source central bank imposes to the recipient central bank is set as a spread over a risk-free rate (usually an overnight index swap rate). Maturities are usually overnight, 1 week, and 1 month in practice with the maximum of 3 months. Limits are also specified in the swap line arrangement while it is unlimited for the standing facilities (with Bank of Canada, European Central Bank, Bank of England, Bank of Japan, and Swiss National Bank).



Figure 8: Central Bank Swap Lines

Note. This figure shows the basic structure of central bank swap lines. In line with previous notations, the currency of the source central bank is denoted as USD (\$) while the currency of the recipient central bank is denoted as EUR (€).

Considering the major role of the USD in international financial markets, the Federal Reserve is usually the source central bank. From now on, the source central bank is denoted as the Fed while the recipient central bank is denoted as the ECB. Then, the dollar swap line policy can be interpreted as a collateralized public liquidity line that the Fed injects USD to international financial markets, *i.e.* lender of the last resort policy. It has been implemented as measures to stabilize international financial markets since the GFC, and more actively during the Covid-19 crisis.³³

As central bank swap lines provide dollar liquidity into international financial markets, the cost of USD can become lower. According to Bahaj and Reis (2022), the swap line spread ss_t works as an upper bound on CIP deviations as

$$-cid_t \leq ss_t + (r_t^{p*} - r_t^{\nu*})$$

where r_t^{p*} is the monetary policy rate and $r_t^{\nu*}$ is the interest on excess reserves of the ECB. Here, lower cases are used to denote net interest rates. cid_t is measured using OIS rates as risk-free rates.

³¹During the Covid-19 crisis, repo lines were introduced. Repo lines are different from swap lines in terms of collateral and eligibility. In this paper, I will focus on the swap line policy for simplicity.

³²For repo lines, securities denominated in source currency, such as US treasuries, are used as collateral.

³³For more information on the history of central bank swap lines, see Bahaj and Reis (2023).

The above inequality holds due to the no-arbitrage condition.³⁴ Let us assume that European banks can borrow USD from the ECB at the same rate as the swap line policy: $r_t^{OIS} + ss_t$. Note that this borrowing rate is a fixed rate. Then, the European banks can convert this USD into EUR, cover currency risks by purchasing FX swap, and deposit in the ECB. From this transaction, they can earn $r_t^{\nu*} + (r_t^{OIS} - cid_t - r_t^{OIS*})$. Since $r_t^{\nu*}$ is a floating rate, they cover interest rate risks using overnight index swap getting the spread of $r_t^{OIS*} - r_t^{p*}$. In total, the European banks earn $r_t^{OIS} - cid_t + (r_t^{\nu*} - r_t^{p*})$, and this should be lower than or equal to $r_t^{OIS} + ss_t$ for no-arbitrage. This is an international version of discount window of which discount rate imposes an upper bound on the federal funds rate.

When central bank swap lines exist, then CIP deviations may not widen due to the ceiling imposed by swap lines. Then, the transmission channel through the change in synthetic dollar funding costs can also be affected. However, [Bahaj and Reis \(2022\)](#) claims no direct relationship between the conventional monetary policy and the swap line policy since the swap line policy determines the swap line spread, which is independent from the short-term interest rate as the base rate. In order to investigate the potential interdependence between the conventional monetary policy and the swap line policy, this section compares impulse responses with and without central bank swap lines.

First, the central bank swap line policy is modeled as the following ceiling on $-cid_t$:

$$-cid_t \leq ss_t \quad (4.1)$$

Here, $r_t^{p*} - r_t^{\nu*}$ in the original ceiling from [Bahaj and Reis \(2022\)](#) is omitted since there are no difference between risk-free rates in this model. Also, I assume that there is no limit on arbitrage regarding borrowing from the central bank. For simplicity, the swap spread is set at the value of steady-state CIP deviations as $ss_t = -\overline{cid}$. Note that (4.1) is an occasionally binding constraint. It binds only if CIP deviations widen compared to their steady-state levels. If (4.1) does not bind, then swap lines are not used by non-US banks.

Let us define the amount of USD provided through swap lines as X_t^{SL} . Since the US government provides X_t^{SL} to the non-US while getting repaid with the gross interest rate of $R_t - cid_t$ in the next period, the government budget constraint becomes

$$s \left(P_{H,t} Y_{H,t} + \frac{1}{S_t} P_{H,t}^* Y_{H,t}^* \right) + tr_t + X_t^{SL} = (R_{t-1} - cid_{t-1}) X_{t-1}^{SL} \quad (4.2)$$

The market clearing condition for the FX swap market is given by

$$X_t + X_t^{SL} = x_t^* Q_t K_{H,t}^* \quad (4.3)$$

³⁴Even when the no-arbitrage condition is violated, the less restrictive version of the inequality holds. For more details, see [Bahaj and Reis \(2022\)](#).

Due to the ceiling on CIP deviations, there can be an excess demand for synthetic dollar funding in the FX swap market. X_t^{SL} provided by the US government fills the excess demand and clears the market. Figure 9 describes the amount of swap lines provided by the Fed. In response to a contractionary US monetary policy shock, the supply function of synthetic dollar funding decreases. Without the swap line policy, CIP deviations would rise and synthetic dollar funding would decrease. However, since the swap line policy imposes a ceiling, CIP deviations do not rise. Instead, there is an excess demand for synthetic dollar funding, filled by swap lines X_t^{SL} .

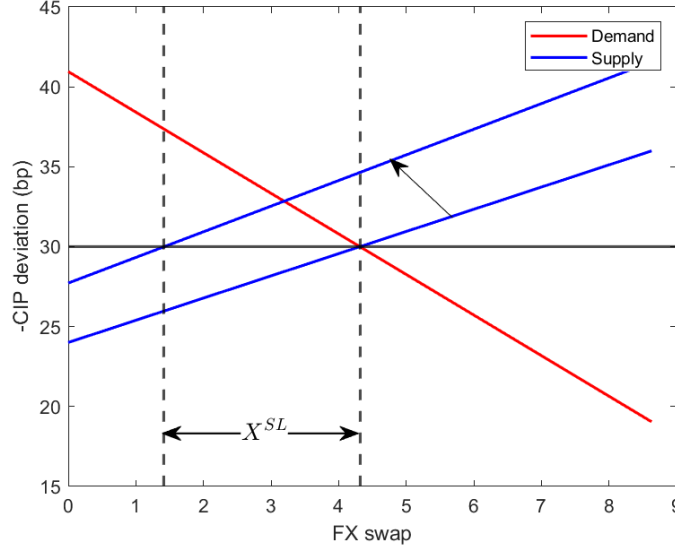


Figure 9: FX Swap Market and Swap Lines

Note. This figure shows the demand and supply functions for the synthetic dollar funding in the FX swap market with swap lines. These functions are evaluated around the steady-state.

Finally, the complementary slackness condition is given by

$$(cid_t - \overline{cid})X_t^{SL} = 0 \quad (4.4)$$

When (4.1) does not bind, then there is no excess demand for synthetic dollar funding and swap lines are not used, *i.e.* $X_t^{SL} = 0$. On the other hand, if $X_t^{SL} > 0$, then the ceiling should bind.

Following Guerrieri and Iacoviello (2015), the model with the swap line policy as the occasionally binding constraint is solved by the piecewise linear method. Then, we compare the transmission channel of US monetary policy with and without central bank swap lines. For this purpose, I derive relative impulse responses defined as ratios of the impulse responses with central bank swap lines to the one without swap lines. These relative responses higher than 1 means that impulse responses with central bank swap lines are larger than the ones without swap lines.

Relative impulse responses are displayed in Figure 10. Since contractionary US monetary policy

shocks put downward pressure on CIP deviations, (4.1) binds and the CIP deviation is equivalent to the swap spread $-\overline{cip}$. Hence, as panel (10a), the size of CIP deviations are lower when there are central bank swap lines. This is line with larger net worth of US and non-US banks (panel (10b) and (10c)) and the following lower Lagrangian multipliers of those banks (panel (10d) and (10e)).

Since the size of CIP deviations is reduced under the existence of central bank swap lines, synthetic dollar funding becomes larger as in panel (10f). As a result, in panel (10g) and (10h), US capital holdings by non-US banks are larger while US capital holdings by US banks are smaller. In other words, central bank swap lines relieve the global retrenchment toward domestic assets in response to contractionary US monetary policy shocks.

Consequently, in panel (10i) and (10j), both the US and the non-US aggregate capital are larger when there are central bank swap lines. Output and investment of the US and the non-US show similar patterns as the aggregate capital (panel (10k), (10l), (10m), and (10n)). Inflation rates of both countries are higher with central bank swap lines as in panel (10o) and (10p), implying that the swap line policy weakens the effect of monetary policy on moderating inflation.

US consumption is lower under the swap line policy at first since the ceiling on CIP deviations implies smaller transfer of wealth to the US. However, it becomes higher after 4 quarters due to lower frictions in the FX swap market. Non-US consumption is higher under the swap line policy on the other hand due to the smaller transfer of wealth to the US (panel (10q) and (10r)).

In panel (10s), (10t) and (10u), USD appreciation rate, real spot exchange rate and real forward exchange rate are lower.

Note that this section does not deal with the optimal central bank swap line policy or optimal policy mix. Instead of normative analysis, this section conducts a positive analysis focusing on how the transmission channel of US monetary policy changes when there are central bank swap lines. This positive analysis is more relevant than the normative analysis in this paper since this model cannot deal with costs of the swap line policy such as moral hazard problem. Moreover, the swap line policy is usually for stabilizing international financial markets during financial distress periods. Coordination with monetary policy for managing business cycles is outside the realm of the swap line policy.

Another related caveat is that we cannot say there is a conflict between the conventional monetary policy and the swap line policy in managing inflation and output gap. When there is a limit on CIP arbitrage and CIP deviations emerge as a consequence, effects of US monetary policy on inflation and output are amplified. It can be said that the swap line policy reduces this amplification. As long as we do not conduct welfare analysis, we cannot tell whether the swap line policy interferes with the conventional monetary policy or not. What we can only say in this paper is that the swap line policy dampens the transmission channel of US monetary policy.

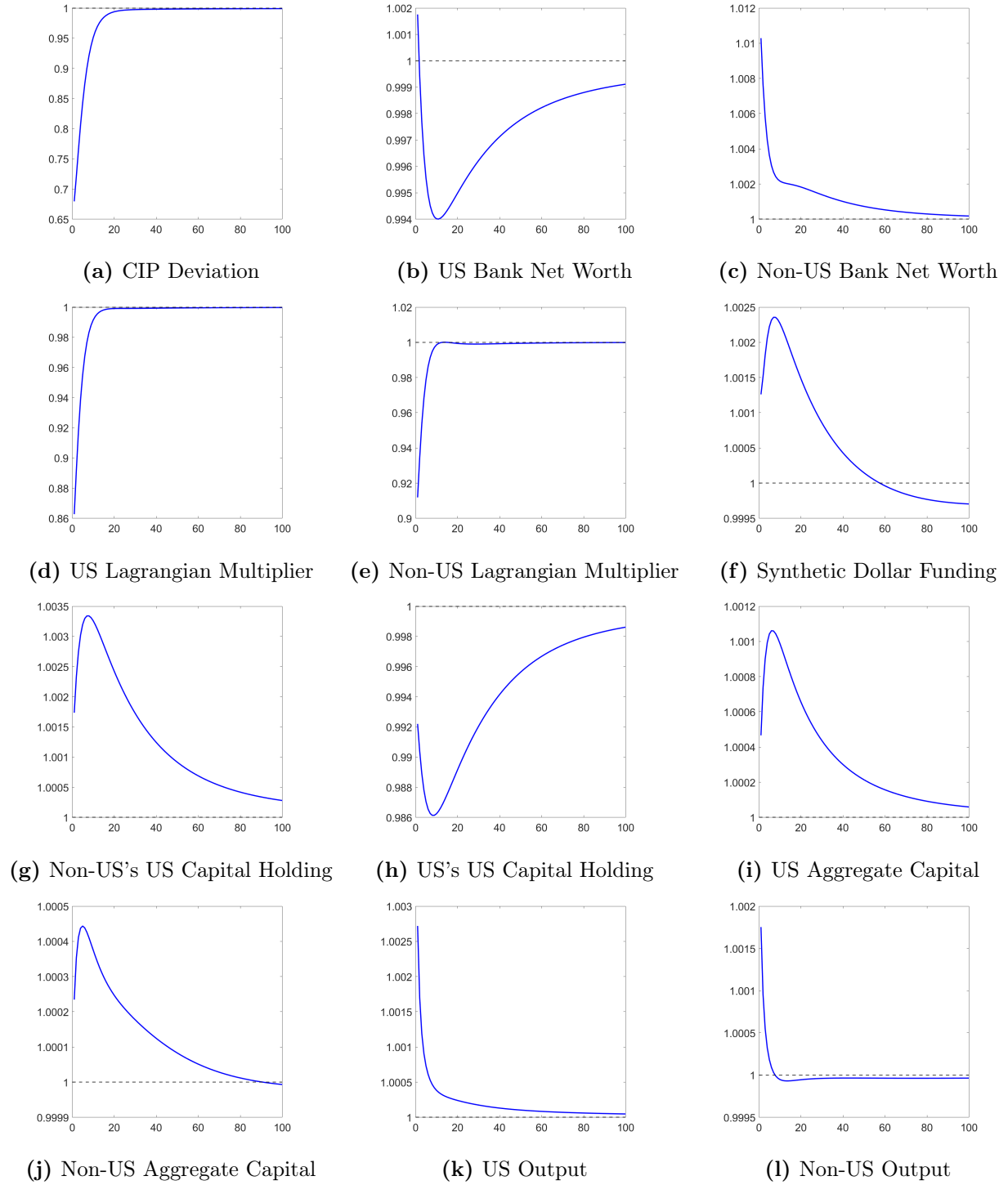


Figure 10: Relative Impulse Responses: With v.s. Without Swap Lines

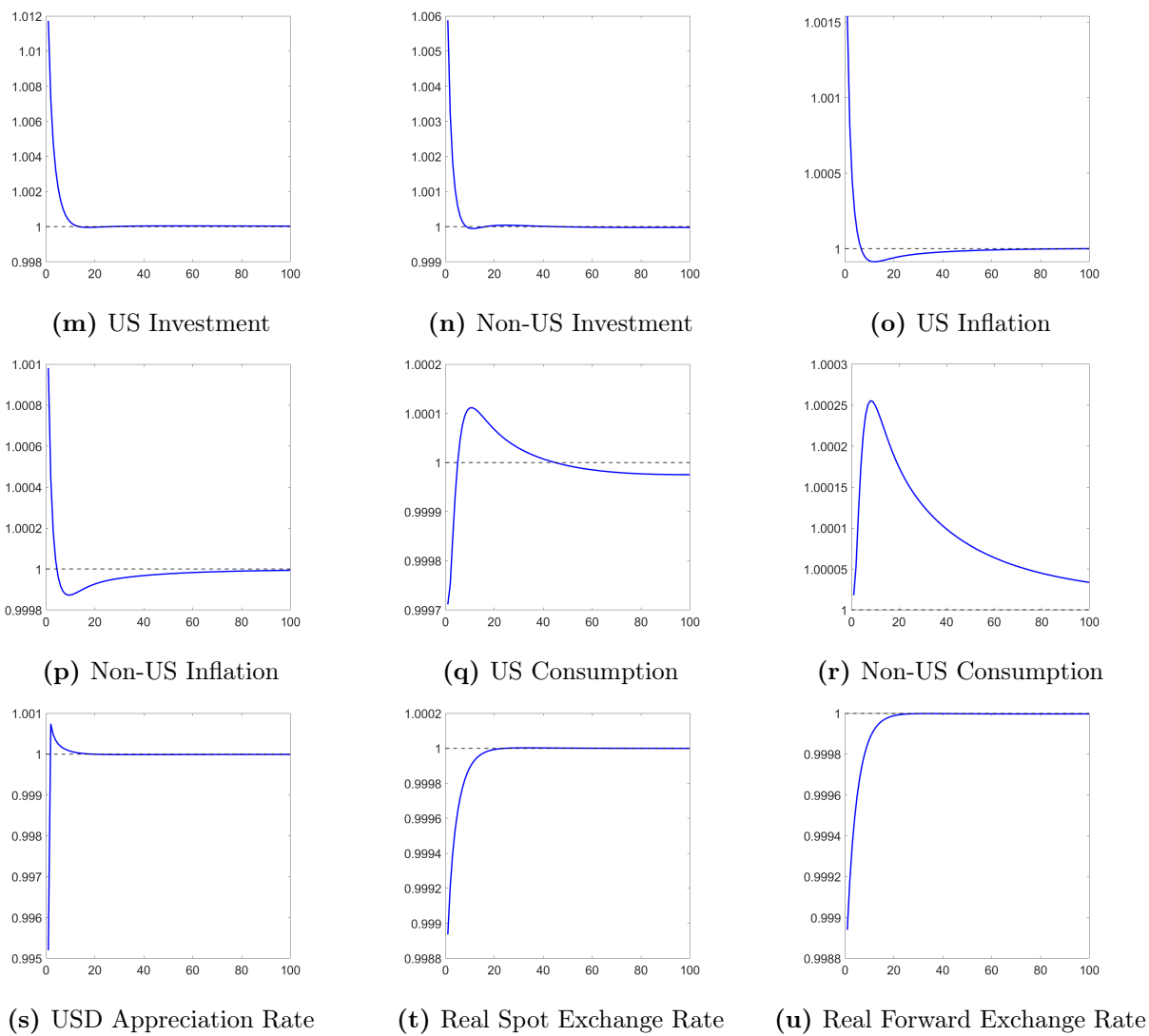


Figure 10: Relative Impulse Responses: With v.s. Without Swap Lines (Continued)

Note. This figure shows relative impulse responses to 100bp contractionary US monetary policy shocks. The relative impulse response of a variable is defined as a ratio of the impulse response with central bank swap lines to the one without swap lines. Time periods of the impulse responses are in quarterly frequency.

5 Conclusion

This paper investigates the effect of US monetary policy on CIP deviations, and provides the source for this effect as well as a new transmission channel of US monetary policy to global economies.

First, I show empirically that CIP deviations widen in response to contractionary US monetary policy shock. CIP deviations are measured as LIBOR-bases of G10 currencies while US monetary policy shocks are identified by high-frequency method. Then, I run OLS regression of CIP deviations on US monetary policy shocks from January 2000 to April 2021. In the post-GFC periods, CIP deviations widen in response to a rise in US policy rate, with the effects declining across maturities. This is in stark contrast to insignificant estimates in the pre-GFC periods. These effects are shown to be robust to using OIS-bases as CIP deviations and to the information effect of monetary policy.

Next, this paper constructs a two-country New Keynesian model with banks and the FX swap market to explain the empirical results and to provide its implication for global economies. US and non-US banks which are subject to leverage constraints constitute the FX swap market. US banks supply synthetic dollar funding by committing CIP arbitrage, and CIP deviations emerge due to the limit on CIP arbitrage. Non-US banks demand synthetic dollar funding in order to match the currency of their USD-denominated capital holdings assets by paying CIP deviations as intermediation fees. CIP deviations are thus determined in the equilibrium of the FX swap market.

Then, I investigate impulse responses to a contractionary US monetary policy shock and compare with the counterfactual without limit on CIP arbitrage. CIP deviations widen, by the similar amount to the empirical estimate, since the leverage constraint of US banks tightens. Thus, the synthetic dollar funding cost rises more than the direct dollar funding cost, leading to the larger decrease in US capital held by non-US banks. As a result, both US and non-US capital are reduced more than the counterfactual, implying the amplification of spillover and spillback. Output, investment, and inflation of both countries show similar patterns. US (Non-US) consumption becomes higher (lower) than the counterfactual since CIP deviations transfer wealth from the non-US to the US.

Finally, this paper studies the synthetic dollar funding channel of US monetary policy when there are central bank swap lines. Since central bank swap lines impose ceilings on CIP deviations, the rise in synthetic dollar funding costs becomes smaller. Accordingly, the swap line policy dampens the synthetic dollar funding channel of US monetary policy.

For the future research, this paper can contribute to normative analysis on central bank swap lines. After the GFC, and particularly during the COVID-19 crisis, central bank swap lines have been used prominently. However, the optimal swap line policy is understudied area of research. In particular, the potential trade-off of the swap line policy considering its side effects on the ex-ante stability of financial sectors has not been analyzed yet. We can extend this paper by incorporating the moral hazard problem and derive the optimal swap line policy, evaluating the (sub)optimality of the current policy.

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