The Synthetic Dollar Funding Channel of US Monetary Policy*

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Abstract

This paper proposes 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) in the post-global financial crisis 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 for 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 can 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

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1 Introduction

The previous literature on the transmission of US monetary policy has focused on direct dollar funding markets where non-US countries can borrow US dollar (USD) directly as the transmission mechanism (see Bräuning and Ivashina (2020), for example). US monetary policy is transmitted to foreign countries through capital flows determined by the cost of direct dollar funding, such as the London Inter-Bank Offered Rate (LIBOR), that tracks the policy rate of the Federal Reserve closely.

However, many financial intermediaries of non-US countries lack access to direct dollar funding markets and instead rely on foreign exchange (FX) swap markets for dollar funding (Du and Schreger, 2022). Dollar funding through FX swap markets is referred to as synthetic dollar funding since local currency borrowing is swapped into US dollar using FX swap contracts. The differential between the cost of synthetic dollar funding and direct dollar funding is equal to deviations from Covered Interest Rate Parity (CIP).[1] According to Du, Tepper, and Verdelhan (2018), CIP deviations has emerged since the global financial crisis (GFC) due to several reasons including the regulation on risk-less arbitrage. As CIP deviations for G10 currencies have been negative on average, synthetic dollar funding costs are higher than direct dollar funding costs.

Based on the above observation, this paper proposes a novel transmission channel of US monetary policy through FX swap markets: the synthetic dollar funding channel. The key mechanism of the synthetic dollar funding channel is the effect of US monetary policy on CIP deviations and its implications for amplifying the global transmission of US monetary policy shocks. In this sense, this paper is in line with the longstanding literature on the credit channel of monetary policy, starting from Bernanke and Gertler (1995). According to the credit channel, monetary contraction raises the external finance premium, which in turn amplifies the transmission of monetary shocks.[2] CIP deviations in this paper play a similar role as the external finance premium in the credit channel literature since CIP deviations represent wedges in dollar funding markets.

First, I provide empirical findings about effects of US monetary policy on CIP deviations. Using high-frequency data, a US monetary policy shock is estimated to have large and significant effects on CIP deviations in the post-GFC (2008-) period. For instance, 3-month CIP deviations widen by 35bp in response to a 100bp contractionary shock, which is substantial considering that the post-GFC average of CIP deviations for G10 currencies is about 20bp. These results are shown to be robust to different constructions of changes in CIP deviations, the information effect of monetary policy, and the Fed response to news channel.

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

[2] When internal financing is unavailable or insufficient, borrowers, such as firms, need to rely on external financing. However, external financing is more expensive than internal financing, with the wedge as the external financing premium. The external financing premium comoves with monetary policy shocks through balance sheets of borrowers or lending by financial intermediaries. This comovement is the main mechanism of financial accelerator and amplifies the transmission channel of monetary policy.

Given the above empirical evidence on the synthetic dollar funding channel, I construct a two-country New Keynesian model with financially-constrained banks to shed light on why these happen. The novel part of this model is embedding a FX swap market into a standard general equilibrium model. US and non-US banks constitute the FX swap market, and CIP deviations are endogenously determined as the equilibrium price in the FX swap market.

According to the model, the supply of synthetic dollar funding by US banks is increasing in the size of CIP deviations. Supplying synthetic dollar funding is equivalent to arbitraging negative CIP deviations because US banks sell US dollar and buy non-US currency in the spot market. However, there is a key financial friction that US banks are subject to a limit on arbitrage, reflecting the strengthened regulation on risk-less arbitrage after the GFC. Then, CIP deviations reflect shadow costs of balance sheet space of US banks. Since the size of CIP deviations is the arbitrage profit, it can be interpreted as an intermediation fee that US banks obtain by supplying synthetic dollar funding. In order for US banks to supply larger amount of synthetic dollar funding, CIP deviations need to be larger, generating a upward-sloping supply schedule of synthetic dollar funding.

The model also predicts that non-US banks' demand for synthetic dollar funding is decreasing in the size of CIP deviations. Non-US banks hold non-US capital denominated in non-US currency as well as US capital denominated in US dollar. In order to simplify the analysis, I assume that direct dollar funding is not available to non-US banks. Then, liabilities of non-US banks are denominated in only non-US currency, creating currency mismatch between US capital holdings and liabilities. Non-US banks can match currencies by funding US dollar synthetically with the amount of synthetic dollar funding optimally chosen taking CIP deviations as given. As CIP deviations become more negative, the synthetic dollar funding cost rises and the demand for synthetic dollar funding falls. In other words, non-US banks need to pay CIP deviations as intermediation fees for currency matching.

The model is calibrated targeting long-run first moments of the US and the rest of the world. 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 an impact response of CIP deviations that is quantitatively similar to the empirical estimate. 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 do. 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 effects of central bank swap lines on the synthetic dollar funding channel. The swap line policy is known to impose an upper bound on CIP deviations, stabilizing FX swap markets during financial distress periods (Bahaj and Reis, 2022). Then, the swap line policy can prevent the widening of CIP deviations following US monetary contraction and mitigate the amplification effects. In order to investigate these effects on the transmission channel, the swap line policy is modeled as an occasionally binding upper bound on CIP deviations. Then, I compare impulse responses with and 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 ceiling imposed by the swap line policy. Thus, the decline in synthetic dollar funding is dampened, leading to higher US capital holdings by non-US banks and attenuating the transmission to capital, output, investment, and inflation.

Related Literature

After the onset of the GFC, there has been extensive literature on the emergence of CIP deviations (see Baba, Packer, and Nagano (2008), Du and Schreger (2016), Du, Tepper, and Verdelhan (2018), Du, Im, and Schreger (2018)). Du, Tepper, and Verdelhan (2018) and Cerutti, Obstfeld, and Zhou (2021) regress CIP deviations on interest rate differentials and suggest the role of monetary policy, though they do not estimate the causal effects. Jiang, Krishnamurthy, and Lustig (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, Scharfstein, and Stein (2015) derives CIP deviations from margin requirement for the arbitrage. Iida, Kimura, and Sudo (2018) extend Ivashina, Scharfstein, and Stein (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, Şebnem Kalemli-Özcan, Ulu, and Baskaya (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, Şebnem Kalemli-Özcan, and Queralto (2022) and Devereux, Engel, and Wu (2023) have methodological similarities to this paper. Akinci, Şebnem Kalemli-Özcan, and Queralto (2022) investigate the effect of uncertainty shock while Devereux, Engel, and Wu (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 deviations are usually higher than CIP deviations, CIP deviations are crucial for banks since they are usually required to hedge currency risks. Said differently, CIP deviations are pivotal barometers for gauging the cost of dollar funding in the international financial markets. 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, Krishnamurthy, and Lustig (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, Krishnamurthy, and Lustig, 2020) or money-in-the-utility function (Kekre and Lenel, 2021). Bianchi, Bigio, and Engel (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 effects 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. In Section 5, effects of central bank swap lines on the synthetic dollar funding channel are discussed. Section 6 concludes.

2 Empirical Evidence

In this section, I estimate effects of US monetary policy on CIP deviations in order to provide empirical evidence on the transmission of US monetary policy to synthetic dollar funding costs. For this purpose, I construct panel dataset consisting of CIP deviations of G10 currencies and high-frequency identified US monetary policy shocks from January 2008 to April 2021. Then, effects of US monetary policy on CIP deviations in the post-GFC period are estimated by OLS regression with currency fixed effects. It is shown that a contractionary US monetary policy shock widens 3-month CIP deviations significantly.

2.1 Empirical Strategy

Effects of US monetary policy on CIP deviations are estimated by the following OLS regression with currency fixed effects:

$$\Delta cid_{j,h,t} = \alpha_j + \beta_h \Delta mp_t + \epsilon_{j,h,t} \tag{2.1}$$

The dependent variable $\Delta cid_{j,h,t}$ is the one-day change in CIP deviations between currency j and USD with maturity h. In the right-hand side, the explanatory variable Δmp_t is the change in US monetary indicator while α_j is the currency fixed effect and $\epsilon_{j,h,t}$ is the disturbance term. Then, β_h measures effects of US monetary policy on CIP deviations for each maturity h. The sample consists of G10 currencies with maturities spanning from 3-month to 10-year.[3,4] 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, Tepper, and Verdelhan, 2018). The sample period starts from January 2008 and ends at April 2021, which is the post-GFC period with non-zero CIP deviations.

In order to identify β_h, Δmp_t needs to be an exogenous monetary policy "shock". Since CIP deviations are market prices of synthetic dollar funding in FX swap markets, they are general equilibrium objects. This means that CIP deviations depend not only on monetary policy stance but also on other macroeconomic variables that affect supply or demand of synthetic dollar funding. Since those macroeconomic variables are also correlated with US monetary policy, (2.1) is susceptible to the endogeneity problem.

This paper identifies Δmp_t following an extensive literature on high-frequency identification of monetary policy shocks (see Gürkaynak, Sack, and Swanson, 2005; Nakamura and Steinsson, 2018 for example). As those papers, one or multiple principal components from changes in interest rate futures over a narrow window around each FOMC announcement are regarded as US monetary policy shocks. The key identifying assumption is that all the information on fundamentals are reflected to monetary policy just before the FOMC announcement. This assumption is satisfied since we take the window narrow enough that monetary policy cannot respond to the changes in fundamentals over that window. Hence, surprises in the interest rate futures are only due to unsystematic part of monetary policy. Details for this identification will be covered in Section 2.2.

2.2 Measurement and Data

2.2.1 CIP Deviations

CIP deviations of G10 currencies are measured as

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

where $r_{\$,h,t}$ and $r_{j,h,t}$ are risk-free rates of the USD and currency j respectively that mature h periods after time t. $\rho_{j,h,t}$ 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 rates. Spot and forward exchange rates are expressed in units of currency j per USD, so the increase in the exchange rate means the appreciation of the US dollar.

For 3-month maturity, cross-currency bases are calculated by the above equation. First, the

[3] G10 currencies include 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).

[4] Maturities in this sample are 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year.

interbank offered rate (IBOR) is used as the proxy for the risk-free rate.[5] Daily data of IBORs for each currency can be obtained from Bloomberg.[6] Next, $\rho_{j,h,t}$ is measured as the mid price of bid and ask for the forward premium using London closing rates, and is adjusted by the actual trading days.

For maturities longer than or equal to 1-year, the forward premium is inaccurate due to the illiquidity of forward exchange markets. Instead, following Du, Tepper, and Verdelhan (2018), CIP deviations are directly measured as cross-currency bases from cross-currency swaps traded in over-the-counter (OTC) markets. Similar to the forward premium above, the mid price of bid and ask for the cross-currency bases is used.[7] Daily data for cross-currency bases are available at Bloomberg, and Jesse Schreger kindly shared the data with me.

Figure 1 shows 3-month CIP deviations of G10 currencies against the USD. As Baba, Packer, and Nagano (2008) report, there have been substantial deviations from CIP since the GFC while CIP deviations had been negligible before the GFC. Note that CIP deviations can take both positive or negative values. For example, CIP deviations of Australian Dollar (AUD) and New Zealand Dollar (NZD) are positive on average while those of other currencies are negative on average.[8] In Table 1 which presents simple averages of summary statistics of CIP deviations across all G10 currencies in the pre-GFC (2000-2007) and the post-GFC (2008-) period, we can see that mean and median of CIP deviations are negative for every maturity in the post-GFC period. This means that CIP deviations are negative on average in the post-GFC period despite heterogeneity across currencies.

After calculating CIP deviations, I take an one-day change in CIP deviations $\Delta cid_{j,h,t} \equiv cid_{j,h,t} - cid_{j,h,t-1}$ as the dependent variable of the regression (2.1). If t corresponds to the date of the FOMC meeting, then $\Delta cid_{j,h,t}$ measures the change in CIP deviations from one day before the FOMC meeting to the day of the FOMC meeting. Even though there are time-zone differences between various currencies, currency markets and cross-currency swap markets are primarily OTC markets with 24-hour trading. Hence, the one-day change in CIP deviations is used as the baseline dependent variable in this empirical analysis. In Appendix B.1, I show that the results do not change much even if I use the two-day change in CIP deviations as the dependent variable.

[5]IBORs have been replaced by the Secured Overnight Financing Rate (SOFR) since December 31 2021. Because the sample period ends at April 2021, the replacement of the IBORs does not matter in this paper.

[6]For 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, Im, and Schreger (2018) for details.

[7]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 $r^{irs}_{j,h,t}$ 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 $r^{irs}_{\$,h,t}$. Since this investment strategy replicates the fixed-for-fixed currency swap with the return rate of the forward premium, $\rho_{j,h,t} = r^{irs}_{j,h,t} + cid_{j,h,t} - r^{irs}_{\$,h,t}$.

[8]Liao and Zhang (2020) show that CIP deviations are 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 CIP deviations should be negative for positive arbitrage profits. In light of this argument, CIP deviations of AUD and NZD are positive since these countries have negative net foreign asset positions.

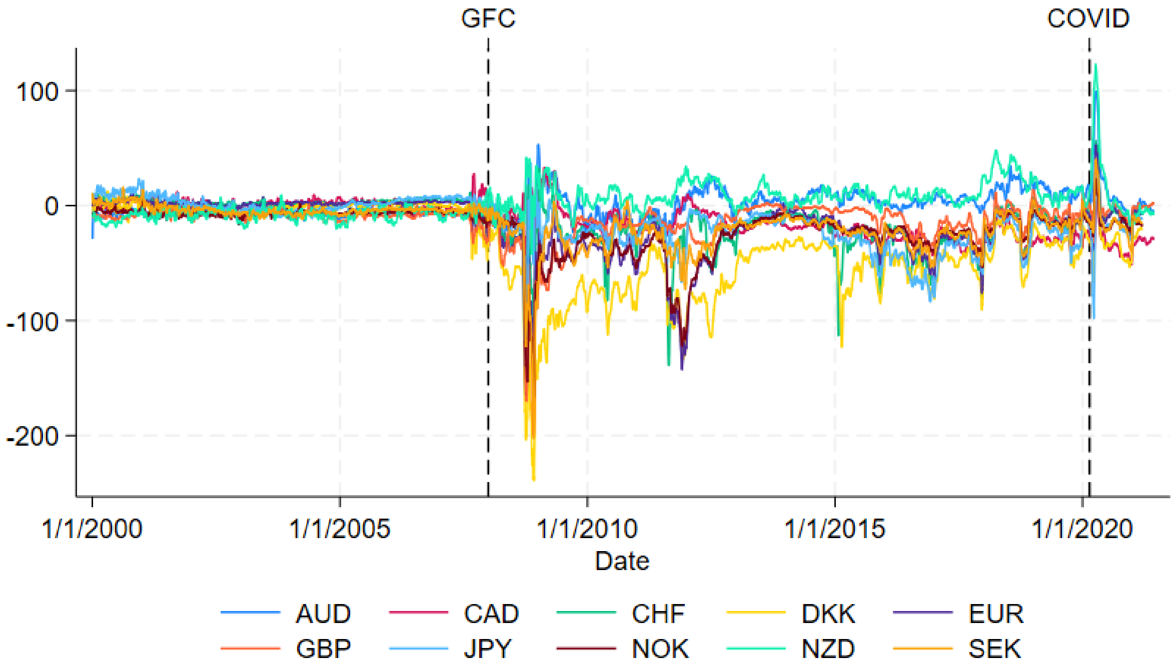


Figure 1: 3-month CIP Deviations of G10 Currencies against the USD

Note. This figure shows 10-day moving average of 3-month CIP deviations for G10 currencies against the USD from 1/1/2000 to 4/30/2021.

Table 1: Summary Statistics of CIP Deviations

	3M		1Y		2Y		3Y	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
Mean	-2.48	-20.93	0.25	-17.82	0.49	-16.31	0.60	-15.11
Median	-2.40	-17.87	0.18	-15.94	0.56	-15.01	0.74	-13.97
S.D.	5.42	20.99	2.11	14.29	1.99	12.79	2.10	12.43
Autocorr.	0.52	0.75	0.72	0.78	0.72	0.79	0.72	0.79
	5Y		7Y		10Y			
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC		
Mean	0.76	-13.29	0.58	-12.02	0.34	-10.13		
Median	1.06	-12.08	1.03	-10.70	0.75	-8.70		
S.D.	2.51	12.63	2.79	12.89	3.12	13.14		
Autocorr.	0.72	0.79	0.72	0.79	0.73	0.79		

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

However, there is a caveat to the interpretation of $\Delta cid_{j,h,t}$ because CIP deviations can take both positive or negative values. 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 decline in CIP deviations means the narrowing in this case. Since CIP deviations are negative on average as shown in Table 1, we can consider the decline in CIP deviations as the widening of CIP deviations. If I instead take the absolute value of CIP deviations, then an increase in this value always indicates a widening of the CIP deviations. Appendix B.2 shows that using the absolute value of CIP deviations as the dependent variable does not change the results.

2.2.2 US Monetary Policy Shocks

In order to identify 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 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 GFC 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 ($Target$) and path factor ($Path$), following Gürkaynak, Sack, and Swanson (2005). $Target$ indicates the shock only on federal funds target while $Path$ can be interpreted as the forward guidance shock. All three series of monetary policy shocks are normalized such that a 1pp increase in the shock raises the 1-year US treasury rate by 1pp. Thus, we can treat the one unit of shock as a 1pp or 100bp contractionary shock on US monetary policy. Series of monetary policy shocks used in this paper come from Acosta (2023).

2.3 Results

Table 2 displays β_h of the regression (2.1) for each maturity h. This measures the basis point change in CIP deviations in response to 1pp contractionary US monetary policy shock. This regression is conducted at the frequency of the FOMC announcement.[9]

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.[10] For example, if β_h is estimated

[9] There are 8 regularly scheduled FOMC meetings in a year. The sample in this empirical analysis does not include unscheduled meetings.

[10] In Section 2.2, we have seen that the average CIP deviations are negative, implying that negative β_h corresponds to the widening of CIP deviations.

as -35, then the synthetic dollar funding rises 35bp more than the direct dollar funding cost.[11]

In Table 2, we have results for seven maturities 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. In order to consider cross-sectional dependence across G10 currencies, Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is estimated to be weak by the test of Pesaran and Xie (2021). In that case, standard errors clustered at the level of currency are reported. N is the number of observations used in the estimation.

In response to 1pp contractionary NS shock, 3-month CIP deviations are estimated to decline by 35bp. This estimate is significant not only statistically but also economically; 3-month synthetic dollar funding cost increases 35bp more than direct dollar funding cost does when the US policy rate rises by 100bp. This implies profound amplification of the effect of US monetary policy on the dollar funding cost through FX swap markets. When we decompose NS into target and path factors, we can see that most of the effect comes from the federal funds target rather than the forward guidance; $Target$ ($Path$) declines 3-month CIP deviations by 28bp (7bp).

Since $cid_{j,h,t} \equiv r_{\$,h,t} - (r_{j,h,t} - \rho_{j,h,t})$, β_h can be decomposed into effects on $r_{\$,h,t}$, $-r_{j,h,t}$, and $\rho_{j,h,t}$. In Table A.1 of Appendix A.1, we can see that effects on synthetic dollar funding costs mostly come from effects on forward premium. Note that this decomposition is just an accounting exercise, and does not provide a causal explanation that effects on CIP deviations come from FX swap market frictions.[12]

Moreover, we can see that the size of β^h is smaller for longer-term maturities, *i.e.* the US monetary policy has less effects on longer-term CIP deviations. 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. Since a contractionary US monetary policy shock is shown to decrease both the level and the slope factor, the slope factor amplifies decreases in the level factor in short-term maturities while it dampens those in long-term maturities, leading to the term structure observed in Table 2.

In Appendix B, I show that the baseline results are robust to different choices of the dependent variable such as two-day changes in CIP deviations, changes in absolute values of CIP deviations, and different choices of the explanatory variable such as information-robust monetary policy shocks (Miranda-Agrippino and Ricco, 2021), and monetary policy shocks robust to Fed response to news channel (Bauer and Swanson, 2023b).

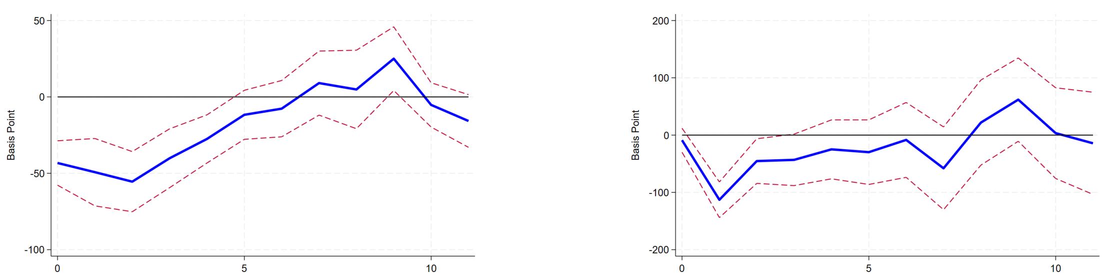
[11] Direct dollar funding cost, for example LIBOR, does not move 1-1 with 1-year US treasury rate as it will be shown in Appendix A.1. For this reason, we cannot interpret β_h as an additional *percentage* increase in the synthetic dollar funding cost.

[12] According to Du, Tepper, and Verdelhan (2018), CIP deviations have emerged due to FX swap market frictions such as limit on arbitrage since the GFC.

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

	3M		1Y		2Y		3Y	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NS	-35.34***		-5.095		-0.526		-0.303	
	(13.40)		(3.505)		(1.330)		(0.713)	
Target		-28.33***		-3.471*		-0.289		0.031
		(6.386)		(1.785)		(1.051)		(0.674)
Path		-7.006*		-1.662		-0.297		-0.397
		(3.626)		(1.776)		(0.865)		(0.584)
R^2	0.135	0.203	0.021	0.027	0.001	0.001	0.000	0.001
N	1047	1047	1022	1022	1028	1028	1030	1030
	5Y		7Y		10Y			
	(7)	(8)	(9)	(10)	(11)	(12)		
NS	0.602		1.267		0.445			
	(1.021)		(0.793)		(0.597)			
Target		0.998		1.658		0.256		
		(0.936)		(1.042)		(0.312)		
Path		-0.459		-0.445		0.148		
		(0.846)		(0.836)		(0.476)		
R^2	0.001	0.006	0.003	0.011	0.001	0.001		
N	1031	1031	1039	1039	1024	1024		

Note. This table presents the regression results of CIP deviations on 1pp 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. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. N denotes the number of observations of the regression respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$



(a) 3-month CIP Deviations **(b)** 3-month Forward Premium

Figure 2: Impulse Responses to 100bp US Monetary Policy Shock

Note. This figure shows impulse responses to 100bp contractionary US monetary policy shock. Time periods of the impulse responses are in monthly frequency.

3 The Model

I construct a two-country (the US and non-US) production economy with nominal price rigidity and financial intermediaries subject to leverage constraints. The novel contribution of this model is embedding a FX swap market into a standard business cycle model. As a CIP deviation is the price of synthetic dollar funding in the FX swap market, it is determined as a general equilibrium object from the supply and the demand for synthetic dollar funding.

3.1 Structure of FX Swap Market

Before moving on to the theoretical analysis, I first start with describing the basic and simplified structure of FX swap markets and FX swap contracts. In this model, US banks and non-US banks are main players in the FX swap market. Suppliers of synthetic dollar funding in FX swap markets are large global banks who can borrow US dollar directly from households or MMFs in the US. They sell the US dollar and buy and invest the foreign currencies in spot exchange markets while taking the opposite position in forward markets to hedge currency risks. In doing so, global banks arbitrage CIP deviations, and at the same time supply synthetic dollar funding by selling US dollar in spot markets.[13] These top-tier global banks are usually US banks, so US banks are suppliers in FX swap markets.[14]

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 demand synthetic dollar funding in FX swap markets. In order to simplify the analysis, this paper focuses on the banking sector in non-US countries as the demand-side of FX swap markets. Since non-US banks usually lack access to direct dollar funding, there is a currency mismatch problem when they hold USD-denominated assets. As banks are heavily penalized on currency mismatches, they fund US dollar synthetically by buying dollar spot and selling dollar forward in FX swap markets. In this way, non-US banks are demanders of synthetic dollar funding as counterparties of US banks in FX swap markets. Kloks, Mattille, and Ranaldo (2024) support this setting using data from Continuous Linked Settlement (CLS), the largest multi-currency cash settlement system.[15]

Figure 3 summarizes cash flows of a FX swap contract between a US and non-US bank. For notational convenience, the currency of the US is denoted as USD ($) while the non-US currency is

[13] Arbitrage is usually mediated by broker-dealers in practice, but this paper does not distinguish them from global banks because most broker-dealers are part of global banks in the form of subsidiaries. In other words, balance sheets of broker-dealers and global banks are consolidated in this paper.

[14] Arbitraging CIP deviations by borrowing in US dollar and lending in foreign currency implicitly assumes that CIP deviations defined as cross-currency bases are negative. As we can see from Table 1, CIP deviations for G10 currencies are negative on average since 2008.

[15] Non-US global banks borrow dollar synthetically from US global banks, but they are net suppliers of synthetic dollar funding due to their supply to non-US smaller banks and other financial intermediaries. Since US banks are counterparties in this paper, it is without loss of generality to assume that non-US banks are demanders for synthetic dollar funding.

denoted as EUR (€). The FX swap contract consists of two legs: spot leg and forward leg. Today, both parties of the FX swap exchange their own currencies at the spot exchange rate S expressed in units of EUR per USD. The US bank exchanges \$$X$ into €$S \cdot X$, so it obtains €$S \cdot X$ while the non-US bank obtains \$$X$. At the same time, they enter into a forward contract at the forward exchange rate F. This forward leg locks in the exchange rate of tomorrow by the forward exchange rate predetermined today. The notional value of the FX swap is assumed to be \$$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 €$S \cdot X$. Indeed, US bank gets \$$R^*(S/F)X$ while paying back €$R^*S \cdot X$ to the non-US bank, which are the proceeds from investing €$S \cdot X$ into non-US risk-free assets.

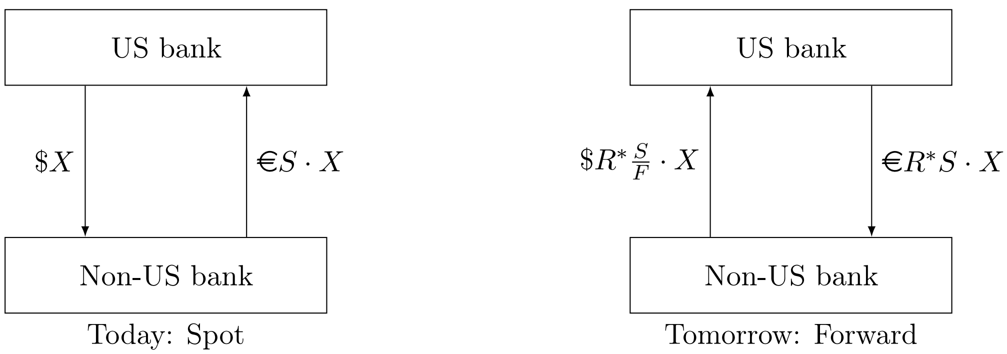


Figure 3: Structure of a FX Swap Contract

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 C_t at the price of 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 lump-sum transfer TR_t from the US government. Then, the sequential budget constraint of the household is given by

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

The first-order conditions of the household's utility maximization problem with respect to C_t, L_t, and D_t give rise to

$$\kappa C_t^{\gamma} L_t^{\varphi} = \frac{W_t}{P_t} \tag{3.2}$$

$$E_t \left[\Lambda_{t,t+1}\right] R_t = 1 \tag{3.3}$$

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

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

(3.2) is the intratemporal condition between consumption and labor supply while (3.3) is the standard 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 banks at Q_t. The law of motion for the aggregate capital stock is then

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

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

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

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 I_t as

$$Q_t = P_t \left[1 + \frac{\psi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 + \psi_I \frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}} - 1\right)\right] - E_t\left[\Lambda_{t,t+1} P_{t+1} \psi_I \left(\frac{I_{t+1}}{I_t}\right)^2 \left(\frac{I_{t+1}}{I_t} - 1\right)\right] \tag{3.6}$$

3.2.3 Retailers

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 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 for $C_{H,t}$ and $C_{F,t}$ as

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

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

for the aggregate consumer price index (CPI) 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 goods and $P_{F,t}$ is the price of imported goods.

Let us define the terms-of-trade T_t faced by the US as $P_{F,t}/P_{H,t}$. From the above equation for P_t, $P_{H,t}$ and $P_{F,t}$ can be expressed as functions of the terms-of-trade as

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

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

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

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

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[16]

$$I_{H,t} = \omega\Big(\frac{P_{H,t}}{P_t}\Big)^{-\nu} I_t \left(1 + \frac{\psi_I}{2}\Big(\frac{I_t}{I_{t-1}} - 1\Big)^2\right) \tag{3.11}$$

$$I_{F,t} = (1-\omega)(\frac{P_{F,t}}{P_t}\Big)^{-\nu} I_t \left(1 + \frac{\psi_I}{2}\Big(\frac{I_t}{I_{t-1}} - 1\Big)^2\right) \tag{3.12}$$

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 technologies 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

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

$$Y^*_{H,t}(j) = \left(\frac{P^*_{H,t}(j)}{P^*_{H,t}}\right)^{-\epsilon} Y^*_{H,t} \tag{3.14}$$

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.[17]

[16]The aggregate price of investment goods is the same as the CPI because the aggregate consumption goods and the aggregate investment goods have the same aggregator.

[17]In Appendix H, 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

3.2.5 Firm

A monopolistically competitive firm $j \in [0,1]$ produces each variety from the production function:[18]

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

Since this paper focuses on monetary policy shocks, total factor productivity is assumed to be constant at the value of one.

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

$$W_t = (1-\alpha) MC_t \frac{Y_t(j)}{L_t(j)} \tag{3.15}$$

$$\tilde{R}_{K,t} = \alpha MC_t \frac{Y_t(j)}{K_{t-1}(j)} \tag{3.16}$$

for the nominal marginal cost MC_t

$$MC_t = \frac{1}{Z_t} \frac{W_t^{1-\alpha} \tilde{R}_{K,t}^{\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}} \tag{3.17}$$

Note that the marginal cost is common across firms.

Now, I discuss the pricing decision of firm j. We assume LCP, *i.e.*, prices of domestically-sold goods and exported goods are denominated and sticky in the currency of the destination market. Hence, domestically-sold goods are sticky in USD while exported goods are sticky in EUR. Price rigidity is modelled 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 $\Pi_t^P(j)$ expressed 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, firm j's life-time profit

differences come from the exchange rate pass-through to the import price.

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

maximization problem from period t defined as

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

yields the following first-order conditions as

$$\begin{aligned}(1+s)(\epsilon-1) = \epsilon\frac{MC_t}{P_{H,t}} &- \psi_P\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)\frac{P_{H,t}}{P_{H,t-1}} \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\left(\frac{P_{H,t+1}}{P_{H,t}}-1\right)\left(\frac{P_{H,t+1}}{P_{H,t}}\right)^2\frac{Y_{H,t+1}}{Y_{H,t}}\right] \end{aligned} \tag{3.18}$$

$$\begin{aligned}(1+s)(\epsilon-1) = \epsilon\frac{S_tMC_t}{P^*_{H,t}} &- \psi_P\left(\frac{P^*_{H,t}}{P^*_{H,t-1}}-1\right)\frac{P^*_{H,t}}{P^*_{H,t-1}} \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\left(\frac{P^*_{H,t+1}}{P^*_{H,t}}-1\right)\left(\frac{P^*_{H,t+1}}{P^*_{H,t}}\right)^2\frac{S_t}{S_{t+1}}\frac{Y^*_{H,t+1}}{Y^*_{H,t}}\right] \end{aligned} \tag{3.19}$$

Note that $P_{H,t}(j) = P_{H,t}$ and $P^*_{H,t}(j) = P^*_{H,t}$ for all $j \in [0,1]$ in Rotemberg model.

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 deposits from US households.[19] From this funding, they can purchase US capital or arbitrage CIP deviations by lending to non-US banks in the cash market.[20] The detailed intermediation process is explained below.

Figure 4 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.[21] 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.

After observing the state and conditional on staying in the market, bank i retains its net worth $N_{i,t}$ and issues deposits $D_{i,t}$ with gross interest rate R_t.[22] The asset side of bank i consists of US

[19]There is an implicit assumption that banks cannot issue deposits in foreign currencies. This shuts down direct funding in foreign currencies, simplifying the analysis.

[20]In reality, banks can also arbitrage CIP deviations by taking long and short positions in Treasuries. This "real money investor"-like behavior is excluded in this paper since I focus on the interbank flow of funds and LIBOR-bases rather than Treasury-bases.

[21]Without 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.

[22]In this model, there is no difference between wholesale funding and retail funding. Thus, R_t can be understood as either the deposit rate or the interbank lending rate such as LIBOR, SOFR, or federal funds rate.

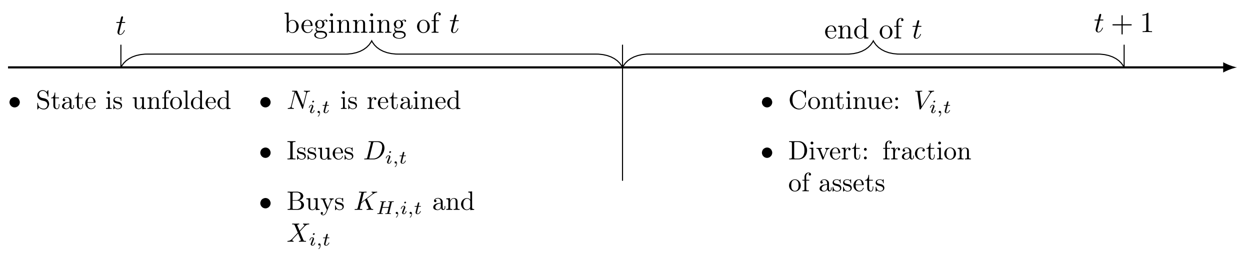


Figure 4: Timeline of Bank i's Decision

capital $K_{H,i,t}$ at the price of Q_t and CIP arbitrage $X_{i,t}$.[23] In the FX swap market, bank i exchanges $\$X_{i,t}$ for €$S_t X_{i,t}$ and lends it to non-US banks in the cash market at non-US interest rate of R_t^* with the exchange rate risk hedged by the swap contract. The balance sheet identity of bank i expressed 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 €$S_t X_{i,t}$ does not appear in period t-balance sheet, meaning that FX swap contracts are off-balance-sheet terms.

From holding $K_{H,i,t}$ from t to $t+1$, bank i earns rental rate of $\tilde{R}_{K,t+1}$ while the capital is depreciated at the rate of δ. The gross return rate on holding capital can be defined 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 €$S_t X_{i,t}$ is lent to non-US banks at period t, €$R_t^* S_t X_{i,t}$ accrues to the US bank at $t+1$. As currency risks are hedged at the forward exchange rate F_t, predetermined at period t, US bank exchanges €$R_t^* S_t X_{i,t}$ for the ultimate return $\$R_t^*(S_t/F_t)X_{i,t}$. With these gross returns from assets and newly issued deposits $D_{i,t+1}$, bank i 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 5. In particular, the red box presents the cash flows from the FX swap contract.

Combining the balance sheet identity and the budget constraint, we can obtain the law of motion for bank i's net worth as

$$N_{i,t+1} = \left[\left(R_{K,t+1} - R_t\right) \phi_{H,i,t} + \underbrace{\left(R_t^* \frac{S_t}{F_t} - R_t \right)}_{\text{Ⓐ}} \phi_{X,i,t} + R_t \right] N_{i,t} \tag{3.20}$$

[23]We exclude the possibility of purchasing non-US capital assets for simplicity.

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

Figure 5: Balance Sheet and Flow of Funds: US Bank

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

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

In (3.20), $R_{K,t+1} - R_t$ is the excess return on US capital holdings while Ⓐ is the excess return on the CIP arbitrage. Indeed, Ⓐ is the negative of CIP deviations, *i.e.* $-cid_t$ where cid_t is defined as[24,25]

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

Hence, US banks earn arbitrage profits of $-cid_t$ as CIP arbitrageurs. At the same time, $-cid_t$ can be interpreted as intermediation fees that US banks obtain from supplying USD through the FX swap market, *i.e.* synthetic dollar funding since they sell US dollar in the spot market. In other words, CIP arbitrageurs are suppliers of synthetic dollar funding.

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

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

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

$$V_{i,t} \geq \left[\left(\theta_{H1} + \theta_{H2}\frac{Q_t K_{H,t}}{P_t}\right) Q_t K_{H,i,t} + \left(\theta_{X1} + \theta_{X2}\frac{X_t}{P_t}\right) X_{i,t}\right] \tag{3.21}$$

where θ_{H1}, θ_{H2}, θ_{X1}, θ_{X2} are parameters for the tightness of the constraint. This constraint is usually

[24] CIP deviations are defined following the tradition of measuring cross-currency bases.

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

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 risk-weighted basis to non-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, Engel, and Wu (2023), quadratic parameters θ_{H2} and θ_{X2} are introduced to induce stationarity, which is similar to external stationary device in Schmitt-Grohé and Uribe (2003). This can be interpreted as state-dependent regulation that becomes tightened when banks hold larger amount of assets.[26] Note that the quadratic parts depend on aggregate assets rather than asset holdings by each individual bank, making quadratic parts exogenous to bank i.

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

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

subject to the law of motion of net worth (3.20) and the leverage constraint (3.21). In Appendix C, 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 each asset class and net worth as

$$\nu_{H,t} \equiv E_t \left[\Omega_{t,t+1} \left(R_{K,t+1} - R_t \right) \right] \tag{3.22}$$

$$\nu_{X,t} \equiv E_t \left[\Omega_{t,t+1} \right] \left(R_t^* \frac{S_t}{F_t} - R_t \right) \tag{3.23}$$

$$\nu_{N,t} \equiv E_t \left[\Omega_{t,t+1} \right] R_t \tag{3.24}$$

for the stochastic discount factor of bank $\Omega_{t,t+1} \equiv \Lambda_{t,t+1}(1 - \sigma + \sigma \nu_{t+1})$.[27] Then, the Bellman

[26] θ_{H2} and θ_{X2} are calibrated as small numbers so that they do not affect dynamics of this model significantly. In Appendix I, I conduct sensitivity analysis on values of quadratic parameters and show that impulse responses do not change significantly.

[27] When 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 banks.

equation is simplified as

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

The first-order conditions of the above Bellman equation are

$$\nu_{H,t} = \mu_t \left(\theta_{H1} + \theta_{H2}\frac{Q_t K_{H,t}}{P_t}\right) \tag{3.25}$$

$$\nu_{X,t} = \mu_t \left(\theta_{X1} + \theta_{X2}\frac{X_t}{P_t}\right) \tag{3.26}$$

where μ_t is the Lagrangian multiplier of the leverage constraint. In contrast to frictionless asset pricing models, $\nu_{H,t}$ and $\nu_{X,t}$ are non-zero even up to first-order to the extent that θ_{H1}, θ_{H2}, θ_{X1}, θ_{X2} are non-zero because the calibration of this model in Section 4.1 guarantees $\mu_t > 0$.

Let us focus on (3.26), the FOC for the CIP arbitrage. Combining (3.23) and (3.26), we can obtain the relationship between CIP deviations and synthetic dollar funding as

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

This equation is the upward-sloping inverse supply function of synthetic dollar funding. When there is no limit on CIP arbitrage, *i.e.* $\theta_{X1} = \theta_{X2} = 0$, 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 each period, with probability σ, banks continue operating with their net worth evolving according to (3.20). 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

$$N_{t+1} = \sigma\left[(R_{K,t+1} - R_t)\phi_{H,t} + \left(R_t^*\frac{S_t}{F_t} - R_t\right)\phi_{X,t} + R_t\right]N_t + (1-\sigma)\xi(\phi_{H,t} + \phi_{X,t})N_t \tag{3.27}$$

3.2.7 Monetary Policy

We assume the following Taylor rule type US monetary policy as

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R}\left(\frac{P_t}{P_{t-1}}\right)^{\phi_\pi(1-\rho_R)}\epsilon_{R,t} \tag{3.28}$$

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

$$\log \epsilon_{R,t} = \rho_m \log \epsilon_{R,t-1} + \sigma_m \epsilon_{m,t} \tag{3.29}$$

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:

$$TR_t + s\left(P_{H,t}Y_{H,t} + \frac{1}{S_t}P^*_{H,t}Y^*_{H,t}\right) = 0 \tag{3.30}$$

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 Appendix D for details. Here, I focus on financial intermediaries. Non-US variables are denoted with asterisk.

3.3.1 Financial Intermediary

As the US, there is a continuum of banks with total measure one and 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 is lending from US banks $S_t\tilde{X}^*_{i,t}$ since they deposit for taking advantage of CIP arbitrage opportunities.[28] Then, the total amount of deposits is $D^*_{i,t} + S_t\tilde{X}^*_{i,t}$. Note that non-US banks cannot issue deposits in US dollar, implying that direct dollar funding is not available to them. We will see the importance of this assumption below. From these sources of funding, bank i purchases non-US capital $K^*_{F,i,t}$ at the price of Q^*_t and US capital $K^*_{H,i,t}$ at Q_t. Then, the balance sheet identity of bank i is given by

$$Q^*_tK^*_{F,i,t} + S_tQ_tK^*_{H,i,t} = D^*_{i,t} + S_t\tilde{X}^*_{i,t} + N^*_{i,t}$$

In 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 $K^*_{F,i,t}$ and $R_{K,t+1}$ from $K^*_{H,i,t}$. With these returns and newly issued deposits $D^*_{i,t+1} + S_{t+1}\tilde{X}^*_{i,t+1}$, it purchases $K^*_{F,i,t+1}$ and $K^*_{H,i,t+1}$ and repays $R^*_t(D^*_{i,t} + S_t\tilde{X}^*_{i,t})$.

The value of US capital holdings $Q_tK^*_{H,i,t}$ is denominated in USD while liabilities $D^*_{i,t} + S_t\tilde{X}^*_{i,t}$ are denominated in EUR, meaning that there is a currency mismatch between $K^*_{H,i,t}$ and liabilities.

[28] $\tilde{X}^*_{i,t}$ is the total amount of lending from US banks that non-US bank i obtains, and it is not necessarily lending from US bank i.

As we will see in (3.32), non-US banks optimally choose the amount of currency matching based on differential regulation on currency matching and uncovered open position.[29] Since direct dollar funding is assumed to be unavailable to non-US banks, synthetic dollar funding through FX swap markets is the only option for currency matching. This assumption is for simplifying the analysis and also not unrealistic because non-US banks, except for some big global banks, usually lack access to direct dollar funding or they need to pay high premium for the dollar funding (see Ivashina, Scharfstein, and Stein, 2015; Du and Schreger, 2022, for instance).[30] This is the important and distinguishing feature of the model that creates the channel through which CIP deviations affect cross-border capital flows and asset prices.

Let bank i's demand for synthetic dollar funding be $x^*_{i,t} Q_t K^*_{H,i,t}$ for $x^*_{i,t} \in [0,1]$. Then, in period $t+1$, €$R^*_t S_t x^*_{i,t} Q_t K^*_{H,i,t}$ is exchanged into \$$R^*_t (S_t/F_t) x^*_{i,t} Q_t K^*_{H,i,t}$ by the forward leg of the FX swap contract. To sum up, the budget constraint expressed in terms of EUR is

$$\begin{aligned} &Q^*_{t+1} K^*_{F,i,t+1} + S_{t+1} Q_{t+1} K^*_{H,i,t+1} + R^*_t (D^*_{i,t} + S_t \tilde{X}^*_{i,t}) + S_{t+1} R^*_t \frac{S_t}{F_t} x^*_{i,t} Q_t K^*_{H,i,t} \\ &\qquad = R^*_{K,t+1} Q^*_t K^*_{F,i,t} + S_{t+1} R_{K,t+1} Q_t K^*_{H,i,t} + (D^*_{i,t+1} + S_{t+1} \tilde{X}^*_{i,t+1}) + R^*_t S_t x^*_{i,t} Q_t K^*_{H,i,t} \end{aligned}$$

Figure 6 summarizes the balance sheet and the flow of funds of non-US bank. Cash flows from the FX swap contract are described in the red box.

Balance Sheet		Flow of Funds	
Asset	Liability	t	$t+1$
$Q^*_t K^*_{F,i,t}$	$D^*_{i,t}$	$-€Q^*_t K_{F,i,t}$	$+€R^*_{K,t+1} Q^*_t K^*_{F,i,t}$
$S_t Q_t K^*_{H,i,t}$	$S_t \tilde{X}^*_{i,t}$	$-\$Q_t K_{H,i,t}$	$+\$R_{K,t+1} Q_t K^*_{H,i,t}$
	$N^*_{i,t}$	$+\$x^*_{i,t} Q_t K^*_{H,i,t}$	$-\$R^*_t (S_t/F_t) x^*_{i,t} Q_t K^*_{H,i,t}$
		$-€S_t x^*_{i,t} Q_t K^*_{H,i,t}$	$+€R^*_t S_t x^*_{i,t} Q_t K^*_{H,i,t}$
		$+€S_t \tilde{X}^*_{i,t}$	$-€R^*_t S_t \tilde{X}^*_{i,t}$
		$+€D^*_{i,t}$	$-€R^*_t D^*_{i,t}$

Figure 6: Balance Sheet and Flow of Funds: Non-US Bank

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

[29]This approach enables us to use the first-order perturbation method unlike the mean-variance framework, and thus is easily applicable to standard business cycle models. Liao and Zhang (2020) derives the demand for currency hedging from mean-variance utility function in a two-period partial equilibrium framework.

[30]Non-US banks cannot usually tap US dollar from deposits. Wholesale dollar funding is also available for only top-tier global banks. Hence, non-US banks with low credit quality have to rely on synthetic dollar funding. See Rime, Schrimpf, and Syrstad (2022) for detailed explanation.

motion for net worth as

$$N^*_{i,t+1} = \Bigg[(R^*_{K,t+1} - R^*_t)\phi^*_{F,i,t} + \frac{S_{t+1}}{S_t}\underbrace{\left(R_{K,t+1} - R^*_t\frac{S_t}{S_{t+1}}\right)}_{\text{Ⓑ}}(1 - x^*_{i,t})\phi^*_{H,i,t} + \frac{S_{t+1}}{S_t}\underbrace{\left(R_{K,t+1} - R^*_t\frac{S_t}{F_t}\right)}_{\text{Ⓒ}}x^*_{i,t}\phi^*_{H,i,t} + R^*_t\Bigg]N^*_{i,t} \tag{3.31}$$

for the ratio of each asset to net worth

$$\phi^*_{F,i,t} = \frac{Q^*_t K^*_{F,i,t}}{N^*_{i,t}}$$
$$\phi^*_{H,i,t} = \frac{S_t Q_t K^*_{H,i,t}}{N^*_{i,t}}$$

In (3.31), each asset-to-net-worth ratio is multiplied by the excess return of the asset. Ⓑ 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, Ⓒ is the dollar return in excess of the synthetic dollar funding cost, implying that the currency of return and cost are matched.[31] It can be expressed as $R_{K,t+1} - (R_t - cid_t)$, so $-cid_t$ is an intermediation fee that non-US banks pay for synthetic dollar funding.

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

$$V^*_{i,t} = E_t\sum_{s=1}^{\infty}(1-\sigma)\sigma^{s-1}\Lambda^*_{t,t+s}N^*_{i,t+s} = E_t\left[\Lambda^*_{t,t+1}\left\{(1-\sigma)N^*_{i,t+1} + \sigma V^*_{i,t+1}\right\}\right]$$

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

$$V^*_{i,t} \geq \Bigg[\left(\theta^*_{F1} + \theta^*_{F2}\frac{Q^*_t K^*_{F,t}}{P^*_t}\right)Q^*_t K^*_{F,i,t} + \left(\theta^*_{H1} + \theta^*_{H2}\frac{(1-x^*_t)S_t Q_t K^*_{H,t}}{P^*_t}\right)(1-x^*_{i,t})S_t Q_t K^*_{H,i,t} + \left(\theta^*_{X1} + \theta^*_{X2}\frac{x^*_t S_t Q_t K^*_{H,t}}{P^*_t}\right)x^*_{i,t}S_t Q_t K^*_{H,i,t}\Bigg] \tag{3.32}$$

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.

[31] One may argue that the return rate in EUR is still subject to exchange rate risk as Ⓒ 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

$$\nu^*_t = \max_{\phi^*_{F,i,t}, \phi^*_{H,i,t}, x^*_{i,t}} \nu^*_{F,t}\phi^*_{F,i,t} + \nu^*_{H,t}(1 - x^*_{i,t})\phi^*_{H,i,t} + \nu^*_{X,t} x^*_{i,t}\phi^*_{H,i,t} + \nu^*_{N,t}$$

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

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

$$\nu^*_{F,t} \equiv E_t\left[\Omega^*_{t,t+1}\left(R^*_{K,t+1} - R^*_t\right)\right] \tag{3.33}$$

$$\nu^*_{H,t} \equiv E_t\left[\Omega^*_{t,t+1}\frac{S_{t+1}}{S_t}\left(R_{K,t+1} - R^*_t\frac{S_t}{S_{t+1}}\right)\right] \tag{3.34}$$

$$\nu^*_{X,t} \equiv E_t\left[\Omega^*_{t,t+1}\frac{S_{t+1}}{S_t}\left(R_{K,t+1} - R^*_t\frac{S_t}{F_t}\right)\right] \tag{3.35}$$

$$\nu^*_{N,t} \equiv E_t\left[\Omega^*_{t,t+1}\right] R^*_t \tag{3.36}$$

The first-order conditions for the above problem are

$$\nu^*_{F,t} = \mu^*_t\left(\theta^*_{F1} + \theta^*_{F2}\frac{Q^*_t K^*_{F,t}}{P^*_t}\right) \tag{3.37}$$

$$\nu^*_{H,t} = \mu^*_t\left(\theta^*_{H1} + \theta^*_{H2}\frac{(1-x^*_t)S_t Q_t K^*_{H,t}}{P^*_t}\right) \tag{3.38}$$

$$\nu^*_{X,t} = \mu^*_t\left(\theta^*_{X1} + \theta^*_{X2}\frac{x^*_t S_t Q_t K^*_{H,t}}{P^*_t}\right) \tag{3.39}$$

where μ^*_t is the Lagrangian multiplier of the leverage constraint. In particular, (3.35) and (3.39) yield the inverse demand function for the synthetic dollar funding as

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

The demand for synthetic dollar funding $x^*_t Q_t K^*_{H,t}$ is decreasing in $-cid_t$ unless $\theta^*_{X1} = \theta^*_{X2} = 0$.

The law of motion for the aggregate net worth is

$$N^*_{t+1} = \sigma \Bigg[(R^*_{K,t+1} - R^*_t)\phi^*_{F,t} + \frac{S_{t+1}}{S_t}\left(R_{K,t+1} - R^*_t \frac{S_t}{S_{t+1}}\right)(1 - x^*_t)\phi^*_{H,t} + \frac{S_{t+1}}{S_t}\left(R_{K,t+1} - R^*_t \frac{S_t}{F_t}\right) x^*_t \phi^*_{H,t} + R^*_t \Bigg] N^*_t + (1-\sigma)\xi^* \left(\phi^*_{F,t} + \phi^*_{H,t}\right) N^*_t \tag{3.40}$$

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

$$X_t = x^*_t Q_t K^*_{H,t} \tag{3.41}$$

Figure 7 plots the downward-sloping demand and upward-sloping supply of synthetic dollar funding around the steady-state.

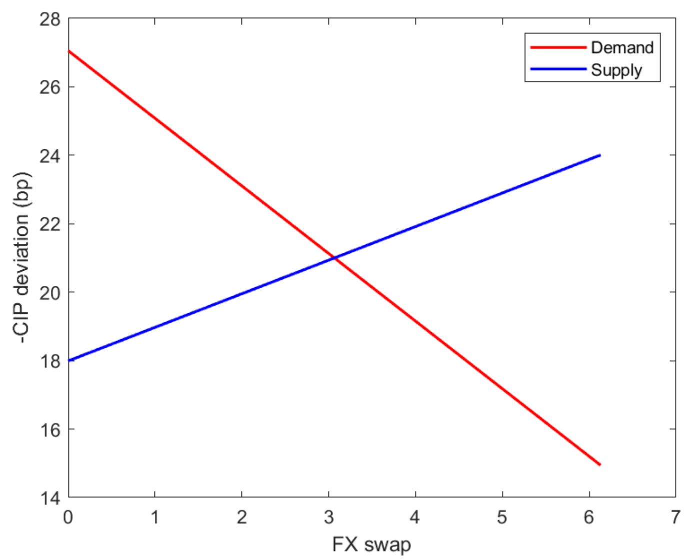


Figure 7: Demand and Supply Function of the FX Swap Market

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 the bank budget constraint with the profit functions of the firms, we can obtain the US balance of payment equation as

$$TB_t + \left(R^*_{t-1}\frac{S_{t-1}}{F_{t-1}} - 1\right)X_{t-1} - (R_{K,t}-1)Q_{t-1}K^*_{H,t-1} = (X_t - Q_tK^*_{H,t}) - (X_{t-1} - Q_{t-1}K^*_{H,t-1}) \tag{3.42}$$

for the trade balance TB_t defined as

$$\begin{aligned} TB_t \equiv & \left(1-\frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)^2\right)P_{H,t}Y_{H,t} + \left(1-\frac{\psi_P}{2}\left(\frac{P^*_{H,t}}{P^*_{H,t-1}}-1\right)^2\right)\frac{1}{S_t}P^*_{H,t}Y^*_{H,t} \\ & -P_t\Big(C_t + I_t + K_{t-1}\frac{\psi_K}{2}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\Big) \end{aligned} \tag{3.43}$$

The LHS of (3.42) is the current account of the US, which consists of the trade balance and the income balance. The trade balance is the difference between the output (net of price adjustment costs) and the domestic absorption (net of capital adjustment costs). The income balance is the return on CIP arbitrage net of the return on US capital held by non-US. According to the balance of payment identity, the current account is equal to the change in US net foreign asset (NFA) position, which is the RHS of (3.42). Here, US NFA is given by $X_t - Q_tK^*_{H,t}$.

All equations characterizing the equilibrium are summarized in Appendix E.

4 Results

Based on the model in Section 3, I investigate effects of US monetary policy on CIP deviations, synthetic dollar funding, and implications for the transmission channel of US monetary policy. First, parameters of this model are calibrated to match long-run first moments of the US and the rest of the world. Then, impulse responses to a contractionary US monetary policy shock are derived. US monetary contraction lowers US banks' supply of synthetic dollar funding because it tightens the limit on CIP arbitrage. This leads to the widening of CIP deviations and lower synthetic dollar funding. Compared to the counterfactual case where CIP always holds, spillovers and spillbacks to output, investment, and inflation are amplified due to the widening of CIP deviations.

4.1 Calibration

Table 3 presents calibrated parameters of the model in quarterly frequency. First, in the household side, the discount factor $\beta = \beta^*$ is given by 0.99 to produce 4% 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 Bajzik, Havranek, Irsova, and Schwarz (2020). 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. 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 adjustment cost ψ_P is calibrated as 155.88 in order to match the Calvo parameter of 0.84.[32] Capital depreciation rate δ is set at 0.04 while the investment adjustment cost ψ_I is set at 0.7.

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 0.117 and 0.090 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 100bp, excess return on non-US capital of 100bp, US NFA-to-GDP ratio of -43.9%, non-US banks' domestic investment share of 54%, and post-GFC CIP deviations of -21bp. 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 100bp following Akinci, Şebnem Kalemli-Özcan, and Queralto (2022). Net foreign asset position in this model is $X - x^* Q K^*_H$, so the third empirical moment targets $(X - x^* Q K^*_H)/(4 * P_H * Y)$. 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, Hau, and Rey (2022) who analyzed fund-level data from FactSet for the period 1999-2015. Post-GFC CIP deviation of -21bp comes from the average of 3-month LIBOR basis of G10 currencies for the period 1/1/2008 to 4/30/2021.

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) for solving the indeterminacy problem in a small open economy model with incomplete markets. Following Devereux, Engel, and Wu (2023), all parameters θ_{H2}, θ_{X2}, θ^*_{F2}, θ^*_{H2}, and θ^*_{X2} are set at a low value of 0.005. In Appendix I, I conduct a sensitivity analysis showing that the results of the model are not driven by the choice of these quadratic parameters.

Regarding the monetary policy, ϕ_π is 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 0.7 while the persistence of monetary policy shocks ρ_m and ρ^*_m are 0.25. The standard deviations σ_m and σ^*_m of

[32] Corsetti, Dedola, and Leduc (2008) show that the Rotemberg parameter ψ_P corresponds to $(\epsilon - 1)\lambda/(1-\lambda)(1-\beta\lambda)$ for the Calvo parameter λ.

monetary policy shocks are given by 0.25% to produce 1% annual standard deviation.

Detailed explanations for the calibration and the steady-state of the model can be found in Appendix F.

Table 3: Parameter Values

Parameter	Value	Description	Source or Target
$\beta = \beta^*$	0.99	Discount factor	4% risk-free rate
γ	2	Inverse of intertemporal elasticity of substitution	Standard literature
ω	0.8	Home bias	Standard literature
ν	3.8	Elasticity of substitution across country	Bajzik, Havranek, Irsova, and Schwarz (2020)
ϵ	6	Elasticity of substitution within country	Standard literature
φ	1	Inverse of Frisch elasticity	Standard literature
κ	13.97	US Disutility of labor	Steady-state L of 1/3
κ^*	11.83	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	Standard literature
ψ_P	155.88	Rotemberg price adjustment cost	Calvo parameter of 0.84
δ	0.04	Capital depreciation rate	Standard literature
ψ_I	0.7	Investment adjustment cost	Standard literature
σ	0.95	Survival rate of banks	Average survival horizon of 5 years
ξ	0.12	Transfer to new US banks	Steady-state bank leverage of 6
ξ^*	0.09	Transfer to new Non-US banks	Steady-state bank leverage of 6
θ_{H1}	0.53	US bank friction on US capital	Excess return on US capital of 100bp
θ_{X1}	0.11	US bank friction on FX swap	Excess return on non-US capital of 100bp
θ^*_{F1}	0.25	Non-US bank friction on non-US capital	US NFA-to-GDP ratio of -43.9%
θ^*_{H1}	0.25	Non-US bank friction on unhedged US capital	Domestic investment share of 54%
θ^*_{X1}	0.19	Non-US bank friction on hedged US capital	Post-GFC CIP deviation of -21bp
θ_{H2}	0.005	Quadratic term corresponding to θ_{H1}	Devereux, Engel, and Wu (2023)
θ_{X2}	0.005	Quadratic term corresponding to θ_{X1}	Devereux, Engel, and Wu (2023)
θ^*_{F2}	0.005	Quadratic term corresponding to θ^*_{F1}	Devereux, Engel, and Wu (2023)
θ^*_{H2}	0.005	Quadratic term corresponding to θ^*_{H1}	Devereux, Engel, and Wu (2023)
θ^*_{X2}	0.005	Quadratic term corresponding to θ^*_{X1}	Devereux, Engel, and Wu (2023)
ϕ_π	1.5	Taylor coefficient on inflation	Standard literature
ρ_r	0.7	US interest rate smoothing parameter	Standard literature
ρ^*_r	0.7	Non-US interest rate smoothing parameter	Standard literature
ρ_m	0.25	Persistence of US MP shock	Standard literature
ρ^*_m	0.25	Persistence of non-US MP shock	Standard literature
σ_m	0.01/4	S.D. of US MP shock	
σ^*_m	0.01/4	S.D. of non-US MP shock	

4.2 Impulse Responses

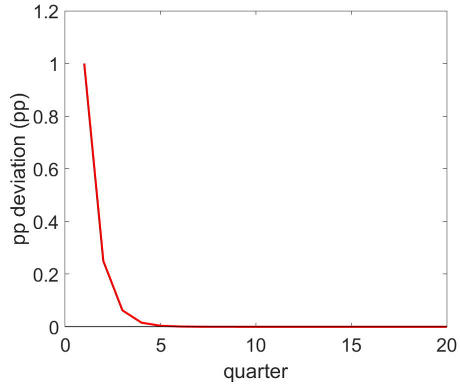
Based on the calibrated model, I produce impulse responses to 100bp contractionary US monetary policy shock. Figure 8 displays impulse responses of interest rates, CIP deviations, forward premium with reasons for the response in CIP deviations. Time periods in the x-axis are in quarterly frequency, and the impulse responses are shown up to 5 years. In response to 100bp US monetary policy shock in panel (8a), US nominal interest rate rises initially in panel (8b), with some decreases along the way to lower inflation rate and high persistence in policy rate.

The main mechanism of the synthetic dollar funding channel works through the effect of US monetary policy on CIP deviations. First, panel (8c) shows that CIP deviations decline about 30bp from their steady-state in the baseline economy. Since CIP deviations are negative (-21bp) in the steady-state, the decline in CIP deviations is equivalent to the widening of CIP deviations. After about 10 quarters, CIP deviations return to their steady-state level of -21bp. Panel (8d) shows that forward premium $\rho_t \equiv logF_t - \log S_t$ declines about 106bp. Since $cid_t \approx \log R_t - \log R_t^* + \rho_t$, this means that ρ_t is the main variable leading to the widening of CIP deviations. This is in line with the observation in Appendix A.1 that most of the responses in CIP deviations to US monetary policy shock comes from the responses in forward premium.

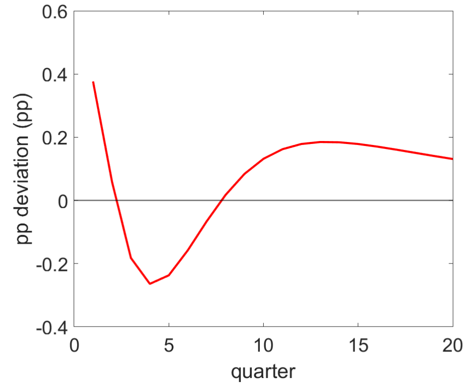
CIP deviations widen due to the decrease in net worth of US banks and the resulting tighter limit on CIP arbitrage. In panel (8e), net worth of US banks decreases in response to the contractionary US monetary policy shock. If the US policy rate rises, the aggregate demand of the US is reduced, exerting downward pressure on the price of the US capital. As US banks hold US capital, the asset values of their balance sheets go down, lowering their net worth. In panel (8f), the Lagrangian multipliers of US banks rise about 1.5 log points. This means that the leverage constraints of US banks are tightened due to their lower net worth. As implied by the supply function of FX swap (3.26), the increase in the Lagrangian multiplier of the US bank leads to the widening of CIP deviations.

Next, I investigate how the widening of CIP deviations affects impulse responses of other macroeconomic variables. For this purpose, the baseline impulse responses are compared with counterfactual impulse responses without limit on CIP arbitrage, *i.e.* $\theta_{X1} = \theta_{X2} = 0$. This counterfactual setting models the economy where CIP always holds, which is the case in the pre-GFC period. All other parameters of the counterfactual economy are set to be the same as the baseline model in order to focus on differences in impulse responses only due to CIP deviations coming from the limit on CIP arbitrage. In all figures, red solid lines are baseline impulse responses while black dotted lines are counterfactual ones.

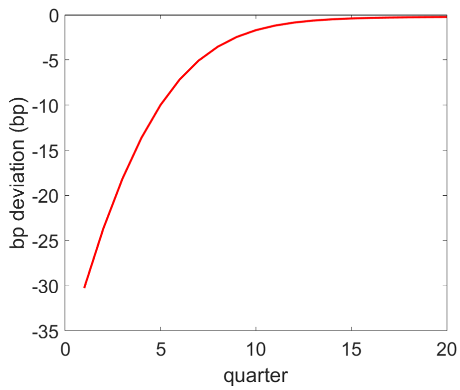
Figure 9 presents impulse response of global capital flows mediated by US and non-US banks. First, as in panel (9a), synthetic dollar funding decreases in response to a contractionary US monetary policy shock. Since US monetary contraction leads to higher λ_t, the supply schedule of synthetic



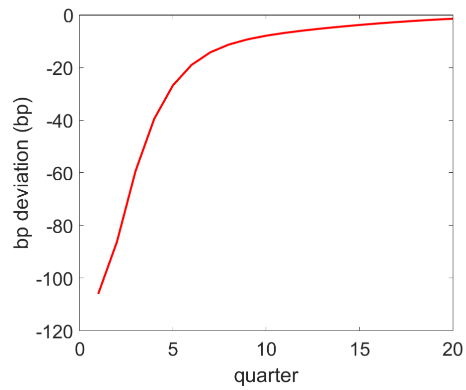
(a) $\log \epsilon_{R,t}$



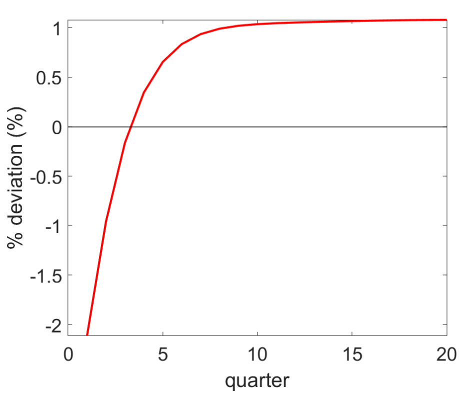
(b) R_t



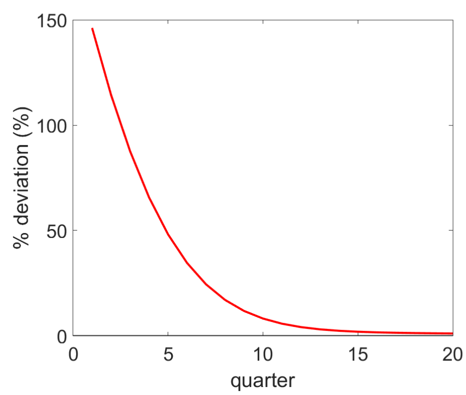
(c) cid_t



(d) ρ_t



(e) N_t/P_t



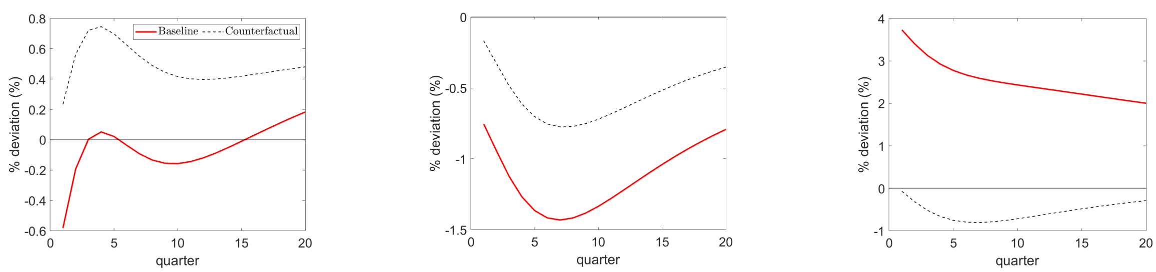
(f) λ_t

Figure 8: Impulse Responses to 100bp US Monetary Policy Shock: CIP Deviations

Note. This figure shows quarterly impulse responses to 100bp contractionary US monetary policy shock. Each impulse response is the deviation from the steady-state. $\log \epsilon_{R,t}$ is the US monetary policy shock, R_t is the US nominal interest rate, cid_t is the CIP deviation, ρ_t is the forward premium, N_t/P_t is the real net worth of US banks, and λ_t is the Lagrangian multiplier of US banks' leverage constraints.

dollar funding decreases in the baseline economy.[33] 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.

Then, $K^*_{H,t}$ declines by about 0.8% on impact, reaching a trough of 1.4% after 7 quarters, as shown in panel (9b). This is much larger than the counterfactual impulse response of 0.8% at the trough, implying significant amplification of the decrease in cross-border positions by the non-US. The main reason for this amplification is the decrease in synthetic dollar funding. As non-US banks desire to hedge currency risks in holding US capital, they demand X_t. The widening of CIP deviations and lower demand for X_t amplifies the decrease in $K^*_{H,t}$ compared to the conventional effect without CIP deviations. On the other hand, $K_{H,t}$ shows a persistent increase with an impact response of 3.7%, which stands in stark contrast to the decrease observed in the counterfactual economy. These predictions are in line with the role of US monetary policy in the global retrenchment of international capital flows (Miranda-Agrippino and Rey, 2020).



(a) X_t/P_t **(b)** $K^*_{H,t}$ **(c)** $K_{H,t}$

Figure 9: Impulse Responses to 100bp US Monetary Policy Shock: Capital Flows

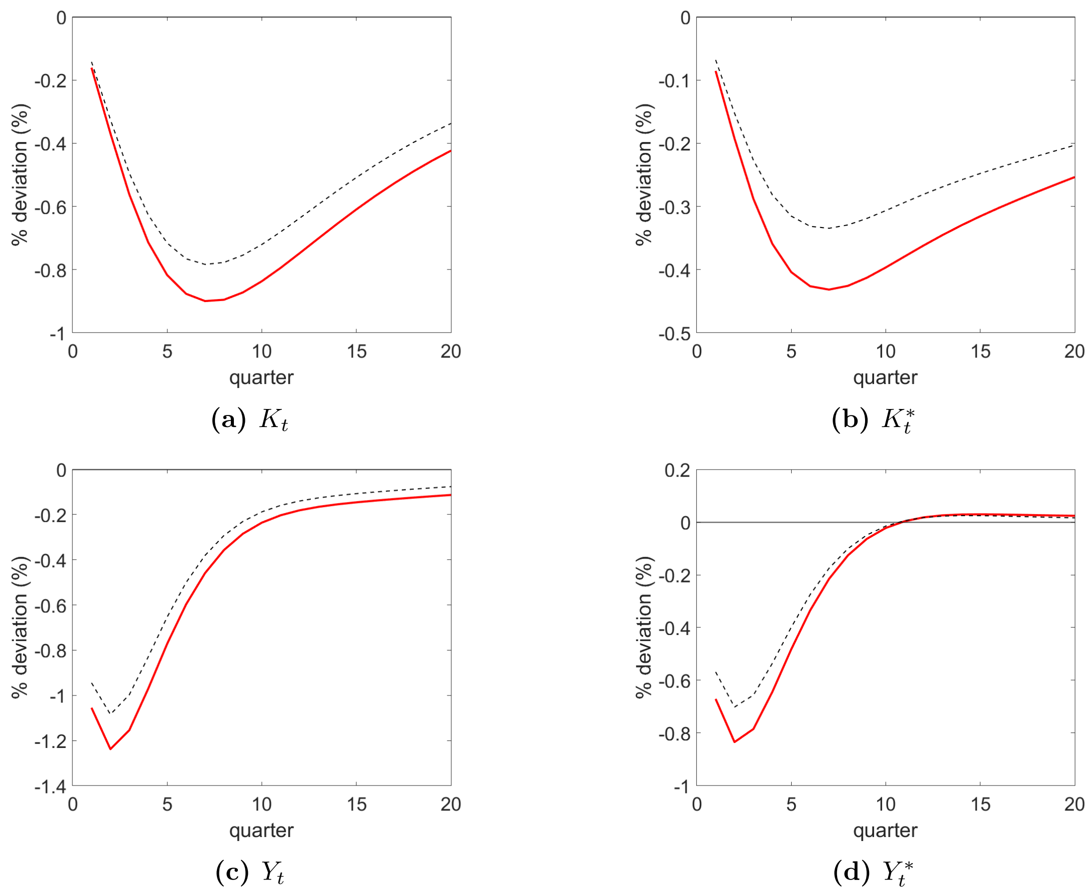
Note. This figure shows quarterly impulse responses to 100bp contractionary US monetary policy shock. Each impulse response is the deviation from the steady-state. In each panel, red solid line is the baseline impulse response while the black dotted line is the counterfactual impulse response without limit on CIP arbitrage. X_t/P_t is the real synthetic dollar funding, $K^*_{H,t}$ is US capital holdings by non-US banks, and $K_{H,t}$ is US capital holdings by US banks.

In Figure 10, we can see the role of CIP deviations and synthetic dollar funding in spillovers to the non-US as well as spillbacks to the US. First, panel (10a) and (10b) show the impulse responses of the aggregate US capital K_t and non-US capital K^*_t. K_t decreases by 0.9% at its trough in the baseline economy while the counterfactual decrease is about 0.8%. The amplification of 0.1pp is due to the widening of CIP deviations and the resulting reduction in synthetic dollar funding. As we have seen in Figure 9, synthetic dollar funding X_t and non-US banks' cross-border asset holdings $K^*_{H,t}$ decrease more when CIP does not hold. Although $K_{H,t}$ is higher under the baseline economy,

[33] In Appendix G, we can see that λ^*_t also increases in response to US monetary contraction, resulting in the decrease in the demand for synthetic dollar funding. The supply-side effect is larger than the demand-side effect in the general equilibrium effect so that CIP deviations widen and synthetic dollar funding decreases.

the total amount of capital $K_t = K_{H,t} + K^*_{H,t}$ is lower because the share of $K^*_{H,t}$ is about 86% in the steady-state. On the other hand, K^*_t goes down by 0.4%, with the amplification of 0.1pp compared to the counterfactual impulse response. This is due to larger intermediation fees—CIP deviations—that non-US banks have to pay for currency matching. Even though CIP deviations are not directly related to non-US capital holdings, larger CIP deviations yields lower net worth of non-US banks, which leads to the larger reduction in K^*_t than the counterfactual economy.

Similar to capital stocks, impulse responses of US output Y_t and non-US output Y^*_t are amplified in the presence of the limit on CIP arbitrage. In the baseline economy, Y_t declines by 1.2% while Y^*_t is reduced by 0.8%. Compared to the counterfactual without CIP deviations, the amplification effect is about 15-20% with persistence; this is non-trivial considering that CIP deviations widen by 30bp in response to 100bp US monetary policy shock. The reason for the amplification effect is similar to the capital stock: the widening of CIP deviations. Since the widening of CIP deviations make the aggregate capital be lower, Y_t and Y^*_t also become lower. Investments, inflation, and exchange rates show similar patterns. See Appendix G for details.



(a) K_t **(b)** K_t^* **(c)** Y_t **(d)** Y_t^*

Figure 10: Impulse Responses to 100bp US Monetary Policy Shock

Note. This figure shows quarterly impulse responses to 100bp contractionary US monetary policy shock. Each impulse response is the deviation from the steady-state. In each panel, red solid line is the baseline impulse response while the black dotted line is the counterfactual impulse response without limit on CIP arbitrage. K_t is US capital, K_t^* is non-US capital, Y_t is US output, and Y_t^* is non-US output.

5 Central Bank Swap Lines and Synthetic Dollar Funding Channel

In this section, we analyze how central bank swap liens affect the transmission channel of US monetary policy.[34] 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 11 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.[35] 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 11: 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.[36]

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 a 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,

[34] During 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.

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

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

lower cases are used to denote net interest rates. cid_t is measured using OIS rates as risk-free rates.

The above inequality holds due to the no-arbitrage condition.[37] 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 $-cid_t$:

$$-cid_t \leq ss_t \tag{5.1}$$

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. Based on the swap spreads of standing facilities, ss_t is set at 25 basis points. Note that (5.1) is an occasionally binding constraint since the steady-state value of $-cid_t$ is 21 basis points. It binds only if CIP deviations widen compared to their steady-state levels. If (5.1) does not bind, then swap lines are not used by non-US banks because swap liens are more expensive than private FX swaps.

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

$$s\left(P_{H,t}Y_{H,t} + \frac{1}{S_t}P_{H,t}^{*}Y_{H,t}^{*}\right) + tr_t + X_t^{SL} = \left(R_{t-1} - cid_{t-1}\right) X_{t-1}^{SL} \tag{5.2}$$

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

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

$$X_t + X_t^{SL} = x_t^* Q_t K_{H,t}^* \tag{5.3}$$

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 12 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}.

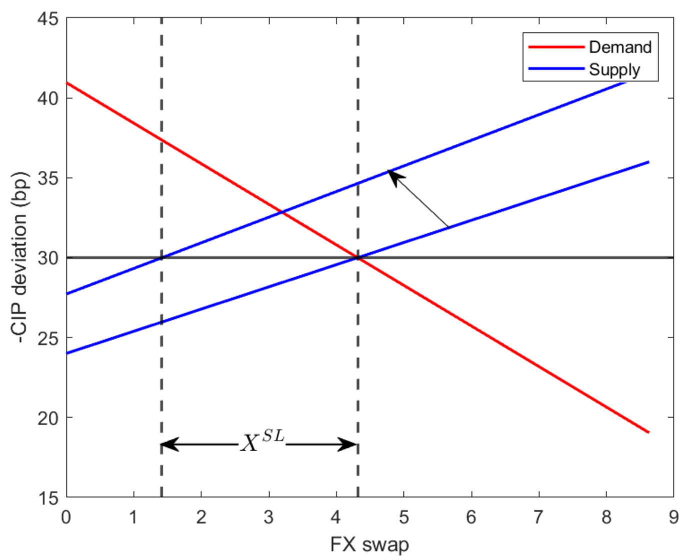


Figure 12: FX Swap Market and Swap Lines

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

$$(cid_t + ss_t) X_t^{SL} = 0 \tag{5.4}$$

When (5.1) 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 13. Since contractionary US monetary policy shocks put downward pressure on CIP deviations, (5.1) binds and the CIP deviation is equivalent to the swap spread. Hence, as panel (13a), 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 (13b) and (13c)) and the following lower Lagrangian multipliers of those banks (panel (13d) and (13e)).

Since the size of CIP deviations is reduced under the existence of central bank swap lines, synthetic dollar funding becomes larger as in panel (13f). As a result, in panel (13g) and (13h), 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.

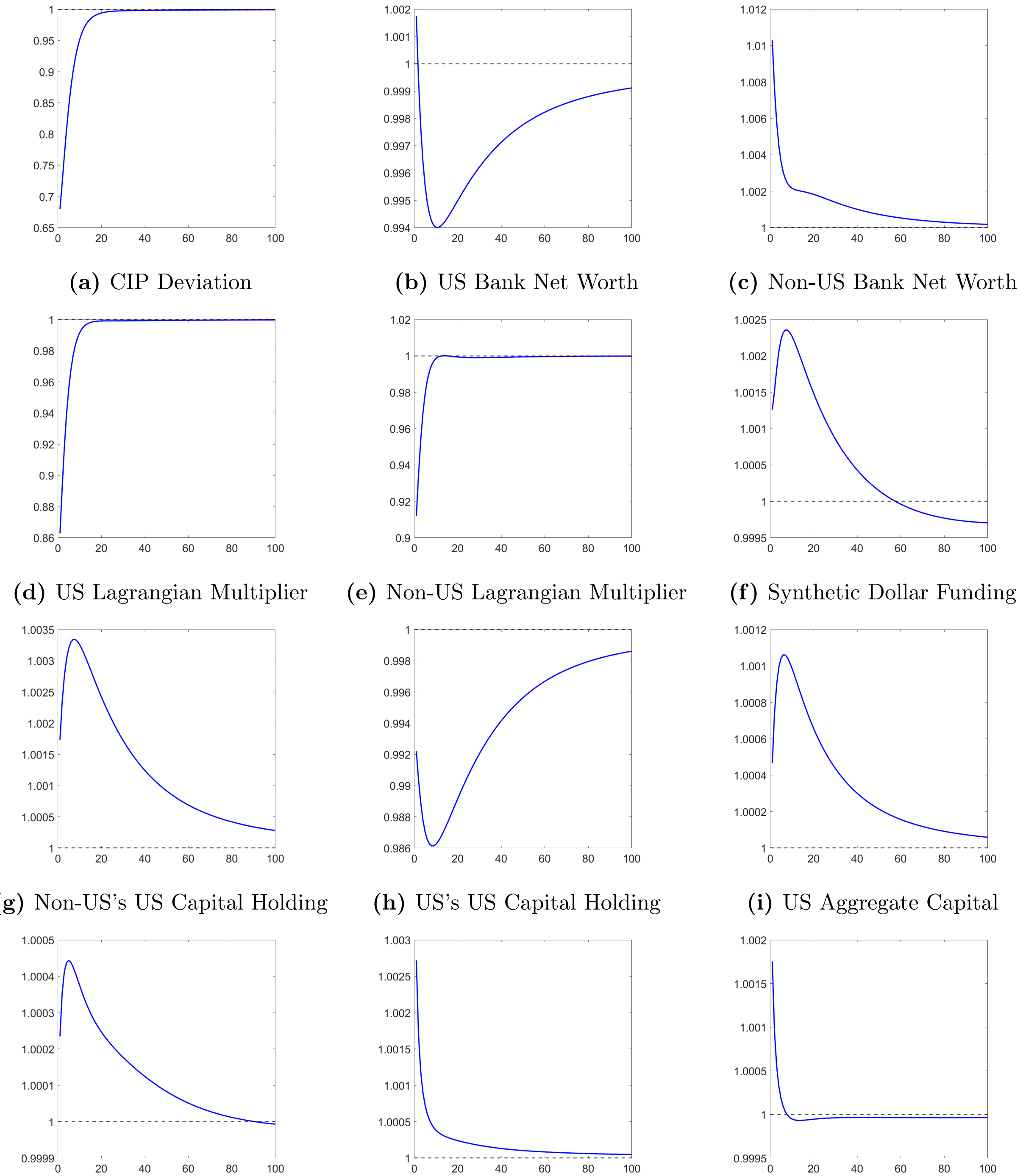
Consequently, in panel (13i) and (13j), both the US and the non-US aggregate capital are larger when there are central bank swap lines. Output and investment of the US and the non-US show similar patterns as the aggregate capital (panel (13k), (13l), (13m), and (13n)). Inflation rates of both countries are higher with central bank swap lines as in panel (13o) and (13p), 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 (13q) and (13r)).

In panel (13s), (13t)) and (13u), 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.



(a) CIP Deviation

(b) US Bank Net Worth

(c) Non-US Bank Net Worth

(d) US Lagrangian Multiplier

(e) Non-US Lagrangian Multiplier

(f) Synthetic Dollar Funding

(g) Non-US's US Capital Holding

(h) US's US Capital Holding

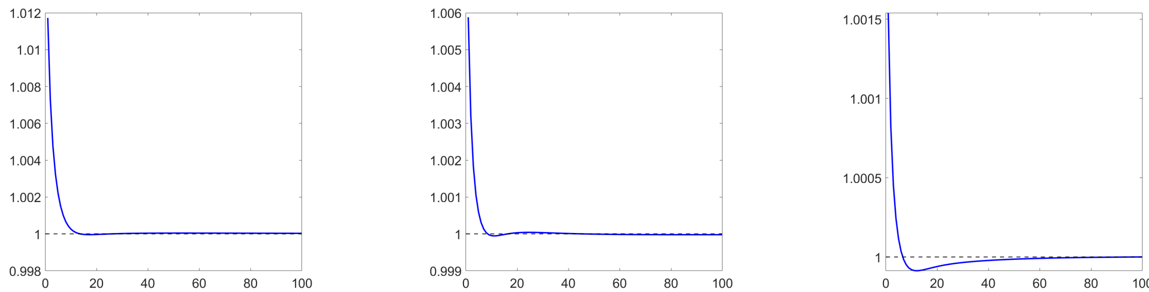
(i) US Aggregate Capital

(j) Non-US Aggregate Capital

(k) US Output

(l) Non-US Output

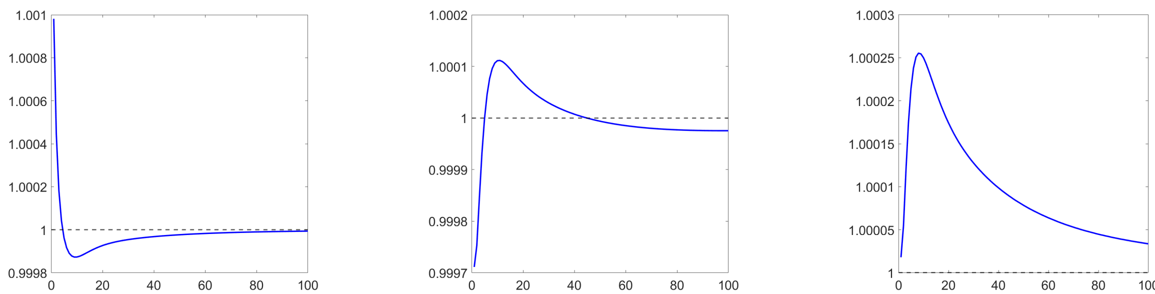
Figure 13: Relative Impulse Responses: With v.s. Without Swap Lines



(m) US Investment

(n) Non-US Investment

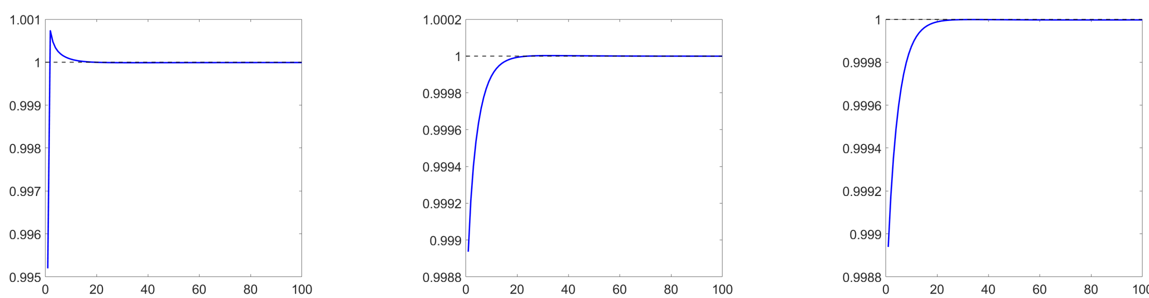
(o) US Inflation



(p) Non-US Inflation

(q) US Consumption

(r) Non-US Consumption



(s) USD Appreciation Rate

(t) Real Spot Exchange Rate

(u) Real Forward Exchange Rate

Figure 13: 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.

6 Conclusion

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

First, I show empirically that US monetary contraction widens CIP deviations and this widening amplifies spillovers and spillbacks of US monetary policy. CIP deviations are measured as LIBOR-bases of G10 currencies while US monetary policy shocks are identified by high-frequency method. By regressing CIP deviations on US monetary policy for the post-GFC periods, it is shown that CIP deviations widen in response to a rise in US policy rate. In addition, by comparing effects of US monetary policy on stock market indices and nominal exchange rates, the amplification of spillovers and spillbacks are estimated to be significant in the post-GFC periods.

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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Appendix A Additional Empirical Analyses

A.1 Decomposition of the effect of US Monetary Policy on CIP Deviations

We can decompose the effect of the US monetary policy shock on LIBOR-based CIP deviations further since CIP deviations are given by $cid_{j,h,t} = r_{\$,h,t} - (r_{j,h,t} - \rho_{j,h,t})$. From the definition of CIP deviations, the effect on CIP deviations can be decomposed into the effect on the US LIBOR, (negative of) the currency j IBOR, and the forward premium. Table A.1 displays the decomposition for NS, $Target$, and $Path$ respectively.

In Table A.1, there are three panels showing the decomposition for each monetary policy shock: top panel for NS, middle panel for $Target$, and bottom panel for $Path$. In each panel, the top row Δcid indicates the total effect which is equivalent to the baseline estimates in Table 2. The three rows below Δcid are the decomposed effects which sum up to the total effect. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead.

First, US LIBOR $\Delta r^{\$}$ reacts less than one-to-one in response to the US monetary policy shock, implying imperfect pass-through of the US monetary policy on interbank rates. On the other hand, changes in synthetic dollar funding costs $\Delta r^j - \Delta \rho^j$ mostly come from forward premium $\Delta \rho^j$. This makes sense because the interbank rates of other countries which are affected by those countries' policy would be less connected to the US monetary policy than the US LIBOR is. Note that this decomposition is just an accounting exercise, and does not provide causal explanation that changes in synthetic dollar funding cost come from FX swap market frictions. According to Du, Tepper, and Verdelhan (2018), CIP deviations have emerged due to FX swap market frictions such as limit on arbitrage since the GFC.

A.2 Term Structure of Effects of US Monetary Policy on CIP Deviations

In order to analyze the term structure of the effects of US monetary policy on CIP deviations, the relationship between principal components of CIP deviations and the US monetary policy is investigated. First, principal components (PCs) are extracted from Δcid across maturities for each currency. For instance, from the seven series of Australian Dollar CIP deviations consisting of maturities from 3-month to 10-year, I extract principal components. These factors summarize the information in Δcid across maturities. From Table A.2, we can see that the first two PCs explain about 58.5% - 87.6% of the variations in the changes in CIP deviations. For this reason, I will focus on the first two factors: PC1 and PC2.

Table A.3 displays factor loadings on PC1 and PC2 for each currency and each maturity. The upper panel of Table A.3 reports the factor loadings on PC1 while the factor loadings on PC2 are

Table A.1: Decomposition of the Effect of US Monetary Policy Shock on LIBOR-Basis

	Full Sample						
NS	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid	-35.34***	-5.095	-0.526	-0.303	0.602	1.267	0.445
	(13.40)	(3.505)	(1.330)	(0.713)	(1.021)	(0.793)	(0.597)
$\Delta r^{\$}$	6.602**	62.48***	79.87***	84.59***	83.06***	42.52***	65.55***
	(3.221)	(0.299)	(6.324)	(0.017)	(0.138)	(0.057)	(14.87)
$-\Delta r^j$	-2.063*	-9.465**	-12.30***	-12.75**	-12.35*	-11.75*	-10.95**
	(2.576)	(3.846)	(4.180)	(4.147)	(3.943)	(3.558)	(2.782)
$\Delta \rho^j$	-39.88**	-58.52***	-67.65***	-71.35***	-70.42***	-30.30***	-54.20***
	(15.71)	(4.729)	(4.744)	(4.920)	(6.026)	(5.770)	(11.80)
$Target$	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid	-28.33***	-3.471*	-0.289	0.031	0.998	1.658	0.256
	(6.386)	(1.785)	(1.051)	(0.674)	(0.936)	(1.042)	(0.312)
$\Delta r^{\$}$	5.246	30.99***	37.37***	35.36***	33.82***	10.08***	27.60***
	(3.415)	(0.151)	(6.798)	(0.040)	(6.181)	(0.020)	(6.610)
$-\Delta r^j$	-0.370	-8.411**	-9.461***	-10.28***	-7.640***	-5.986*	-4.034**
	(0.891)	(2.911)	(2.045)	(3.044)	(2.249)	(2.660)	(1.784)
$\Delta \rho^j$	-33.21***	-25.94***	-27.92***	-24.81***	-25.34***	-3.154	-23.26***
	(8.785)	(2.597)	(5.296)	(3.104)	(4.503)	(3.044)	(5.921)
$Path$	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid	-7.006*	-1.662	-0.297	-0.397	-0.459	-0.445	0.148
	(3.626)	(1.776)	(0.865)	(0.584)	(0.846)	(0.836)	(0.476)
$\Delta r^{\$}$	1.382	31.09***	41.85***	48.30***	48.21***	31.60***	37.08***
	(1.854)	(0.176)	(6.928)	(0.051)	(9.954)	(0.036)	(11.52)
$-\Delta r^j$	-1.693*	-1.029	-2.922	-2.592	-4.555	-5.630	-6.705*
	(0.859)	(1.791)	(2.797)	(2.398)	(3.085)	(3.363)	(3.969)
$\Delta \rho^j$	-6.695*	-32.18***	-39.24***	-45.63***	-44.26***	-26.25***	-30.33***
	(3.676)	(2.705)	(5.667)	(2.253)	(8.039)	(3.435)	(8.926)

Note. This table presents the decomposition of effects of US monetary policy on CIP deviations. The top panel is the decomposition for NS, the medium panel is for $Target$, and the bottom panel is for $Path$. In each panel, the top row shows the total effect of which estimates are from the baseline regression shown in Table 2. The below three rows are decomposed effects respectively, and they sum up to the total effect. Units of the estimates are in basis points. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. N denotes the number of observations of the regression respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

reported in the lower panel. Each column indicates factor loadings for each currency while each row reports loadings for each maturity. In the upper panel, loadings on PC1 are relatively constant across maturities for all currencies. This means that PC1 moves Δcid across all maturities similarly. On the other hand, loadings on PC2 have "slope" in the sense that loadings of short-term bases are high and positive while those of long-term bases are low and negative. A decrease in PC2 then leads to the decline in short-term Δcid and the rise in long-term Δcid. Following the terminology used in finance literature, PC1 and PC2 will be referred to as level factor and slope factor respectively.

Table A.2: Cumulative Explained Variance of Δcid

Δcid	PC1	PC2	PC3	PC4	PC5
AUD	0.5619	0.7057	0.8214	0.9001	0.9444
CAD	0.6540	0.7931	0.8694	0.9162	0.9571
CHF	0.6450	0.8091	0.8848	0.9263	0.9576
DKK	0.4929	0.6478	0.7882	0.8619	0.9138
EUR	0.7088	0.8761	0.9287	0.9555	0.9749
GBP	0.6045	0.7832	0.8625	0.9149	0.9557
JPY	0.6730	0.8411	0.9085	0.9475	0.9724
NOK	0.4275	0.5852	0.7076	0.7978	0.8767
NZD	0.5778	0.7269	0.8519	0.9055	0.9497
SEK	0.5829	0.7596	0.8568	0.9080	0.9484

Note. This table presents cumulative explained variance in Δcid in the post-GFC periods. For each currency, principal components of Δcid with maturities of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year are extracted. Five principal components are displayed in this table.

Table A.3: Factor Loadings on PC1 and PC2 across Maturities

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

Note. This table presents factor loadings on the first two principal components for each currency. The first panel shows the factor loadings on the first principal component while the second panel displays those on the second principal component. Each column indicates factor loadings for each G10 currency. In a column, elements are factor loadings for each maturity from 3-month to 10-year.

Next, PC1 and PC2 are regressed onto the US monetary policy shock respectively. Since we have principal components for each currency, we can run OLS regressions with currency fixed effects similar to (2.1) as

$$PC1_t^j = \alpha_j + \beta \Delta mp_t + \epsilon_t^j$$
$$PC2_t^j = \alpha_j + \beta \Delta mp_t + \epsilon_t^j$$

Table A.4 shows the estimation results of the above regressions. Column (1) and (2) are the results for PC1 as the dependent variable while column (3) and (4) are the case of PC2 as the dependent variable. For each dependent variable PC1 and PC2, the left column is the result when NS is used as the monetary policy shock while the right column is the one with $Target$ and $Path$ as monetary policy shocks. Note that the unit of the estimates has no meaning since the dependent variables are principal components.

In Table A.4, NS and $Target$ are estimated to have significantly negative effect on PC2, and its effect on PC1 is also negative although it is insignificant. As the baseline estimation results, $Path$ has insignificant effect on both PC1 and PC2. Hence, in response to the contractionary monetary policy shock, both the level and the slope factor decrease. Since PC1 is a level factor and the factor loadings are positive, Δcid declines in response to the contractionary US monetary policy shock across all maturities. On the other hand, short-term Δcid decreases while long-term increases following the contractionary shock because PC2 is the slope factor. Recall that loadings on short-term bases are positive while those on long-term bases are negative. Combining these two observations, the decline in short-term Δcid is amplified while the decline in long-term Δcid is dampened due to the two offsetting forces. This makes β_h more negative for short-term CIP deviations and nearly zero for long-term CIP deviations, which sheds light on the term structure of β^h.

Table A.4: Principal Components of Δcid and the US Monetary Policy

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

Note. This table presents the regression results of principal components of Δcid on 1%p contractionary US monetary policy shock. For each principal component, there are two columns: the left column is the estimation result when NS is used as the US monetary policy shock whereas the right column is the one when $Target$ and $Path$ are used as proxies for the shock. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix B Robustness Check

In this section, I show that empirical results in Section 2 are robust to different choices of the dependent variable and the explanatory variable. For the dependent variable, I consider two-day changes in CIP deviations and changes in absolute values of CIP deviations. For the explanatory variable, information-robust monetary policy shock (Miranda-Agrippino and Ricco, 2021) and monetary policy shock robust to Fed response to news channel (Bauer and Swanson, 2023b) are considered.

B.1 Dependent Variable: Two-Day Change in CIP Deviations

First, I change measurements of $\Delta cid^j_{t,h}$ from one-day difference to two-day difference $cid^j_{t+1,h} - cid^j_{t-1,h}$ considering time-zone differences.

Table A.5 displays estimation results of regressing newly defined series of $\Delta cid^j_{t,h}$ on Δmp_t. Similar to the baseline estimation in Table 2, a contractionary US monetary policy shock declines CIP deviations with larger effects on short-term bases. The effect on 3-month basis is smaller than the baseline result while effects on longer-term bases are larger and significant. Also, $Path$ factor leads to a rise in 3-month CIP deviation, which is at odds with the baseline result. For the most part, we can see that empirical results are robust to changing the dependent variable to a two-day difference in CIP deviations.

B.2 Dependent Variable: Change in Absolute Value of CIP Deviations

Since CIP deviations can take positive values, a decline in CIP deviations is not always equivalent to widening CIP deviations. A widening of CIP deviations is by definition larger size of CIP deviations, which can be measured by taking the absolute value of CIP deviations. Hence, in order to look at widening (or narrowing) more directly, I consider changes in absolute value of CIP deviations $\Delta|cid^j_{t,h}|$ as the dependent variable.

Then, I run the following regression:

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

CIP deviations widen in response to a contractionary US monetary policy shock if $\beta_h > 0$. In Table A.6, we can see that β_h of NS and $Target$ are estimated to be significantly positive though the size of estimates is smaller than baseline results.

B.3 Information-Robust Monetary Policy Shock

I also 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 effect:

Table A.5: Effects of US Monetary Policy Shock on CIP deviations

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

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

Note. This table presents the regression results of CIP deviations on 1pp 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. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. N denotes the number of observations of the regression respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

the 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

Table A.6: Effects of US Monetary Policy Shock on CIP deviations

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

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

Note. This table presents the regression results of size of CIP deviations on 1pp 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. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. N denotes the number of observations of the regression respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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

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

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.[38] 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 $x^f_{t,i} - x^f_{t-1,i}$ which is the difference between forecasts published in current meeting and previous meeting.

The results of (B.1) are reported in Table A.7. Columns with NS, $Target$, and $Path$ refer to the regression results when each monetary policy indicator is used as the dependent variable. Rows are Greenbook forecasts for fundamentals and their first difference from the previously published forecast. Estimates are roughly in line with the ones in Romer and Romer (2004), with the R^2 of 0.13 - 0.22 in this paper compared to 0.28 in Romer and Romer (2004). Also, the p-values of F-statistics from the regressions for NS and $Path$ are below 0.001, implying that we can reject the null hypothesis that there is no signaling channel. The regression for $Target$ has the p-value of 0.569, so the signaling channel does not exist for the target factor. Nevertheless, information-robust $Target$ will be used in order to compare the information-robust shock with the baseline shock.

In the next step, we take the residual term $\Delta\widetilde{mp}$ from (B.1). $\Delta\widetilde{mp}$ 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 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:

$$\Delta cid^j_{t,h} = \alpha_j + \beta_h \Delta mpi_t + \epsilon^j_{t,h} \tag{B.2}$$

Table A.8 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 2, effects of monetary policy are on short-term basis are large and significant for post-GFC periods. 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. Information-robust effects

[38]Greenbook 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.

Table A.7: Signaling Channel of US Monetary Policy

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

Note. This table presents the regression results of high-frequency identified monetary policy shocks on Greenbook forecasts for GDP growth rate, inflation, and unemployment rate. For GDP growth rate and inflation, forecast horizons of -1 (previous quarter), 0 (current quarter), 1 (next quarter), and 2 (two quarters ahead) are included. For the case of unemployment rate, only contemporaneous forecast is included. Changes in forecasts for GDP growth rate and inflation from previous Greenbook are also included. Three columns NS, $Target$, and $Path$ indicate regression results when each monetary policy indicator is used as the dependent variable. Heteroscedasticity-robust standard errors are reported in the parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

are larger for 3-month maturity while they are more muted for other maturities.

B.4 Monetary Policy Shock Robust to the Fed Response to News Channel

According to Bauer and Swanson (2023a), there is another concern on the exogeneity of high-frequency identified monetary policy shock: Fed response to news channel. This arises due to imperfect information on the Fed's monetary policy rule, resulting in correlation between high-frequency identified surprises and macroeconomic and financial data available before FOMC announcements. Bauer and Swanson (2023a) tackles this endogeneity by orthogonalizing high-frequency identified shocks with respect to macroeconomic and financial data:

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

Table A.8: Effect of Information-robust US Monetary Policy Shock on CIP deviations

	3M		1Y		2Y		3Y	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NS	-24.51**		-1.581		1.000		1.823*	
	(9.894)		(2.086)		(1.478)		(0.992)	
Target		-24.96***		-2.267*		-0.487		0.252
		(7.581)		(1.151)		(1.282)		(0.777)
Path		1.663		1.084		2.228*		1.909***
		(3.162)		(1.255)		(1.260)		(0.382)
R^2	0.045	0.098	0.001	0.007	0.002	0.012	0.006	0.011
N	879	879	862	862	869	869	871	871

	5Y		7Y		10Y	
	(7)	(8)	(9)	(10)	(11)	(12)
NS	2.614*		2.441		0.680	
	(1.226)		(1.553)		(0.867)	
Target		1.068		1.779		-0.040
		(1.123)		(1.352)		(0.431)
Path		1.706***		0.877		0.966
		(0.465)		(0.803)		(0.796)
R^2	0.012	0.014	0.009	0.012	0.001	0.003
N	873	873	879	879	866	866

Note. This table presents the regression results of CIP deviations on 1pp contractionary information-robust 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. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. N denotes the number of observations of the regression respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Here, X_t is a vector of macroeconomic and financial data while Δmpn_t is the orthogonalized high-frequency identified shock which is robust to the Fed Response to news channel.

Table A.9 presents estimation results when the explantory variable is Δmpn_t. Series of Δmpn_t are obtained from Bauer and Swanson (2023b). Note that they provide only Nakamura-Steinsson type monetary policy shocks robust to Fed response to news channel, so Table A.9 does not have estimates for $Target$ and $Path$ factors. Similar to the results in Bauer and Swanson (2023b) regarding financial variables, estimates remain largely unchanged, confirming that the baseline estimation is also robust to Fed response to news channel.

Table A.9: Effect of Bauer-Swanson US Monetary Policy Shock on CIP deviations

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

Note. This table presents the regression results of CIP deviations on 1pp contractionary Bauer-Swanson US monetary policy shock for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. Units of the estimates are in basis points. Driscoll-Kraay standard errors are reported in the parentheses unless the cross-sectional dependence is weak. If the cross-sectional dependence is weak, standard errors clustered at the currency level are reported instead. N denotes the number of observations of the regression respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix C Proof: Value Function Is Linear in Net Worth

In this section, I prove that the value function of US bank i is linear in its net worth, *i.e.* $V_{i,t} = \nu_t N_{i,t}$ by guess and verify method (see Section 3.2.6). First, let us guess $V_{i,t} = \nu_t N_{i,t}$. Note that ν_t is assumed to be common across all banks. Then, the optimization problem becomes

$$\nu_t = \max_{\phi_{H,i,t},\phi_{X,i,t}} E_t \left[\Omega_{t,t+1} \left\{ (R_{K,t+1} - R_t)\phi_{H,i,t} + \left(R_t^* \frac{S_t}{F_t} - R_t \right) \phi_{X,i,t} + R_t \right\} \right]$$
$$\text{s.t.} \quad \nu_t \geq \left[\left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right) \phi_{H,i,t} + \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right) \phi_{X,i,t} \right]$$

for the stochastic discount factor of bank $\Omega_{t,t+1}$ defined as

$$\Omega_{t,t+1} \equiv \Lambda_{t,t+1}(1 - \sigma + \sigma \nu_{t+1}) \tag{C.1}$$

Banks' SDF is equivalent to the SDF of the representative household augmented by the expected value from bank's net worth $1 - \sigma + \sigma\nu_{t+1}$. When the bank exits with probability $1 - \sigma$, then one unit of net worth just transfers one unit to the households. If it stays with probability σ on the other hand, ν_{t+1} is created per unit of net worth. When ν_{t+1} is different from one, which happens in the existence of binding leverage constraint, the SDF of banks becomes different from that of households. Intuitively, the expected marginal value of net worth conditional on continuing business is equal to one if the leverage constraint does not bind and thus one unit of net worth does not produce any additional value. Conversely, if the leverage constraint binds, then marginal net worth loosens the leverage constraint and provides additional value, creating wedge between the SDF of households and the SDF of banks.

Defining the expected discounted returns on assets and net worth as

$$\nu_{H,t} \equiv E_t \left[\Omega_{t,t+1} \left(R_{K,t+1} - R_t \right) \right] \tag{C.2}$$
$$\nu_{X,t} \equiv E_t \left[\Omega_{t,t+1} \right] \left(R_t^* \frac{S_t}{F_t} - R_t \right) \tag{C.3}$$
$$\nu_{N,t} \equiv E_t \left[\Omega_{t,t+1} \right] R_t \tag{C.4}$$

the Bellman equation becomes

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

Then, we can obtain the first-order conditions as

$$\nu_{H,t} = \mu_t \left(\theta_{H1} + \theta_{H2} \frac{Q_t K_{H,t}}{P_t} \right) \tag{C.5}$$

$$\nu_{X,t} = \mu_t \left(\theta_{X1} + \theta_{X2} \frac{X_t}{P_t} \right) \tag{C.6}$$

for the Lagrangian multiplier μ_t of the leverage constraint.

Plugging the first-order conditions (C.5) and (C.6) into the leverage constraint and combining with the value function, we can obtain the franchise value per unit of net worth as

$$\nu_t = \frac{\nu_{N,t}}{1 - \mu_t} \tag{C.7}$$

Since ν_t is the same for all banks and thus it does not depend on an individual bank's net worth, we can verify that $V_{i,t} = \nu_t N_{i,t}$.

Lastly, we aggregate variables across all banks for each period. Let us define the aggregate net worth, US government bond holding, and synthetic dollar funding as

$$N_t \equiv \int_0^1 N_{i,t} di$$

$$K_{H,t} \equiv \int_0^1 K_{H,i,t} di$$

$$X_t \equiv \int_0^1 X_{i,t} di$$

Since bank i's optimization problem does not depend on its net worth due to the linearity of the value function, $\phi_{H,i,t}$ and $\phi_{X,i,t}$ are identical for all banks. Then,

$$\phi_{H,t} = \frac{Q_t K_{H,t}}{N_t} \tag{C.8}$$

$$\phi_{X,t} = \frac{X_t}{N_t} \tag{C.9}$$

Aggregating the leverage constraint (3.21) over all banks, we can obtain the relationship between leverage ratios and the franchise value as

$$\nu_t = \frac{1}{\mu_t} \left(\nu_{H,t} \phi_{H,t} + \nu_{X,t} \phi_{X,t} \right) \tag{C.10}$$

The proof for non-US banks are the same. From (3.37), (3.38), (3.39), and (3.32),

$$\nu_t^* = \frac{\nu_{N,t}^*}{1 - \mu_t^*} \tag{C.11}$$

This implies that ν_t^* is the same for all banks and thus the conjecture that $V_{i,t}^* = \nu_t^* N_{i,t}^*$ is verified.

Let us aggregate asset holdings and net worth across all banks as

$$N_t^* \equiv \int_0^1 N_{i,t}^* di$$
$$K_{F,t}^* \equiv \int_0^1 K_{F,i,t}^* di$$
$$K_{H,t}^* \equiv \int_0^1 K_{H,i,t}^* di$$

Since $\phi_{F,i,t}^*$, $\phi_{H,i,t}^*$, and $x_{i,t}^*$ are identical for all banks,

$$\phi_{F,t}^* = \frac{Q_t^* K_{F,t}^*}{N_t^*} \tag{C.12}$$
$$\phi_{H,t}^* = \frac{S_t Q_t K_{H,t}^*}{N_t^*} \tag{C.13}$$
$$\nu_t^* = \frac{1}{\mu_t^*}\left(\nu_{F,t}^* \phi_{F,t}^* + \nu_{H,t}^*(1-x_t^*)\phi_{H,t}^* + \nu_{X,t}^* x_t^* \phi_{H,t}^*\right) \tag{C.14}$$

Appendix D Additional Blocks of the Model

In this section, we describe sectors of the non-US economy other than financial intermediaries: households, capital good producers, consumption and investment good retailers, wholesalers, firms, and the government. In addition, we specify market clearing conditions except the FX swap market and the balance of payment equation.

D.1 Non-US Household

Preference of non-US households is represented by the following CRRA utility function

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

where C_t^* is the aggregate consumption and L_t^* is the labor supply of the non-US. The elasticity of intertemporal substitution and the Frisch elasticity are all set to be the same as the home country while the disutility of labor κ^* is allowed to be different from the US.

For each period, the household can consume C_t^* or deposit D_t^* to financial intermediaries. Gross return rate of deposits from period t to $t+1$ is denoted as R_t^*. Therefore, the sequential budget constraint of the household is given by

$$P_t^* C_t^* + D_t^* = W_t^* L_t^* + R_{t-1}^* D_{t-1}^* + \Pi_t^* + TR_t^* \tag{D.1}$$

where Π_t^* is the net profit that the household obtains from all firms including financial intermediaries while TR_t^* is the net transfer from the government. Then, the optimality conditions from the household's optimization problem are

$$\kappa^* C_t^{*\gamma} L_t^{*\varphi} = \frac{W_t^*}{P_t^*} \tag{D.2}$$

$$E_t \left[\Lambda_{t,t+1}^* \right] R_t^* = 1 \tag{D.3}$$

for the SDF of the household defined as

$$\Lambda_{t,t+1}^* \equiv \beta \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma} \left(\frac{P_t^*}{P_{t+1}^*} \right) \tag{D.4}$$

D.2 Non-US Capital Good Producers

Similar to the US, there are perfectly competitive capital good producers purchasing aggregate investment goods at P_t^* and selling at Q_t^*. The aggregate capital evolves following the law of motion

$$K_t^* = I_t^* + (1-\delta)K_{t-1}^* \tag{D.5}$$

Since the per-period profit of capital good producer is given by

$$\Pi_t^{K*} \equiv Q_t^* I_t^* - P_t^* I_t^* \left(1 + \frac{\psi_I}{2}\left(\frac{I_t^*}{I_{t-1}^*} - 1\right)^2\right)$$

we can get the optimality condition as

$$Q_t^* = P_t^*\Big[1 + \frac{\psi_I}{2}\Big(\frac{I_t^*}{I_{t-1}^*} - 1\Big)^2 + \psi_I \frac{I_t^*}{I_{t-1}^*}\Big(\frac{I_t^*}{I_{t-1}^*} - 1\Big)\Big] - E_t\Big[\Lambda_{t,t+1}^* P_{t+1}^* \psi_I \Big(\frac{I_{t+1}^*}{I_t^*}\Big)^2\Big(\frac{I_{t+1}^*}{I_t^*} - 1\Big)\Big] \tag{D.6}$$

D.3 Non-US Retailers

Domestically-produced consumption good $C_{F,t}^*$ and imported consumption good $C_{H,t}^*$ are aggregated into C_t^* by perfectly competitive consumption good retailers whose aggregation technology is described as the following CES function:

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

Here, the home-bias parameter ω and the elasticity of substitution between domestically-produced and imported goods are set at the same value as the US. Then, the following demand functions are obtained from the profit maximization problem of consumption good retailers

$$C_{F,t}^* = \omega \left(\frac{P_{F,t}^*}{P_t^*}\right)^{-\nu} C_t^* \tag{D.7}$$

$$C_{H,t}^* = (1-\omega) \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\nu} C_t^* \tag{D.8}$$

where $P_{F,t}^*$ and $P_{H,t}^*$ are non-US prices of goods produced in the non-US and in the US respectively. Also, the aggregate price index P_t^* is given by

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

Let us define the non-US' terms-of-trade T^*_t as $P^*_{F,t}/P^*_{H,t}$. Note that $T^*_t = T_t$ under the law of one price, but it does not hold generally under the LCP. Then,

$$P^*_{H,t} = P^*_t \left[\omega T^{*1-\nu}_t + 1 - \omega\right]^{-\frac{1}{1-\nu}} \tag{D.9}$$

$$P^*_{F,t} = P^*_t \left[\omega + (1-\omega) T^{*-(1-\nu)}_t\right]^{-\frac{1}{1-\nu}} \tag{D.10}$$

Similarly, perfectly competitive investment goods retailers aggregate domestically produced investment goods I^*_{Ft} (produced in the non-US) and imported investment goods I^*_{Ht} (produced in the US) into I^*_t by the following CES aggregator:

$$I^*_t \left(1 + \frac{\psi_I}{2}\Big(\frac{I^*_t}{I^*_{t-1}} - 1\Big)^2\right) \equiv \big[\omega^{\frac{1}{\nu}} I^{*\frac{\nu-1}{\nu}}_{F,t} + (1-\omega)^{\frac{1}{\nu}} I^{*\frac{\nu-1}{\nu}}_{H,t}\big]^{\frac{\nu}{\nu-1}}$$

Then, we can obtain the following demand functions:

$$I^*_{F,t} = \omega\Big(\frac{P^*_{F,t}}{P^*_t}\Big)^{-\nu} I^*_t \left(1 + \frac{\psi_I}{2}\Big(\frac{I^*_t}{I^*_{t-1}} - 1\Big)^2\right) \tag{D.11}$$

$$I^*_{H,t} = (1-\omega)\Big(\frac{P^*_{H,t}}{P^*_t}\Big)^{-\nu} I^*_t \left(1 + \frac{\psi_I}{2}\Big(\frac{I^*_t}{I^*_{t-1}} - 1\Big)^2\right) \tag{D.12}$$

D.4 Non-US Wholesalers

Similar to the US, there are perfectly competitive wholesalers with aggregation technology given by

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

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

Let us denote the price of $Y^*_{F,t}(j)$ and $Y_{F,t}(j)$ as $P^*_{F,t}(j)$ and $P_{F,t}(j)$ respectively. Then, the demand functions for domestically-spent and exported varieties are

$$Y^*_{F,t}(j) = \left(\frac{P^*_{F,t}(j)}{P^*_{F,t}}\right)^{-\epsilon} Y^*_{F,t} \tag{D.13}$$

$$Y_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}}\right)^{-\epsilon} Y_{F,t} \tag{D.14}$$

D.5 Non-US Firm

Each variety $j \in [0,1]$ in the non-US is also produced by the following production function

$$Y^*_t(j) = Z^*_t L^*_t(j)^{1-\alpha} K^*_{t-1}(j)^{\alpha}$$

where Z_t^* follows an exogenous AR(1) processes

$$\log Z_t^* = \rho_z^* \log Z_{t-1}^* + \sigma_z^* \epsilon_{z,t}^* \tag{D.15}$$

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

From the cost minimization of firm j, we can obtain the following demand functions for labor and capital

$$W_t^* = (1-\alpha) MC_t^* \frac{Y_t^*(j)}{L_t^*(j)} \tag{D.16}$$

$$\tilde{R}_{K,t}^* = \alpha MC_t^* \frac{Y_t^*(j)}{K_{t-1}^*(j)} \tag{D.17}$$

for the marginal cost MC_t^* given by

$$MC_t^* = \frac{1}{Z_t^*} \frac{W_t^{*1-\alpha} \tilde{R}_{K,t}^{*\alpha}}{(1-\alpha)^{1-\alpha}\alpha^\alpha} \tag{D.18}$$

According to the assumption of LCP, firm j chooses $P_{F,t}^*(j)$ and $P_{F,t}(j)$ separately for its varieties sold in the non-US and in the US. Let us assume that the firm is subject to the same price adjustment cost ψ_P as the US. Then, firm j 's periodic profit $\Pi_t^{P*}(j)$ is

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

From (D.13) and (D.14), firm j's life-time profit maximization problem defined as

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

yields the following first-order conditions:

$$
\begin{aligned}
(1+s^*)(\epsilon-1) = \epsilon\frac{MC_t^*}{P_{F,t}^*} - \psi_P\left(\frac{P_{F,t}^*}{P_{F,t-1}^*}-1\right)\frac{P_{F,t}^*}{P_{F,t-1}^*} \\
+E_t\left[\Lambda_{t,t+1}^*\psi_P\left(\frac{P_{F,t+1}^*}{P_{F,t}^*}-1\right)\left(\frac{P_{F,t+1}^*}{P_{F,t}^*}\right)^2\frac{Y_{F,t+1}^*}{Y_{F,t}^*}\right]
\end{aligned} \tag{D.19}
$$

$$
\begin{aligned}
(1+s^*)(\epsilon-1) = \epsilon\frac{MC_t^*}{S_tP_{F,t}} - \psi_P\left(\frac{P_{F,t}}{P_{F,t-1}}-1\right)\frac{P_{F,t}}{P_{F,t-1}} \\
+E_t\left[\Lambda_{t,t+1}^*\psi_P\left(\frac{P_{F,t+1}}{P_{F,t}}-1\right)\left(\frac{P_{F,t+1}}{P_{F,t}}\right)^2\frac{S_{t+1}}{S_t}\frac{Y_{F,t+1}}{Y_{F,t}}\right]
\end{aligned} \tag{D.20}
$$

D.6 Non-US Monetary Policy

Monetary policy of the EU is

$$
\frac{R_t^*}{\bar{R}^*} = \left(\frac{R_{t-1}^*}{\bar{R}^*}\right)^{\rho_R}\left(\frac{P_t^*}{P_{t-1}^*}\right)^{\phi_\pi(1-\rho_R)}\epsilon_{R,t}^* \tag{D.21}
$$

where

$$
\log\epsilon_{R,t}^* = \rho_m^*\log\epsilon_{R,t-1}^* + \sigma_m^*\epsilon_{m,t}^* \tag{D.22}
$$

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

D.7 Non-US Fiscal Policy

As the US, the fiscal policy of the EU is

$$
TR_t^* + s^*P_{F,t}^*(Y_{F,t}^* + Y_{F,t}) = 0 \tag{D.23}
$$

D.8 Equilibrium

Let us define the real exchange rate $\mathcal{E}_t$ as

$$
\mathcal{E}_t \equiv \frac{S_tP_t}{P_t^*}
$$

Then, it can be expressed as a function of terms-of-trade as

$$
\mathcal{E}_t = \frac{S_tP_{H,t}}{P_{H,t}^*}\left[\frac{\omega+(1-\omega)T_t^{1-\nu}}{\omega T_t^{*1-\nu}+1-\omega}\right]^{\frac{1}{1-\nu}}
$$

for $T_t^* = P_{F,t}^*/P_{H,t}^*$. Let us define deviations from the law of one price for the US and the non-US goods as

$$\mathcal{E}_t^H \equiv \frac{S_t P_{H,t}}{P_{H,t}^*}$$
$$\mathcal{E}_t^F \equiv \frac{S_t P_{F,t}}{P_{F,t}^*}$$

Note that $\mathcal{E}_t^H = \mathcal{E}_t^F = 1$ under the law of one price. From the above definitions,

$$\mathcal{E}_t = \mathcal{E}_t^H \left[\frac{\omega + (1-\omega)T_t^{1-\nu}}{\omega T_t^{*1-\nu} + 1 - \omega}\right]^{\frac{1}{1-\nu}} \tag{D.24}$$
$$\mathcal{E}_t^F = \mathcal{E}_t^H \frac{T_t}{T_t^*} \tag{D.25}$$

Meanwhile, the market clearing conditions for the US and the non-US capital are

$$K_t = K_{H,t} + K_{H,t}^* \tag{D.26}$$
$$K_t^* = K_{F,t}^* \tag{D.27}$$

From the market clearing condition for US goods sold domestically and exported, we can obtain the following resource constraint for $Y_{H,t}$ and $Y_{H,t}^*$ as

$$Y_{H,t} = C_{H,t} + I_{H,t} + \frac{\psi_P}{2}\Big(\frac{P_{H,t}}{P_{H,t-1}} - 1\Big)^2 Y_{H,t}$$
$$Y_{H,t}^* = C_{H,t}^* + I_{H,t}^* + \frac{\psi_P}{2}\Big(\frac{P_{H,t}^*}{P_{H,t-1}^*} - 1\Big)^2 Y_{H,t}^*$$

Combining with (3.7),

$$\left[1 - \frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}} - 1\right)^2\right] Y_{H,t} = \omega \left(\frac{P_{H,t}}{P_t}\right)^{-\nu} \left(C_t + I_t + K_{t-1}\frac{\psi_K}{2}\Big(\frac{I_t}{K_{t-1}} - \delta\Big)^2\right) \tag{D.28}$$
$$\left[1 - \frac{\psi_P}{2}\left(\frac{P_{H,t}^*}{P_{H,t-1}^*} - 1\right)^2\right] Y_{H,t}^* = (1-\omega) \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\nu} \left(C_t^* + I_t^* + K_{t-1}^*\frac{\psi_K}{2}\Big(\frac{I_t^*}{K_{t-1}^*} - \delta\Big)^2\right) \tag{D.29}$$

while the total output Y_t is the sum of $Y_{H,t}$ and $Y_{H,t}^*$ as

$$Y_t = Y_{H,t} + Y_{H,t}^* \tag{D.30}$$

Similarly, the market clearing conditions for EU goods can be obtained as

$$\left[1-\frac{\psi_P}{2}\left(\frac{P^*_{F,t}}{P^*_{F,t-1}}-1\right)^2\right]Y^*_{F,t}=\omega\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\nu}\left(C^*_t+I^*_t+K^*_{t-1}\frac{\psi_K}{2}\Big(\frac{I^*_t}{K^*_{t-1}}-\delta\Big)^2\right) \tag{D.31}$$

$$\left[1-\frac{\psi_P}{2}\left(\frac{P_{F,t}}{P_{F,t-1}}-1\right)^2\right]Y_{F,t}=(1-\omega)\left(\frac{P_{F,t}}{P_t}\right)^{-\nu}\left(C_t+I_t+K_{t-1}\frac{\psi_K}{2}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\right) \tag{D.32}$$

$$Y^*_t=Y^*_{F,t}+Y_{F,t} \tag{D.33}$$

Appendix E Equilibrium Equations

The competitive equilibrium $\{\Lambda_{t,t+1}, \Lambda^*_{t,t+1}, R_t, R^*_t, R_{K,t}, R^*_{K,t}, \mathcal{E}_t, \mathcal{E}^H_t, \mathcal{E}^F_t, f_t, L_t, L^*_t, C_t, C^*_t, \Pi_t, \Pi^*_t, \Pi^S_t, p_{H,t}, p^*_{H,t}, p_{F,t}, p^*_{F,t}, T_t, T^*_t, \Omega_{t,t+1}, \Omega^*_{t,t+1}, n_t, n^*_t, x^*_t, \phi_{H,t}, \phi_{X,t}, \phi^*_{F,t}, \phi^*_{H,t}, \nu_{H,t}, \nu_{X,t}, \nu_{N,t}, \nu_t, \mu_t, \nu^*_{F,t}, \nu^*_{H,t}, \nu^*_{X,t}, \nu^*_{N,t}, \nu^*_t, \mu^*_t, K_t, K^*_t, K_{H,t}, K^*_{F,t}, K^*_{H,t}, x_t, tr_t, tr^*_t, Y_t, Y^*_t, Y_{H,t}, Y^*_{H,t}, Y_{F,t}, Y^*_{F,t}, w_t, w^*_t, \tilde{r}_{K,t}, \tilde{r}^*_{K,t}, mc_t, mc^*_t, I_t, I^*_t, q_t, q^*_t, Z_t, Z^*_t, \epsilon_{R,t}, \epsilon^*_{R,t}\}$ are determined by the following equations.

Here, we converted nominal variables into real variables as

$$\mathcal{E}_t \equiv \frac{S_t P_t}{P^*_t} \quad , \quad f_t \equiv \frac{F_t P^*_t}{P_t}$$

$$\Pi_t \equiv \frac{P_t}{P_{t-1}} \quad , \quad \Pi^*_t \equiv \frac{P^*_t}{P^*_{t-1}} \quad , \quad \Pi^S_t \equiv \frac{S_t}{S_{t-1}}$$

$$p_{H,t} \equiv \frac{P_{H,t}}{P_t} \quad , \quad p_{F,t} \equiv \frac{P_{F,t}}{P_t}$$

$$p^*_{H,t} \equiv \frac{P^*_{H,t}}{P^*_t} \quad , \quad p^*_{F,t} \equiv \frac{P^*_{F,t}}{P^*_t}$$

$$n_t \equiv \frac{N_t}{P_t} \quad , \quad n^*_t \equiv \frac{N^*_t}{P^*_t}$$

$$x_t \equiv \frac{X_t}{P_t} \quad , \quad q_t \equiv \frac{Q_t}{P_t} \quad , \quad q^*_t \equiv \frac{Q^*_t}{P^*_t}$$

$$w_t \equiv \frac{W_t}{P_t} \quad , \quad w^*_t \equiv \frac{W^*_t}{P^*_t}$$

$$\tilde{r}_t \equiv \frac{\tilde{R}_t}{P_t} \quad , \quad \tilde{r}^*_t \equiv \frac{\tilde{R}^*_t}{P^*_t}$$

$$mc_t \equiv \frac{MC_t}{P_t} \quad , \quad mc^*_t \equiv \frac{MC^*_t}{P^*_t}$$

$$tr_t \equiv \frac{TR_t}{P_t} \quad , \quad tr^*_t \equiv \frac{TR^*_t}{P^*_t}$$

$$\kappa C_t^{\gamma} L_t^{\varphi} = w_t \tag{E.1}$$

$$\kappa^* C_t^{*\gamma} L_t^{*\varphi} = w_t^* \tag{E.2}$$

$$\Lambda_{t,t+1} = \beta\Big(\frac{C_{t+1}}{C_t}\Big)^{-\gamma}\frac{1}{\Pi_{t+1}} \tag{E.3}$$

$$\mathcal{E}_t = \mathcal{E}_t^H\Big[\frac{\omega + (1-\omega)T_t^{1-\nu}}{\omega T_t^{*1-\nu} + 1 - \omega}\Big]^{\frac{1}{1-\nu}} \tag{E.4}$$

$$\mathcal{E}_T^F = \mathcal{E}_t^H \frac{T_t}{T_t^*} \tag{E.5}$$

$$p_{H,t} = \big[\omega + (1-\omega)T_t^{1-\nu}\big]^{-\frac{1}{1-\nu}} \tag{E.6}$$

$$p_{F,t} = \big[\omega T_t^{-(1-\nu)} + 1 - \omega\big]^{-\frac{1}{1-\nu}} \tag{E.7}$$

$$p_{H,t}^* = \big[\omega T_t^{*1-\nu} + 1 - \omega\big]^{-\frac{1}{1-\nu}} \tag{E.8}$$

$$p_{F,t}^* = \big[\omega + (1-\omega)T_t^{*-(1-\nu)}\big]^{-\frac{1}{1-\nu}} \tag{E.9}$$

$$\Lambda_{t,t+1}^* = \beta\Big(\frac{C_{t+1}^*}{C_t^*}\Big)^{-\gamma}\frac{1}{\Pi_{t+1}^*} \tag{E.10}$$

$$E_t[\Lambda_{t,t+1}]R_t = 1 \tag{E.11}$$

$$E_t[\Lambda_{t,t+1}^*]R_t^* = 1 \tag{E.12}$$

$$R_{K,t} = \frac{\tilde{r}_{K,t} + (1-\delta)q_t}{q_{t-1}}\Pi_t \tag{E.13}$$

$$R_{K,t}^* = \frac{\tilde{r}_{K,t}^* + (1-\delta)q_t^*}{q_{t-1}^*}\Pi_t^* \tag{E.14}$$

$$\Omega_{t,t+1} = \Lambda_{t,t+1}(1 - \sigma + \sigma\nu_{t+1}) \tag{E.15}$$

$$\Omega_{t,t+1}^* = \Lambda_{t,t+1}^*(1 - \sigma + \sigma\nu_{t+1}^*) \tag{E.16}$$

$$\nu_{H,t} = E_t\left[\Omega_{t,t+1}(R_{K,t+1} - R_t)\right] \tag{E.17}$$

$$\nu_{B,t} = E_t\left[\Omega_{t,t+1}\right]\left(R_t^*\frac{1}{\Pi_{t+1}^S} - R_t\right) \tag{E.18}$$

$$\nu_{X,t} = E_t\left[\Omega_{t,t+1}\right]\left(R_t^*\frac{\mathcal{E}_t}{f_t} - R_t\right) \tag{E.19}$$

$$\nu_{N,t} = E_t\left[\Omega_{t,t+1}\right]R_t \tag{E.20}$$

$$\nu_{H,t} = \mu_t(\theta_{H1} + \theta_{H2}q_t K_{H,t}) \tag{E.21}$$

$$\nu_{B,t} = \mu_t(\theta_{B1} + \theta_{B2}b_t) \tag{E.22}$$

$$\nu_{X,t} = \mu_t(\theta_{X1} + \theta_{X2}x_t) \tag{E.23}$$

$$\nu_t = \frac{\nu_{N,t}}{1 - \mu_t} \tag{E.24}$$

$$\phi_{H,t} = \frac{q_t K_{H,t}}{n_t} \tag{E.25}$$

$$\phi_{B,t} = \frac{b_t}{n_t} \tag{E.26}$$

$$\phi_{X,t} = \frac{x_t}{n_t} \tag{E.27}$$

$$\nu_t = \frac{1}{\mu_t}(\nu_{H,t}\phi_{H,t} + \nu_{B,t}\phi_{B,t} + \nu_{X,t}\phi_{X,t}) \tag{E.28}$$

$$\begin{aligned} n_{t+1} = {} & \sigma \left[(R_{K,t+1} - R_t)\phi_{H,t} + \left(R_t^* \frac{1}{\Pi_{t+1}^S} - R_t \right) \phi_{B,t} + \left(R_t^* \frac{\mathcal{E}_t}{f_t} - R_t \right) \phi_{X,t} + R_t \right] \frac{n_t}{\Pi_{t+1}} \\ & + (1-\sigma)\xi(\phi_{H,t} + \phi_{B,t} + \phi_{X,t}) \frac{n_t}{\Pi_{t+1}} \end{aligned} \tag{E.29}$$

$$\nu_{F,t}^* = E_t \left[\Omega_{t,t+1}^* (R_{K,t+1}^* - R_t^*) \right] \tag{E.30}$$

$$\nu_{H,t}^* = E_t \left[\Omega_{t,t+1}^* \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{1}{\Pi_{t+1}^S} \right) \right] \tag{E.31}$$

$$\nu_{X,t}^* = E_t \left[\Omega_{t,t+1}^* \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{\mathcal{E}_t}{f_t} \right) \right] \tag{E.32}$$

$$\nu_{N,t}^* = E_t \left[\Omega_{t,t+1}^* \right] R_t^* \tag{E.33}$$

$$\nu_{F,t}^* = \mu_t^* (\theta_{F1}^* + \theta_{F2}^* q_t^* K_{F,t}^*) \tag{E.34}$$

$$\nu_{H,t}^* = \mu_t^* (\theta_{H1}^* + \theta_{H2}^* \mathcal{E}_t (q_t K_{H,t}^* - x_t^*)) \tag{E.35}$$

$$\nu_{X,t}^* = \mu_t^* (\theta_{X1}^* + \theta_{X2}^* \mathcal{E}_t x_t^*) \tag{E.36}$$

$$\nu_t^* = \frac{\nu_{N,t}^*}{1-\mu_t^*} \tag{E.37}$$

$$\phi_{F,t}^* = \frac{q_t^* K_{F,t}^*}{n_t^*} \tag{E.38}$$

$$\phi_{H,t}^* = \frac{\mathcal{E}_t q_t K_{H,t}^*}{n_t^*} \tag{E.39}$$

$$\phi_{X,t}^* = \frac{\mathcal{E}_t x_t^*}{n_t^*} \tag{E.40}$$

$$\nu_t^* = \frac{1}{\mu_t^*}(\nu_{F,t}^*\phi_{F,t}^* + \nu_{H,t}^*(\phi_{H,t}^* - \phi_{X,t}^*) + \nu_{X,t}^*\phi_{X,t}^*) \tag{E.41}$$

$$\begin{aligned} n_{t+1}^* = {} & \sigma \left[(R_{K,t+1}^* - R_t^*)\phi_{F,t}^* + \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{1}{\Pi_{t+1}^S} \right) (\phi_{H,t}^* - \phi_{X,t}^*) \right. \\ & \left. + \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{\mathcal{E}_t}{f_t} \right) \phi_{X,t}^* + R_t^* \right] \frac{n_t^*}{\Pi_{t+1}^*} + (1-\sigma)\xi^*(\phi_{F,t}^* + \phi_{H,t}^*) \frac{n_t^*}{\Pi_{t+1}^*} \end{aligned} \tag{E.42}$$

$$K_t = I_t + (1-\delta)K_{t-1} \tag{E.43}$$

$$K_t^* = I_t^* + (1-\delta)K_{t-1}^* \tag{E.44}$$

$$q_t = 1 + \psi_K\Big(\frac{I_t}{K_{t-1}} - \delta\Big) - E_t\Big[\Lambda_{t,t+1}\Pi_{t+1}\psi_K\Big(\frac{I_{t+1}}{K_t} - \delta\Big)\frac{I_{t+1}}{K_t}\Big] \tag{E.45}$$

$$q_t^* = 1 + \psi_K\big(\frac{I_t^*}{K_{t-1}^*} - \delta\big) - E_t\Big[\Lambda_{t,t+1}^*\Pi_{t+1}^*\psi_K\Big(\frac{I_{t+1}^*}{K_t^*} - \delta\Big)\frac{I_{t+1}^*}{K_t^*}\Big] \tag{E.46}$$

$$w_t = (1-\alpha)mc_t\frac{Y_t}{L_t} \tag{E.47}$$

$$\tilde{r}_{K,t} = \alpha mc_t\frac{Y_t}{K_{t-1}} \tag{E.48}$$

$$mc_t = \frac{1}{Z_t}\frac{w_t^{1-\alpha}\tilde{r}_{K,t}^{\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}} \tag{E.49}$$

$$w_t^* = (1-\alpha)mc_t^*\frac{Y_t^*}{L_t^*} \tag{E.50}$$

$$\tilde{r}_{K,t}^* = \alpha mc_t^*\frac{Y_t^*}{K_{t-1}^*} \tag{E.51}$$

$$mc_t^* = \frac{1}{Z_t^*}\frac{w_t^{*1-\alpha}\tilde{r}_{K,t}^{*\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}} \tag{E.52}$$

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R}\Pi_t^{\phi_\pi(1-\rho_R)}\epsilon_{R,t} \tag{E.53}$$

$$\frac{R_t^*}{\bar{R}^*} = \left(\frac{R_{t-1}^*}{\bar{R}^*}\right)^{\rho_R}\Pi_t^{*\phi_\pi(1-\rho_R)}\epsilon_{R,t}^* \tag{E.54}$$

$$tr_t + s\left(p_{H,t}Y_{H,t} + \frac{1}{\mathcal{E}_t}p_{H,t}^*Y_{H,t}^*\right) = 0 \tag{E.55}$$

$$tr_t^* + s^*(p_{F,t}^*Y_{F,t}^* + \mathcal{E}_t p_{F,t}Y_{F,t}) = 0 \tag{E.56}$$

$$\begin{aligned}(1+s)(\epsilon-1) &= \epsilon\frac{mc_t}{p_{H,t}} - \psi_P\Big(\frac{p_{H,t}}{p_{H,t-1}}\Pi_t - 1\Big)\frac{p_{H,t}}{p_{H,t-1}}\Pi_t \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\Big(\frac{p_{H,t+1}}{p_{H,t}}\Pi_{t+1} - 1\Big)\Big(\frac{p_{H,t+1}}{p_{H,t}}\Pi_{t+1}\Big)^2\Big(\frac{Y_{H,t+1}}{Y_{H,t}}\Big)\right]\end{aligned} \tag{E.57}$$

$$\begin{aligned}(1+s)(\epsilon-1) &= \epsilon\frac{\mathcal{E}_t mc_t}{p_{H,t}^*} - \psi_P\Big(\frac{p_{H,t}^*}{p_{H,t-1}^*}\Pi_t^* - 1\Big)\frac{p_{H,t}^*}{p_{H,t-1}^*}\Pi_t^* \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\Big(\frac{p_{H,t+1}^*}{p_{H,t}^*}\Pi_{t+1}^* - 1\Big)\Big(\frac{p_{H,t+1}^*}{p_{H,t}^*}\Pi_{t+1}^*\Big)^2\Big(\frac{1}{\Pi_{t+1}^S}\Big)\Big(\frac{Y_{H,t+1}^*}{Y_{H,t}^*}\Big)\right]\end{aligned} \tag{E.58}$$

$$\begin{aligned}(1+s^*)(\epsilon-1) &= \epsilon\frac{mc_t^*}{p_{F,t}^*} - \psi_P\Big(\frac{p_{F,t}^*}{p_{F,t-1}^*}\Pi_t^* - 1\Big)\frac{p_{F,t}^*}{p_{F,t-1}^*}\Pi_t^* \\ &+ E_t\left[\Lambda_{t,t+1}^*\psi_P\Big(\frac{p_{F,t+1}^*}{p_{F,t}^*}\Pi_{t+1}^* - 1\Big)\Big(\frac{p_{F,t+1}^*}{p_{F,t}^*}\Pi_{t+1}^*\Big)^2\Big(\frac{Y_{F,t+1}^*}{Y_{F,t}^*}\Big)\right]\end{aligned} \tag{E.59}$$

$$\begin{aligned}(1+s^*)(\epsilon-1) &= \epsilon\frac{mc_t^*}{\mathcal{E}_t p_{F,t}} - \psi_P\Big(\frac{p_{F,t}}{p_{F,t-1}}\Pi_t - 1\Big)\frac{p_{F,t}}{p_{F,t-1}}\Pi_t \\ &+ E_t\left[\Lambda_{t,t+1}^*\psi_P\Big(\frac{p_{F,t+1}}{p_{F,t}}\Pi_{t+1} - 1\Big)\Big(\frac{p_{F,t+1}}{p_{F,t}}\Pi_{t+1}\Big)^2\Pi_{t+1}^S\Big(\frac{Y_{F,t+1}}{Y_{F,t}}\Big)\right]\end{aligned} \tag{E.60}$$

$$\left[1-\frac{\psi_P}{2}\Big(\frac{p_{H,t}}{p_{H,t-1}}\Pi_t-1\Big)^2\right]Y_{H,t}=\omega p_{H,t}^{-\nu}\Big(C_t+I_t+\frac{\psi_K}{2}K_{t-1}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\Big) \tag{E.61}$$

$$\left[1-\frac{\psi_P}{2}\Big(\frac{p^*_{H,t}}{p^*_{H,t-1}}\Pi^*_t-1\Big)^2\right]Y^*_{H,t}=(1-\omega)p_{H,t}^{*-\nu}\Big(C^*_t+I^*_t+\frac{\psi_K}{2}K^*_{t-1}\Big(\frac{I^*_t}{K^*_{t-1}}-\delta\Big)^2\Big) \tag{E.62}$$

$$Y_t=Y_{H,t}+Y^*_{H,t} \tag{E.63}$$

$$\left[1-\frac{\psi_P}{2}\Big(\frac{p^*_{F,t}}{p^*_{F,t-1}}\Pi^*_t-1\Big)^2\right]Y^*_{F,t}=\omega p_{F,t}^{*-\nu}\Big(C^*_t+I^*_t+\frac{\psi_K}{2}K^*_{t-1}\Big(\frac{I^*_t}{K^*_{t-1}}-\delta\Big)^2\Big) \tag{E.64}$$

$$\left[1-\frac{\psi_P}{2}\Big(\frac{p_{F,t}}{p_{F,t-1}}\Pi_t-1\Big)^2\right]Y_{F,t}=(1-\omega)p_{F,t}^{-\nu}\Big(C_t+I_t+\frac{\psi_K}{2}K_{t-1}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\Big) \tag{E.65}$$

$$Y^*_t=Y_{F,t}+Y^*_{F,t} \tag{E.66}$$

$$x_t=x^*_t \tag{E.67}$$

$$K_t=K_{H,t}+K^*_{H,t} \tag{E.68}$$

$$K^*_t=K^*_{F,t} \tag{E.69}$$

$$\begin{aligned}&p_{H,t}Y_{H,t}\left[1-\frac{\psi_P}{2}\left(\frac{p_{H,t}}{p_{H,t-1}}\Pi_t-1\right)^2\right]+\frac{1}{\mathcal{E}_t}p^*_{H,t}Y^*_{H,t}\left[1-\frac{\psi_P}{2}\left(\frac{p^*_{H,t}}{p^*_{H,t-1}}\Pi^*_t-1\right)^2\right]\\&-\left(C_t+I_t+\frac{\psi_K}{2}K_{t-1}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\right)+\left(R^*_{t-1}\frac{1}{\Pi^S_t}-1\right)\frac{b_{t-1}}{\Pi_t}+\left(R^*_{t-1}\frac{\mathcal{E}_{t-1}}{f_{t-1}}-1\right)\frac{x_{t-1}}{\Pi_t}\\&-(R_{K,t}-1)\frac{q_{t-1}K^*_{H,t-1}}{\Pi_t}=(b_t+x_t-q_tK^*_{H,t})-\frac{(b_{t-1}+x_{t-1}-q_{t-1}K^*_{H,t-1})}{\Pi_t}\end{aligned} \tag{E.70}$$

$$\mathcal{E}_t=\mathcal{E}_{t-1}\frac{\Pi^S_t\Pi_t}{\Pi^*_t} \tag{E.71}$$

$$\log Z_t=\rho_z\log Z_{t-1}+\sigma_z\epsilon_{zt} \tag{E.72}$$

$$\log Z^*_t=\rho^*_z\log Z^*_{t-1}+\sigma^*_z\epsilon^*_{zt} \tag{E.73}$$

$$\log\epsilon_{R,t}=\rho_m\log\epsilon_{R,t-1}+\epsilon_{m,t} \tag{E.74}$$

$$\log\epsilon^*_{R,t}=\rho_m\log\epsilon^*_{R,t-1}+\epsilon^*_{m,t} \tag{E.75}$$

Appendix F Steady-states

Steady-state variables are denoted as the ones without time subscript. In the steady-state with zero inflation and depreciation rate, equilibrium equations are

$$\kappa C^{\gamma} L^{\varphi} = w \tag{F.1}$$

$$\kappa^* C^{*\gamma} L^{*\varphi} = w^* \tag{F.2}$$

$$\Lambda = \beta \tag{F.3}$$

$$\mathcal{E} = \mathcal{E}_H \Big[\frac{\omega + (1-\omega)T^{1-\nu}}{\omega T^{*1-\nu} + 1 - \omega}\Big]^{\frac{1}{1-\nu}} \tag{F.4}$$

$$\mathcal{E}_F = \mathcal{E}_H \frac{T}{T^*} \tag{F.5}$$

$$p_H = \big[\omega + (1-\omega)T^{1-\nu}\big]^{-\frac{1}{1-\nu}} \tag{F.6}$$

$$p_F = \big[\omega T^{-(1-\nu)} + 1 - \omega\big]^{-\frac{1}{1-\nu}} \tag{F.7}$$

$$p_H^* = \big[\omega T^{*1-\nu} + 1 - \omega\big]^{-\frac{1}{1-\nu}} \tag{F.8}$$

$$p_F^* = \big[\omega + (1-\omega)T^{*-(1-\nu)}\big]^{-\frac{1}{1-\nu}} \tag{F.9}$$

$$\Lambda^* = \beta \tag{F.10}$$

$$\Lambda R = 1 \tag{F.11}$$

$$\Lambda^* R^* = 1 \tag{F.12}$$

$$R_K = \frac{\tilde{r}_K + (1-\delta)q}{q} \tag{F.13}$$

$$R_K^* = \frac{\tilde{r}_K^* + (1-\delta)q^*}{q^*} \tag{F.14}$$

$$\Omega = \Lambda(1 - \sigma + \sigma\nu) \tag{F.15}$$

$$\Omega^* = \Lambda^*(1 - \sigma + \sigma\nu^*) \tag{F.16}$$

$$\nu_H = \Omega(R_K - R) \tag{F.17}$$

$$\nu_B = 0 \tag{F.18}$$

$$\nu_X = \Omega\left(R^* \frac{\mathcal{E}}{f} - R\right) \tag{F.19}$$

$$\nu_N = \Omega R \tag{F.20}$$

$$\nu_H = \mu(\theta_{H1} + \theta_{H2} q K_H) \tag{F.21}$$

$$\nu_B = \mu(\theta_{X1} + \theta_{X2} b) \tag{F.22}$$

$$\nu_X = \mu(\theta_{X1} + \theta_{X2} x) \tag{F.23}$$

$$\nu = \frac{\nu_N}{1-\mu} \tag{F.24}$$

$$\phi_H = \frac{qK_H}{n} \tag{F.25}$$

$$\phi_B = \frac{b}{n} \tag{F.26}$$

$$\phi_X = \frac{x}{n} \tag{F.27}$$

$$\nu = \frac{1}{\mu}(\nu_H\phi_H + \nu_B\phi_B + \nu_X\phi_X) \tag{F.28}$$

$$n = \sigma\left[(R_K - R)\phi_H + (R^* - R)\,\phi_B + \left(R^*\frac{\mathcal{E}}{f} - R\right)\phi_X + R\right]n + (1-\sigma)\xi(\phi_H + \phi_B + \phi_X)n \tag{F.29}$$

$$\nu_F^* = \Omega^*(R_K^* - R^*) \tag{F.30}$$

$$\nu_H^* = \Omega^*(R_K - R^*) \tag{F.31}$$

$$\nu_X^* = \Omega^*\left(R_K - R^*\frac{\mathcal{E}}{f}\right) \tag{F.32}$$

$$\nu_N^* = \Omega^* R^* \tag{F.33}$$

$$\nu_F^* = \mu^*(\theta_{F1}^* + \theta_{F2}^* q^* K_F^*) \tag{F.34}$$

$$\nu_H^* = \mu^*(\theta_{H1}^* + \theta_{H2}^*\mathcal{E}(qK_H^* - x^*)) \tag{F.35}$$

$$\nu_X^* = \mu^*(\theta_{X1}^* + \theta_{X2}^*\mathcal{E}x^*) \tag{F.36}$$

$$\nu^* = \frac{\nu_N^*}{1-\mu^*} \tag{F.37}$$

$$\phi_F^* = \frac{q^*K_F^*}{n^*} \tag{F.38}$$

$$\phi_H^* = \frac{\mathcal{E}qK_H^*}{n^*} \tag{F.39}$$

$$\phi_X^* = \frac{\mathcal{E}x^*}{n^*} \tag{F.40}$$

$$\nu^* = \frac{1}{\mu^*}(\nu_F^*\phi_F^* + \nu_H^*(\phi_H^* - \phi_X^*) + \nu_X^*\phi_X^*) \tag{F.41}$$

$$n^* = \sigma\left[(R_K^* - R^*)\phi_F^* + (R_K - R^*)(\phi_H^* - \phi_X^*) + \left(R_K - R^*\frac{\mathcal{E}}{f}\right)\phi_X^* + R^*\right]n^*$$
$$+ (1-\sigma)\xi(\phi_F^* + \phi_H^*)n^* \tag{F.42}$$

$$I = \delta K \tag{F.43}$$

$$I^* = \delta K^* \tag{F.44}$$

$$q = 1 \tag{F.45}$$

$$q^* = 1 \tag{F.46}$$

$$w = (1-\alpha)mc\frac{Y}{L} \tag{F.47}$$

$$\tilde{r}_K = \alpha mc\frac{Y}{K} \tag{F.48}$$

$$mc = \frac{w^{1-\alpha}\tilde{r}_K^{\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}} \tag{F.49}$$

$$w^* = (1-\alpha)mc^*\frac{Y^*}{L^*} \tag{F.50}$$

$$\tilde{r}_K^* = \alpha mc^*\frac{Y^*}{K^*} \tag{F.51}$$

$$mc^* = \frac{w^{*1-\alpha}\tilde{r}_K^{*\alpha}}{(1-\alpha)^{1-\alpha}\alpha^\alpha} \tag{F.52}$$

$$R = \bar{R} \tag{F.53}$$

$$R^* = \bar{R}^* \tag{F.54}$$

$$tr + s\left(p_H Y_H + \frac{1}{\mathcal{E}}p_H^* Y_H^*\right) = 0 \tag{F.55}$$

$$tr^* + s^*(p_F^* Y_F^* + \mathcal{E}p_F Y_F) = 0 \tag{F.56}$$

$$(1+s)(\epsilon-1) = \epsilon\frac{mc}{p_H} \tag{F.57}$$

$$(1+s)(\epsilon-1) = \epsilon\frac{\mathcal{E}mc}{p_H^*} \tag{F.58}$$

$$(1+s^*)(\epsilon-1) = \epsilon\frac{mc^*}{p_F^*} \tag{F.59}$$

$$(1+s^*)(\epsilon-1) = \epsilon\frac{mc^*}{\mathcal{E}p_F} \tag{F.60}$$

$$Y_H = \omega p_H^{-\nu}(C+I) \tag{F.61}$$

$$Y_H^* = (1-\omega)p_H^{*-\nu}(C^*+I^*) \tag{F.62}$$

$$Y = Y_H + Y_H^* \tag{F.63}$$

$$Y_F^* = \omega p_F^{*-\nu}(C^*+I^*) \tag{F.64}$$

$$Y_F = (1-\omega)p_F^{-\nu}(C+I) \tag{F.65}$$

$$Y^* = Y_F + Y_F^* \tag{F.66}$$

$$x = x^* \tag{F.67}$$

$$K = K_H + K_H^* \tag{F.68}$$

$$K^* = K_F^* \tag{F.69}$$

$$p_H Y_H + \frac{1}{\mathcal{E}}p_H^* Y_H^* - C - I + (R^*-1)b + \left(R^*\frac{\mathcal{E}}{f} - 1\right)x - (R_K-1)qK_H^* = 0 \tag{F.70}$$

First, discount factor β is calibrated as 0.995 to match yearly risk-free rate 2%. Then,

$$\Lambda = \Lambda^* = \beta$$
$$R = R^* = \frac{1}{\beta}$$

Steady-state labor L and L^* are assumed to be 1/3.

Next, in order to calibrate θ_{H1}, θ_{X1}, θ_{F1}^*, θ_{H1}^*, and θ_{X1}^*, we target the following five (yearly) empirical moments:

- Excess return on US capital: 200bp
- Excess return on non-US capital: 200bp
- CIP deviation for post-GFC periods: -30bp
- Domestic investment share : 0.54
- US NFA-to-GDP ratio: -0.185

From the first two empirical moments,

$$R_K = R + 0.02/4$$
$$R_K^* = R^* + 0.02/4$$

From the definition of gross return rate on capital (F.13) and (F.14)

$$\tilde{r}_K = R_K - (1-\delta)$$
$$\tilde{r}_K^* = R_K^* - (1-\delta)$$

The steady-state CIP deviation pins down the forward premium $f/\mathcal{E} = R^*/(R + 0.0030/4)$.

Building on the above steady-state values, we solve for the steady-state terms-of-trade T. (F.6) - (F.9) show that price variables are functions of T. Also, the spot exchange rate $\mathcal{E}$ is expressed in terms of T in (F.4). Since the subsidy s and s^* are imposed to get rid of steady-state markup, $mc = p_H$ and $mc^* = p_F^*$, which are also functions of T. Then, from (F.47) - (F.49) and (F.50) - (F.52), we can derive K and K^* as functions of T:

$$K = \left[\alpha \frac{L^{1-\alpha}}{\tilde{r}_K} mc\right]^{\frac{1}{1-\alpha}}$$
$$K^* = \left[\alpha \frac{L^{*1-\alpha}}{\tilde{r}_K^*} mc^*\right]^{\frac{1}{1-\alpha}}$$

This implies that Y and Y^* are also functions of T, and $I = \delta K$ and $I^* = \delta K^*$ can be expressed in terms of T. From the fourth empirical moment, the share of non-US banks' domestic capital holdings (in value) to the total capital holdings is

$$\frac{q^* K_F^*}{q^* K_F^* + \mathcal{E} q K_H^*} = 0.54$$

Since $q = q^* = 1$ and $K_F^* = K^*$,

$$K_H^* = \frac{1 - 0.54}{0.54} \frac{K^*}{\mathcal{E}}$$

Finally, since the US real NFA in this model is $b + x - qK_H^*$, the final bullet point of the five empirical moments implies

$$b + x = qK_F^* - 0.439 * 4 * p_H * Y$$

Then, the balance of payment equation (F.70) implies that C is also a function of T as

$$C = p_H Y - I - (R_k - 1)q(1 - x^*)K_H^* - \left\{ R_k - \left(R^* + 1 - \frac{f}{\mathcal{E}} \right) \right\} x$$

Combining (F.63) with resource constraints (F.61) and (F.62),

$$C^* = \frac{Y - \omega p_H^{-\nu}(C + I)}{(1 - \omega) p_H^{*-\nu}} - I^*$$

which is also a function of T. Then, T can be solved from

$$Y^* = \omega p_F^{*-\nu}(C^* + I^*) + (1 - \omega) p_F^{-\nu}(C + I)$$

since both the LHS and the RHS are functions of T.

Y_H, Y_H^*, Y_F^*, and Y_F are directly calculated from (F.61), (F.62), (F.64), and (F.65). The steady-state real forward exchange rate is

$$f = \frac{f}{\mathcal{E}} \cdot \mathcal{E}$$

Real wage w and w^* are obtained from (F.47) and (F.50) while κ and κ^* are calibrated as

$$\kappa = \frac{w}{C^\gamma L^\varphi}$$
$$\kappa^* = \frac{w^*}{C^{*\gamma} L^{*\varphi}}$$

Regarding the government side, government transfers tr and tr^* are derived from (F.55) and (F.56) as

$$tr = -s \cdot p_H(Y_H + Y_H^*)$$
$$tr^* = -s^* \cdot p_F^*(Y_F^* + Y_F)$$

σ is calibrated as 0.95 to match banks' expected operation horizon of 5 years. Let us target the aggregate leverage ratio of US and non-US bank of 5 to calibrate ξ. Then,

$$n = \frac{qK_H + x}{5}$$
$$n^* = \frac{q^* K_F^* + \mathcal{E} q K_H^*}{5}$$

We can then derive the steady-state ratio of each asset to net worth as

$$\phi_H = \frac{qK_H}{n}$$
$$\phi_X = \frac{x}{n}$$
$$\phi_F^* = \frac{q^* K_F^*}{n^*}$$
$$\phi_H^* = \frac{\mathcal{E} q K_H^*}{n^*}$$

From the law of motions for aggregate net worth (F.29) and (F.42),

$$\xi = \frac{1 - \sigma \left[(R_K - R)\, \phi_H + \left\{ R^* - \left(R + \frac{f}{\mathcal{E}} - 1 \right) \right\} \phi_X + R \right]}{(1-\sigma)(\phi_H + \phi_X)}$$
$$\xi^* = \frac{1 - \sigma \left[(R_K^* - R^*)\, \phi_F^* + (R_K - R^*)(1 - x^*)\phi_H^* + \left\{ R_K - \left(R^* + 1 - \frac{f}{\mathcal{E}} \right) \right\} x^* \phi_H^* + R^* \right]}{(1-\sigma)(\phi_F^* + \phi_H^*)}$$

(F.17), (F.19), and (F.20) imply that marginal values of b_H, x and net worth are functions of the US bank's SDF Ω. Plugging these into (F.20) and (F.28), we can obtain the steady-state μ as

$$\mu = \frac{(R_k - R)\, \phi_H + \left\{ R^* - \left(R + \frac{f}{\mathcal{E}} - 1 \right) \right\} \phi_X}{(R_k - R)\, \phi_H + \left\{ R^* - \left(R + \frac{f}{\mathcal{E}} - 1 \right) \right\} \phi_X + R}$$

Similarly, since (F.30), (F.31), (F.32) are functions of Ω^*, (F.37) and (F.41) yield

$$\mu^* = \frac{(R_k^* - R^*)\, \phi_F^* + (R_k - R^*)(1 - x^*)\phi_H^* + \left\{ R_k - \left(R^* + 1 - \frac{f}{\mathcal{E}} \right) \right\} x^* \phi_H^*}{\left(R_k^* - R^* \right) \phi_F^* + (R_k - R^*)(1 - x^*)\phi_H^* + \left\{ R_k - \left(R^* + 1 - \frac{f}{\mathcal{E}} \right) \right\} x^* \phi_H^* + R^*}$$

(F.15) and (F.16) suggest that Ω is a function of ν while Ω^* is a function of ν^*. From (F.29) and

(F.42),

$$\nu = \frac{1-\sigma}{1-\sigma-\mu}$$
$$\nu^* = \frac{1-\sigma}{1-\sigma-\mu^*}$$

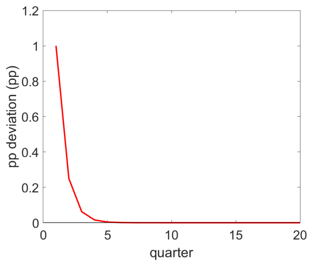
Here, $\mu < 1-\sigma$ and $\mu^* < 1-\sigma$ should hold for ν and ν^* to be strictly positive, which holds in this model's calibration. Since we know ν and ν^*, Ω and Ω^* can also be calculated. Then US banks' marginal values ν_H, ν_X, and ν_N are derived from (F.17)-(F.20). Also, ν_F^*, ν_H^*, ν_X^*, and ν_N^* follow directly from (F.30)-(F.33).

Finally, we calibrate the financial friction parameters. Quadratic parameters θ_{H2}, θ_{X2}, θ_{F2}^*, θ_{H2}^*, and θ_{X2}^* are introduced to guarantee stationarity of this model. These parameters are set as 0.005 following Devereux, Engel, and Wu (2023). Then, θ_{H1}, θ_{X1}, θ_{F1}^*, θ_{H1}^*, and θ_{X1}^* are calibrated as

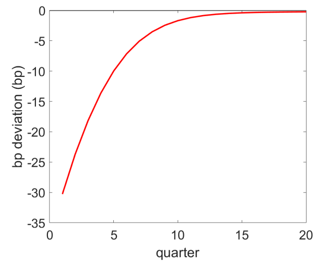
$$\theta_{H1} = \frac{\nu_H}{\mu} - \theta_{H2} q K_H$$
$$\theta_{X1} = \frac{\nu_X}{\mu} - \theta_{X2} x$$
$$\theta_{F1}^* = \frac{\nu_F^*}{\mu^*} - \theta_{F2}^* q^* K_F^*$$
$$\theta_{H1}^* = \frac{\nu_H^*}{\mu^*} - \theta_{H2}^* (1-x^*) \mathcal{E} q K_H^*$$
$$\theta_{X1}^* = \frac{\nu_X^*}{\mu^*} - \theta_{X2}^* x^* \mathcal{E} q K_H^*$$

Appendix G Impulse Responses

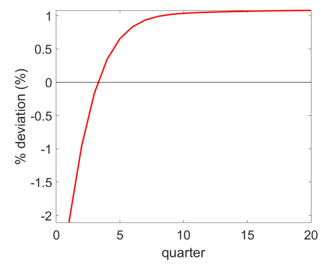
In this section, impulse responses of all variables are presented.



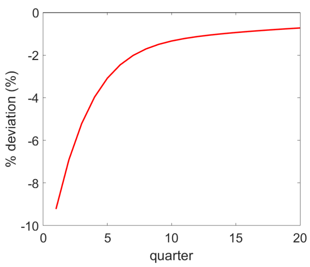
(a) US MP Shock



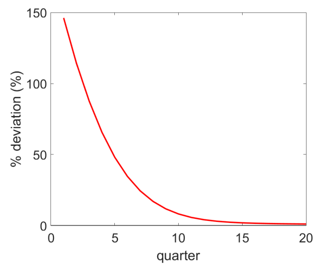
(b) CIP Deviation



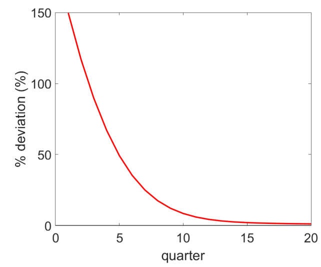
(c) US Bank Net Worth



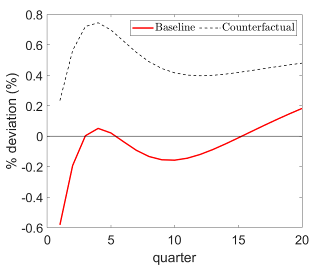
(d) Non-US Bank Net Worth



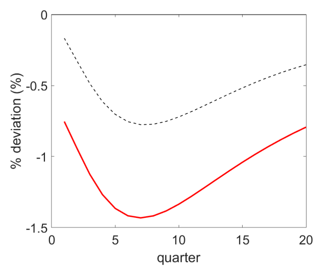
(e) US Lagrangian Multiplier



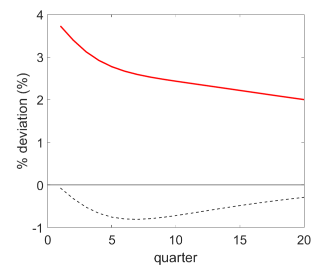
(f) Non-US Lagrangian Multiplier



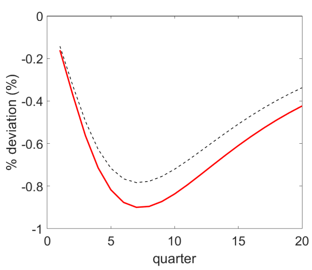
(g) Synthetic Dollar Funding



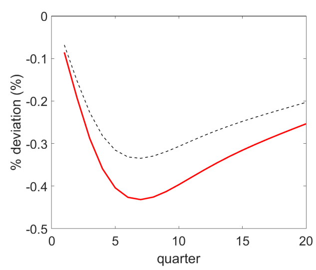
(h) Non-US's US Capital Holding



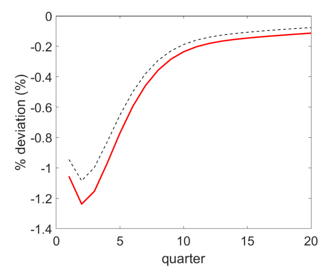
(i) US's US Capital Holding



(j) US Aggregate Capital

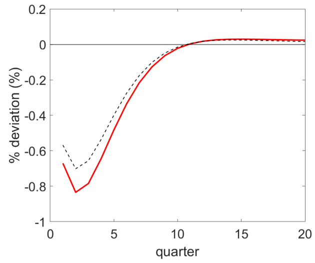


(k) Non-US Aggregate Capital

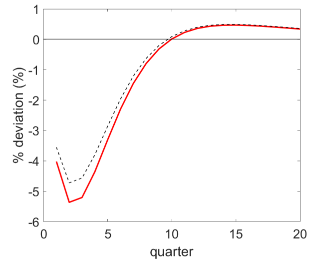


(l) US Output

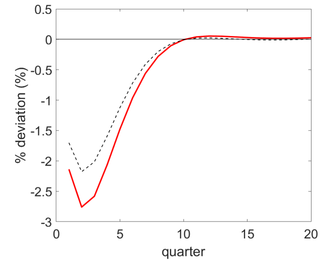
Figure G.1: Impulse Responses to Contractionary US Monetary Policy Shock



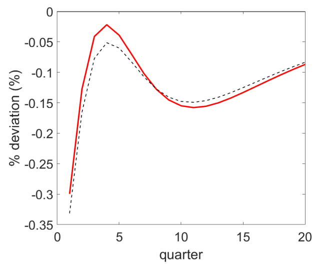
(m) Non-US Output



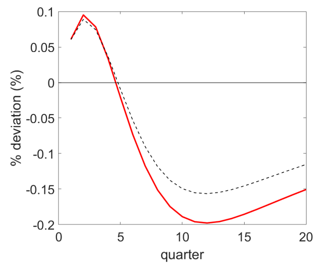
(n) US Investment



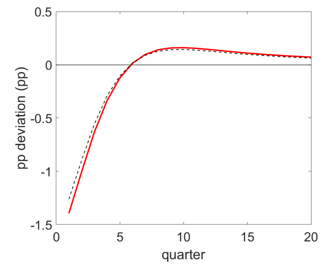
(o) Non-US Investment



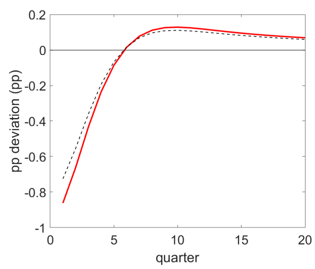
(p) US Consumption



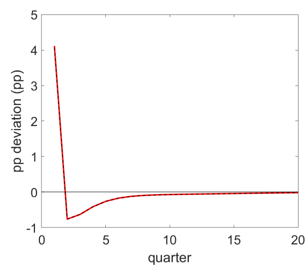
(q) Non-US Consumption



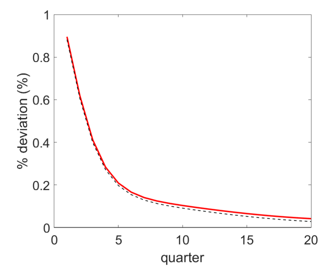
(r) US Inflation



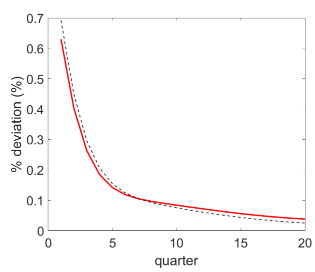
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

Figure G.1: 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. In each panel, red 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 black dotted lines.

Appendix H Alternative Currency Pricing Paradigm

In this section, we look at implications of alternative currency pricing paradigm other than the local currency pricing. All things except the currency in which prices chosen by firms are denominated and sticky are assumed to be the same as the baseline model. Thus, things that are not mentioned here are maintained as the baseline model.

H.1 Producer Currency Pricing

By the assumption of producer currency pricing (PCP), US wholesalers purchase $Y_{H,t}(j)$ and $Y^*_{H,t}(j)$ at the price of $P_{H,t}(j)$ denominated in USD from US firms, and sell to retailers at $P_{H,t}$ and $P^*_{H,t}$ respectively. $P^*_{H,t}$ is denominated in Euro, so the price of exported goods in terms of USD is $P^*_{H,t}/S_t$ for the nominal spot exchange rate S_t. Then, the profit maximization problems of domestic and export wholesalers yield the following demand functions for each variety as

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

where the price indices of domestic and exported goods are

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

This implies that $P^*_{H,t} = S_t P_{H,t}$, *i.e.* the law of one price holds between the domestic price and the export price. Hence, the demand functions for domestic and exported varieties become

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} Y_{H,t} \tag{H.1}$$
$$Y^*_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} Y^*_{H,t} \tag{H.2}$$

Similarly, non-US wholesalers purchase $Y^*_{F,t}(j)$ and $Y_{F,t}(j)$ at the price of $P^*_{F,t}(j)$ denominated in Euro while they are sold at $P^*_{F,t}$ and $P_{F,t}$ respectively. Then, the demand functions for domestically-spent and exported varieties become

$$Y^*_{F,t}(j) = \left(\frac{P^*_{F,t}(j)}{P^*_{F,t}}\right)^{-\epsilon} Y^*_{F,t} \tag{H.3}$$

$$Y_{F,t}(j) = \left(\frac{P^*_{F,t}(j)}{P^*_{F,t}}\right)^{-\epsilon} Y_{F,t} \tag{H.4}$$

using the law of one price $P^*_{F,t} = S_t P_{F,t}$.

Both the prices of domestically-sold and exported US goods are denominated and sticky in USD due to the assumption of PCP. Then, US firm j 's periodic profit $\Pi^P_t(j)$ is given by

$$\Pi^P_t(j) = (1+s)P_{H,t}(j)(Y_{H,t}(j) + Y^*_{H,t}(j)) - TC_t(j) - \frac{\psi_P}{2}\left(\frac{P_{H,t}(j)}{P_{H,t-1}(j)} - 1\right)^2 P_{H,t}(Y_{H,t} + Y^*_{H,t})$$

From (H.1) and (H.2), we know that

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

Hence, we can solve the firm j's life-time profit maximization problem from the period t

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

which yields the first-order condition as

$$\begin{aligned}(1+s)(\epsilon-1) = \epsilon\frac{MC_t}{P_{H,t}} &- \psi_P\left(\frac{P_{H,t}}{P_{H,t-1}} - 1\right)\frac{P_{H,t}}{P_{H,t-1}} \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\left(\frac{P_{H,t+1}}{P_{H,t}} - 1\right)\left(\frac{P_{H,t+1}}{P_{H,t}}\right)^2\left(\frac{Y_{H,t+1} + Y^*_{H,t+1}}{Y_{H,t} + Y^*_{H,t}}\right)\right]\end{aligned} \tag{H.5}$$

By the same way, non-US firm j's periodic profit $\Pi^{P*}_t(j)$ is

$$\Pi^{P*}_t(j) = (1+s^*)P^*_{F,t}(j)(Y^*_{F,t}(j) + Y_{F,t}(j)) - TC^*_t(j) - \frac{\psi_P}{2}\left(\frac{P^*_{F,t}(j)}{P^*_{F,t-1}(j)} - 1\right)^2 P^*_{F,t}(Y^*_{F,t} + Y_{F,t})$$

where $P^*_{F,t}(j)$ is the Euro-denominated price chosen by the firm. Since (H.3) and (H.4) imply

$$Y^*_{F,t}(j) + Y_{F,t}(j) = \left(\frac{P^*_{F,t}(j)}{P^*_{F,t}}\right)^{-\epsilon}(Y^*_{F,t} + Y_{F,t})$$

firm j's life-time profit maximization problem defined as

$$\max_{\{P^*_{F,t+s}(j)\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \Lambda^*_{t,t+s} \Pi^{P*}_{t+s}(j)$$

yields the following first-order condition:

$$\begin{aligned}(1+s^*)(\epsilon-1) = \epsilon \frac{MC^*_t}{P^*_{F,t}} - \psi_P \left(\frac{P^*_{F,t}}{P^*_{F,t-1}} - 1 \right) \frac{P^*_{F,t}}{P^*_{F,t-1}} \\ + E_t \left[\Lambda^*_{t,t+1} \psi_P \left(\frac{P^*_{F,t+1}}{P^*_{F,t}} - 1 \right) \left(\frac{P^*_{F,t+1}}{P^*_{F,t}} \right)^2 \left(\frac{Y^*_{F,t+1} + Y_{F,t+1}}{Y^*_{F,t} + Y_{F,t}} \right) \right] \end{aligned} \tag{H.6}$$

Since the law of one price holds, $T_t = T^*_t$ and $\mathcal{E}^H_t = \mathcal{E}^F_t = 1$. Hence, the real exchange rate $\mathcal{E}_t$ is

$$\mathcal{E}_t = \left[\frac{\omega + (1-\omega) T_t^{1-\nu}}{\omega T_t^{1-\nu} + 1 - \omega} \right]^{\frac{1}{1-\nu}} \tag{H.7}$$

The resource constraints for $Y_{H,t}$, $Y^*_{H,t}$, $Y^*_{F,t}$, and $Y_{F,t}$ are derived as

$$\left[1 - \frac{\psi_P}{2} \left(\frac{P_{H,t}}{P_{H,t-1}} - 1 \right)^2 \right] Y_{H,t} = \omega \left(\frac{P_{H,t}}{P_t} \right)^{-\nu} \left(C_t + I_t + K_{t-1} \frac{\psi_K}{2} \Big(\frac{I_t}{K_{t-1}} - \delta \Big)^2 \right) \tag{H.8}$$

$$\left[1 - \frac{\psi_P}{2} \left(\frac{P_{H,t}}{P_{H,t-1}} - 1 \right)^2 \right] Y^*_{H,t} = (1-\omega) \left(\frac{P^*_{H,t}}{P^*_t} \right)^{-\nu} \left(C^*_t + I^*_t + K^*_{t-1} \frac{\psi_K}{2} \Big(\frac{I^*_t}{K^*_{t-1}} - \delta \Big)^2 \right) \tag{H.9}$$

$$\left[1 - \frac{\psi_P}{2} \left(\frac{P^*_{F,t}}{P^*_{F,t-1}} - 1 \right)^2 \right] Y^*_{F,t} = \omega \left(\frac{P^*_{F,t}}{P^*_t} \right)^{-\nu} \left(C^*_t + I^*_t + K^*_{t-1} \frac{\psi_K}{2} \Big(\frac{I^*_t}{K^*_{t-1}} - \delta \Big)^2 \right) \tag{H.10}$$

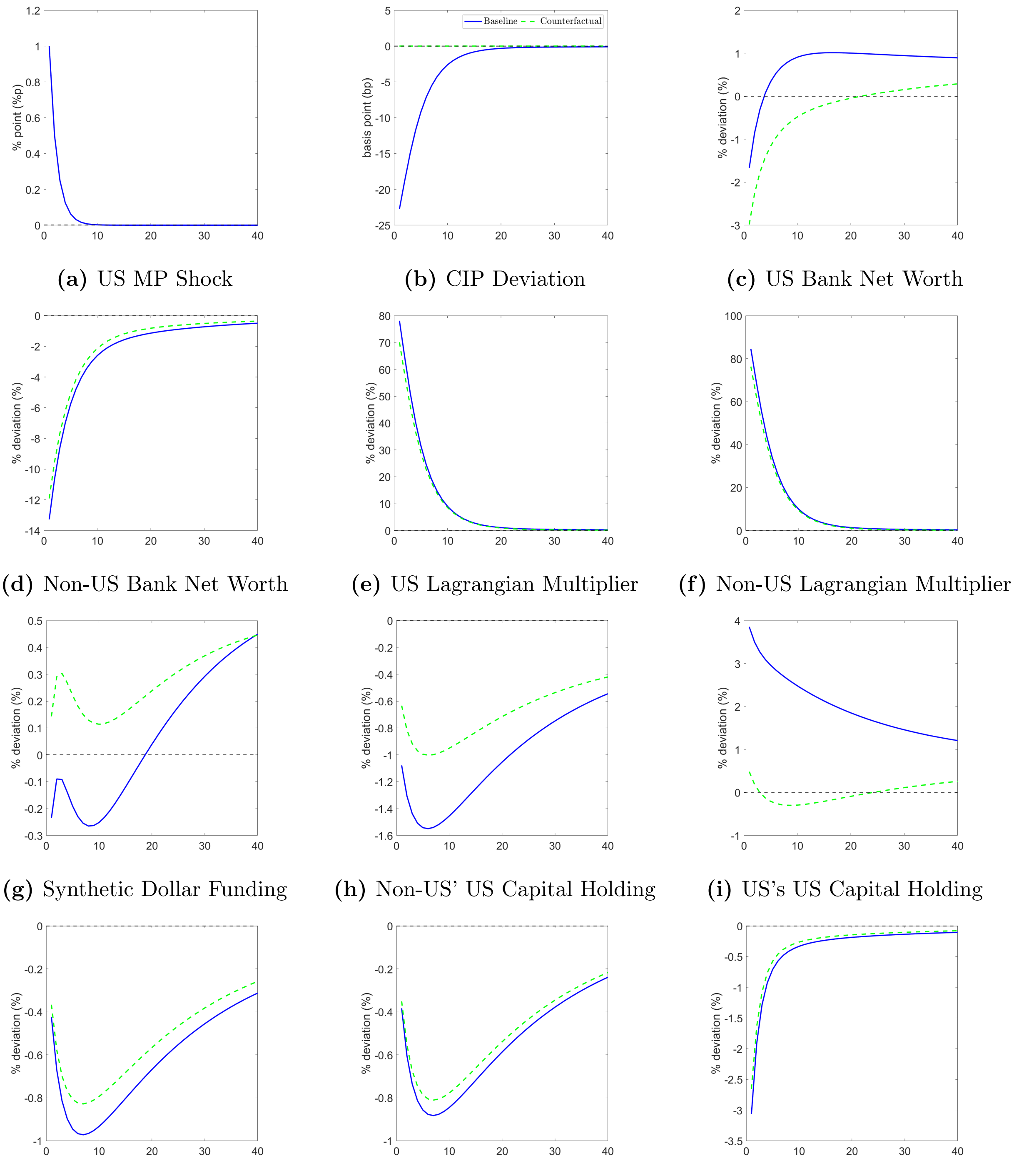
$$\left[1 - \frac{\psi_P}{2} \left(\frac{P^*_{F,t}}{P^*_{F,t-1}} - 1 \right)^2 \right] Y_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t} \right)^{-\nu} \left(C_t + I_t + K_{t-1} \frac{\psi_K}{2} \Big(\frac{I_t}{K_{t-1}} - \delta \Big)^2 \right) \tag{H.11}$$

while the balance of payment equation becomes

$$\begin{aligned} \left(1 - \frac{\psi_P}{2} \left(\frac{P_{H,t}}{P_{H,t-1}} - 1 \right)^2 \right) P_{H,t} Y_t - P_t \Big(C_t + I_t + K_{t-1} \frac{\psi_K}{2} \Big(\frac{I_t}{K_{t-1}} - \delta \Big)^2 \Big) \\ -(R_{K,t} - 1) Q_{t-1} (1 - x^*_{t-1}) K^*_{H,t-1} - \left\{ R_{K,t} - \left(\frac{S_{t-1}}{S_t} R^*_{t-1} + \frac{S_t - F_{t-1}}{S_t} \right) \right\} X_{t-1} \\ = - \left[Q_t (1 - x^*_t) K^*_{H,t} - Q_{t-1} (1 - x^*_{t-1}) K^*_{H,t-1} \right] \end{aligned} \tag{H.12}$$

Figure H.1 shows impulse responses to 100bp contractionary US monetary policy shock under the PCP paradigm. Blue solid line is the impulse responses of the baseline economy while the green dotted line is the impulse responses of the counterfactual economy. Overall, qualitative features of impulse responses are similar to the ones derived from the LCP paradigm: there still exists the amplification of spillover to the non-US and spillback to the US.

The main difference of the PCP paradigm comes from the law of one price and the following complete exchange rate pass-through to import price denominated in the destination country's currency. As the USD appreciates in response to higher US policy rate, the non-US import price (from the US) denominated in EUR rises while the US import price (from the non-US) denominated in USD drops since prices are sticky in their own currency. This strengthens the decline in US inflation rate while dampening the decline in non-US inflation rate. By the systematic component of monetary policy, US policy rate rises less while non-US policy rate rises more. As a result, US capital and investment decrease less while non-US capital and investment decrease more. Also, since US policy rate rises less, the widening of CIP deviations becomes smaller, which implies less amount of amplification.



(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' US Capital Holding

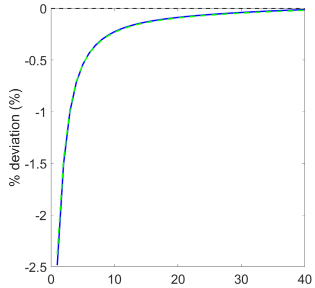
(i) US's US Capital Holding

(j) US Aggregate Capital

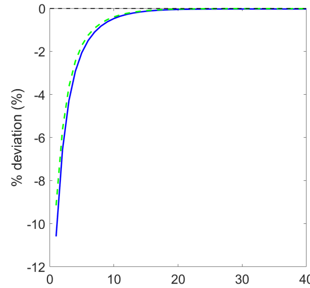
(k) Non-US Aggregate Capital

(l) US Output

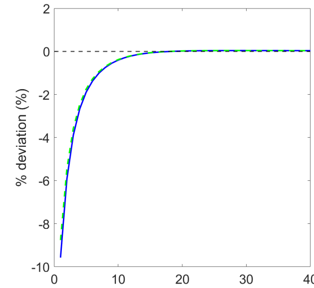
Figure H.1: Impulse Responses to Contractionary US Monetary Policy Shock



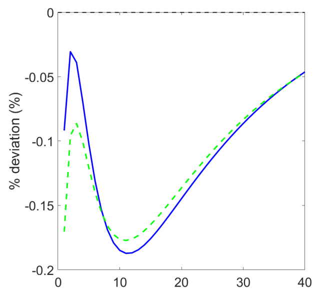
(m) Non-US Output



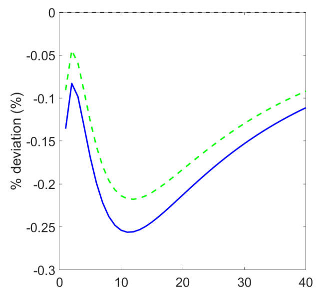
(n) US Investment



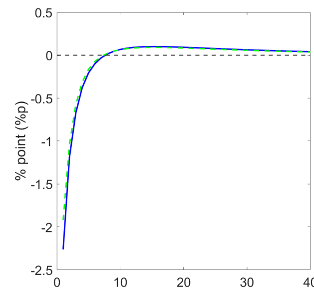
(o) Non-US Investment



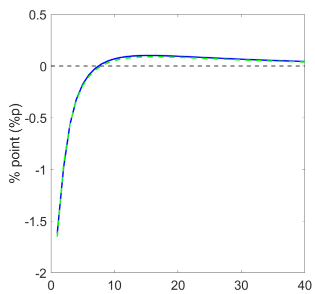
(p) US Consumption



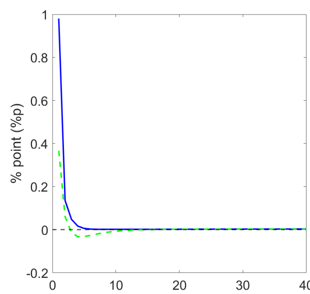
(q) Non-US Consumption



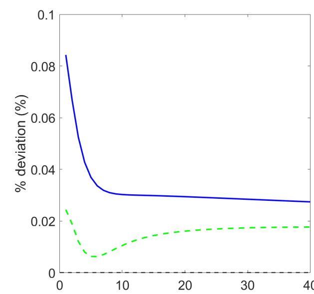
(r) US Inflation



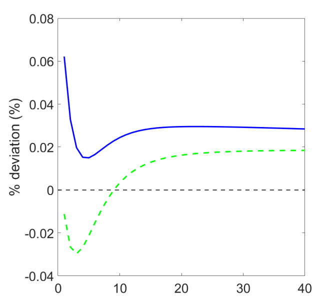
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

Figure H.1: Impulse Responses to Contractionary US Monetary Policy Shock (Continued)

Note. This figure shows impulse responses to 100bp contractionary US monetary policy shock under producer currency pricing. 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.

H.2 Dominant Currency Pricing

Under dominant currency pricing (DCP), prices are denominated and sticky in the dominant currency, which is assumed to be the USD here. For the US, this is exactly the same as the PCP. Alike the PCP, US wholesalers purchase $Y_{H,t}(j)$ and $Y^*_{H,t}(j)$ at $P_{H,t}(j)$ denominated in USD from US firms. Hence, the law of one price between the domestic price and the export price holds, *i.e.*, $P^*_{H,t} = S_t P_{H,t}$, and the demand functions for domestic and exported varieties are

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} Y_{H,t} \tag{H.13}$$

$$Y^*_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} Y^*_{H,t} \tag{H.14}$$

Also, $P_{H,t}(j)$ is determined by the following first-order condition:

$$\begin{aligned}(1+s)(\epsilon-1) = \epsilon\frac{MC_t}{P_{H,t}} &- \psi_P\left(\frac{P_{H,t}}{P_{H,t-1}} - 1\right)\frac{P_{H,t}}{P_{H,t-1}} \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\left(\frac{P_{H,t+1}}{P_{H,t}} - 1\right)\left(\frac{P_{H,t+1}}{P_{H,t}}\right)^2\left(\frac{Y_{H,t+1}+Y^*_{H,t+1}}{Y_{H,t}+Y^*_{H,t}}\right)\right]\end{aligned} \tag{H.15}$$

On the other hand, from the point of view of the non-US, DCP is exactly the same as the LCP. Non-US wholesalers purchase $Y^*_{F,t}(j)$ at $P^*_{F,t}(j)$ denominated in Euro and $Y_{F,t}(j)$ at $P_{F,t}(j)$ denominated in USD since $Y^*_{F,t}(j)$ is sold in domestic market while $Y_{F,t}(j)$ is sold to the US. Then, the demand functions for domestically-spent and exported varieties become

$$Y^*_{F,t}(j) = \left(\frac{P^*_{F,t}(j)}{P^*_{F,t}}\right)^{-\epsilon} Y^*_{F,t} \tag{H.16}$$

$$Y_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}}\right)^{-\epsilon} Y_{F,t} \tag{H.17}$$

Note that the law of one price between $P^*_{F,t}$ and $P_{F,t}$ does not generally hold. Also, $P^*_{F,t}$ and $P_{F,t}$ are determined by the first-order conditions which are the same as the LCP:

$$\begin{aligned}(1+s^*)(\epsilon-1) = \epsilon\frac{MC_t^*}{P_{F,t}^*} - \psi_P\left(\frac{P_{F,t}^*}{P_{F,t-1}^*}-1\right)\frac{P_{F,t}^*}{P_{F,t-1}^*}& \\ +E_t\left[\Lambda_{t,t+1}^*\psi_P\left(\frac{P_{F,t+1}^*}{P_{F,t}^*}-1\right)\left(\frac{P_{F,t+1}^*}{P_{F,t}^*}\right)^2\frac{Y_{F,t+1}^*}{Y_{F,t}^*}\right]&\end{aligned} \tag{H.18}$$

$$\begin{aligned}(1+s^*)(\epsilon-1) = \epsilon\frac{MC_t^*}{S_t P_{F,t}} - \psi_P\left(\frac{P_{F,t}}{P_{F,t-1}}-1\right)\frac{P_{F,t}}{P_{F,t-1}}& \\ +E_t\left[\Lambda_{t,t+1}^*\psi_P\left(\frac{P_{F,t+1}}{P_{F,t}}-1\right)\left(\frac{P_{F,t+1}}{P_{F,t}}\right)^2\frac{S_{t+1}}{S_t}\frac{Y_{F,t+1}}{Y_{F,t}}\right]&\end{aligned} \tag{H.19}$$

The resource constraints for $Y_{H,t}$, $Y_{H,t}^*$, $Y_{F,t}^*$, and $Y_{F,t}$ are

$$\left[1-\frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)^2\right]Y_{H,t} = \omega\left(\frac{P_{H,t}}{P_t}\right)^{-\nu}\left(C_t+I_t+K_{t-1}\frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}}-\delta\right)^2\right) \tag{H.20}$$

$$\left[1-\frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)^2\right]Y_{H,t}^* = (1-\omega)\left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\nu}\left(C_t^*+I_t^*+K_{t-1}^*\frac{\psi_K}{2}\left(\frac{I_t^*}{K_{t-1}^*}-\delta\right)^2\right) \tag{H.21}$$

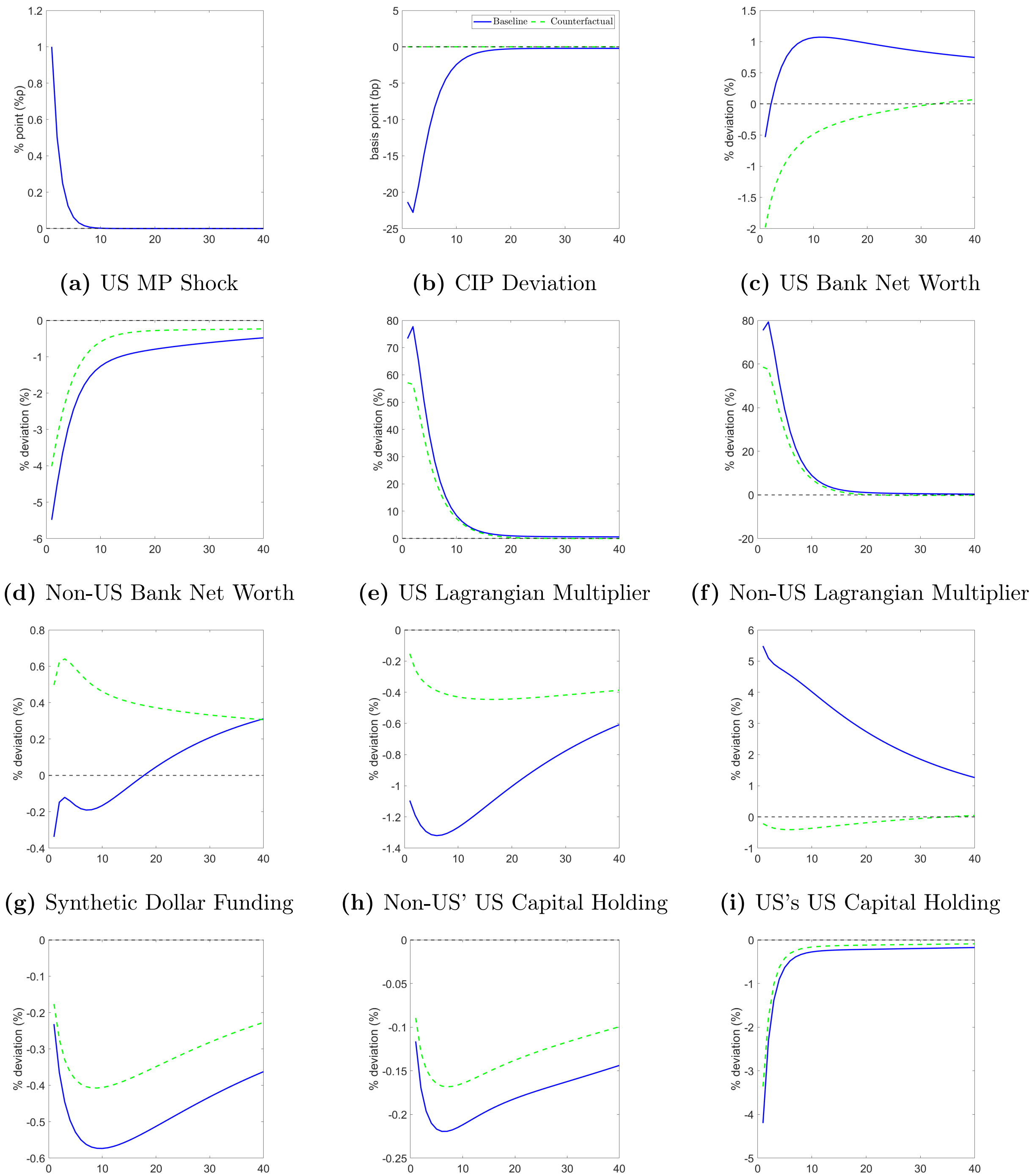
$$\left[1-\frac{\psi_P}{2}\left(\frac{P_{F,t}^*}{P_{F,t-1}^*}-1\right)^2\right]Y_{F,t}^* = \omega\left(\frac{P_{F,t}^*}{P_t^*}\right)^{-\nu}\left(C_t^*+I_t^*+K_{t-1}^*\frac{\psi_K}{2}\left(\frac{I_t^*}{K_{t-1}^*}-\delta\right)^2\right) \tag{H.22}$$

$$\left[1-\frac{\psi_P}{2}\left(\frac{P_{F,t}}{P_{F,t-1}}-1\right)^2\right]Y_{F,t} = (1-\omega)\left(\frac{P_{F,t}}{P_t}\right)^{-\nu}\left(C_t+I_t+K_{t-1}\frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}}-\delta\right)^2\right) \tag{H.23}$$

while the balance of payment equation is

$$\begin{aligned}&\left(1-\frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)^2\right)P_{H,t}Y_t - P_t\left(C_t+I_t+K_{t-1}\frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}}-\delta\right)^2\right) \\ &\quad -(R_{K,t}-1)Q_{t-1}(1-x_{t-1}^*)K_{H,t-1}^* - \left\{R_{K,t}-\left(\frac{S_{t-1}}{S_t}R_{t-1}^*+\frac{S_t-F_{t-1}}{S_t}\right)\right\}X_{t-1} \\ &= -\left[Q_t(1-x_t^*)K_{H,t}^* - Q_{t-1}(1-x_{t-1}^*)K_{H,t-1}^*\right]\end{aligned} \tag{H.24}$$

In Figure H.2, we can see impulse responses of the baseline and the counterfactual economy under DCP. As the PCP paradigm, DCP shows qualitatively similar amplification of spillover and spillback in response to the contractionary US monetary policy shock. Also, since the DCP is in the middle of the PCP and the LCP, impulse responses are also in the middle of the two pricing paradigms. The difference in impulse responses also comes from whether the law of one price holds or not: it holds for US-produced goods but not for non-US-produced goods. The appreciation of the USD leads to the increase in the non-US import price (from the US) denominated in EUR, dampening the decline in non-US inflation rate. Although the US import price (from the non-US) denominated in USD is not directly affected, non-US' lower demand for US goods shrinks US aggregate demand and leads to lower US inflation rate. Accordingly, US policy rate rises less than the LCP but more than the PCP while non-US policy rate rises more than the LCP but less than the PCP. As a result, the widening of CIP deviations is smaller than the LCP but larger than the PCP.



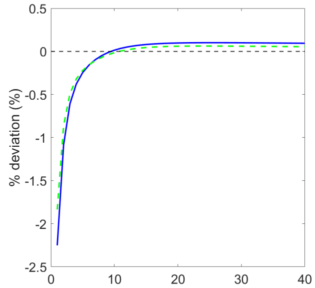
(a) US MP Shock **(b)** CIP Deviation **(c)** US Bank Net Worth

(d) Non-US Bank Net Worth **(e)** US Lagrangian Multiplier **(f)** Non-US Lagrangian Multiplier

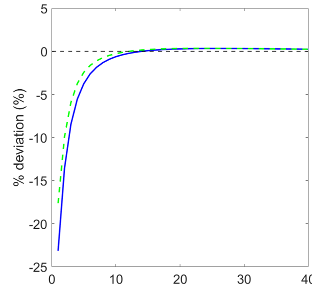
(g) Synthetic Dollar Funding **(h)** Non-US' US Capital Holding **(i)** US's US Capital Holding

(j) US Aggregate Capital **(k)** Non-US Aggregate Capital **(l)** US Output

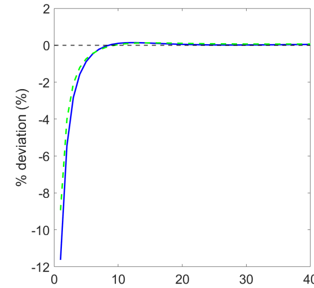
Figure H.2: Impulse Responses to Contractionary US Monetary Policy Shock



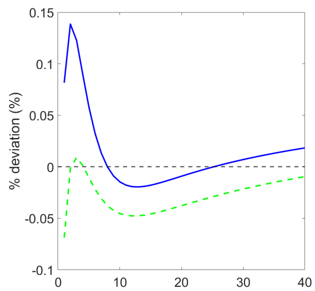
(m) Non-US Output



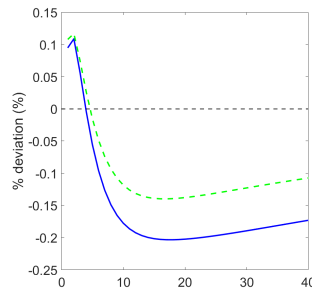
(n) US Investment



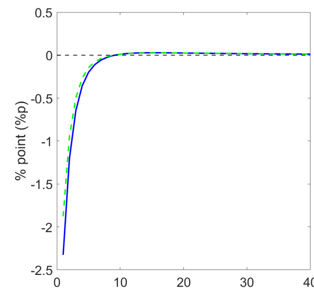
(o) Non-US Investment



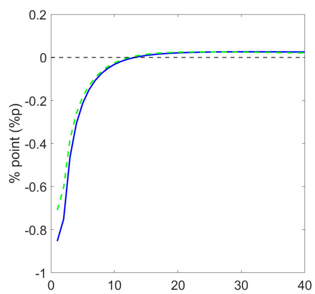
(p) US Consumption



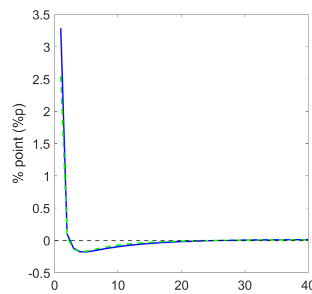
(q) Non-US Consumption



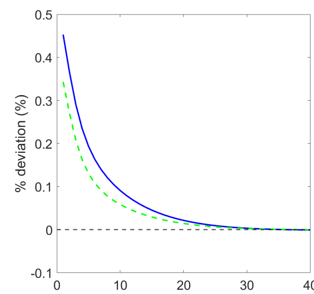
(r) US Inflation



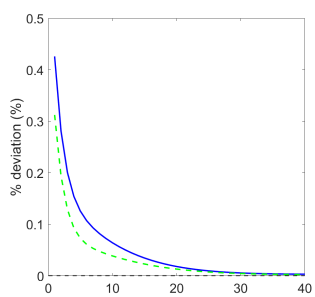
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

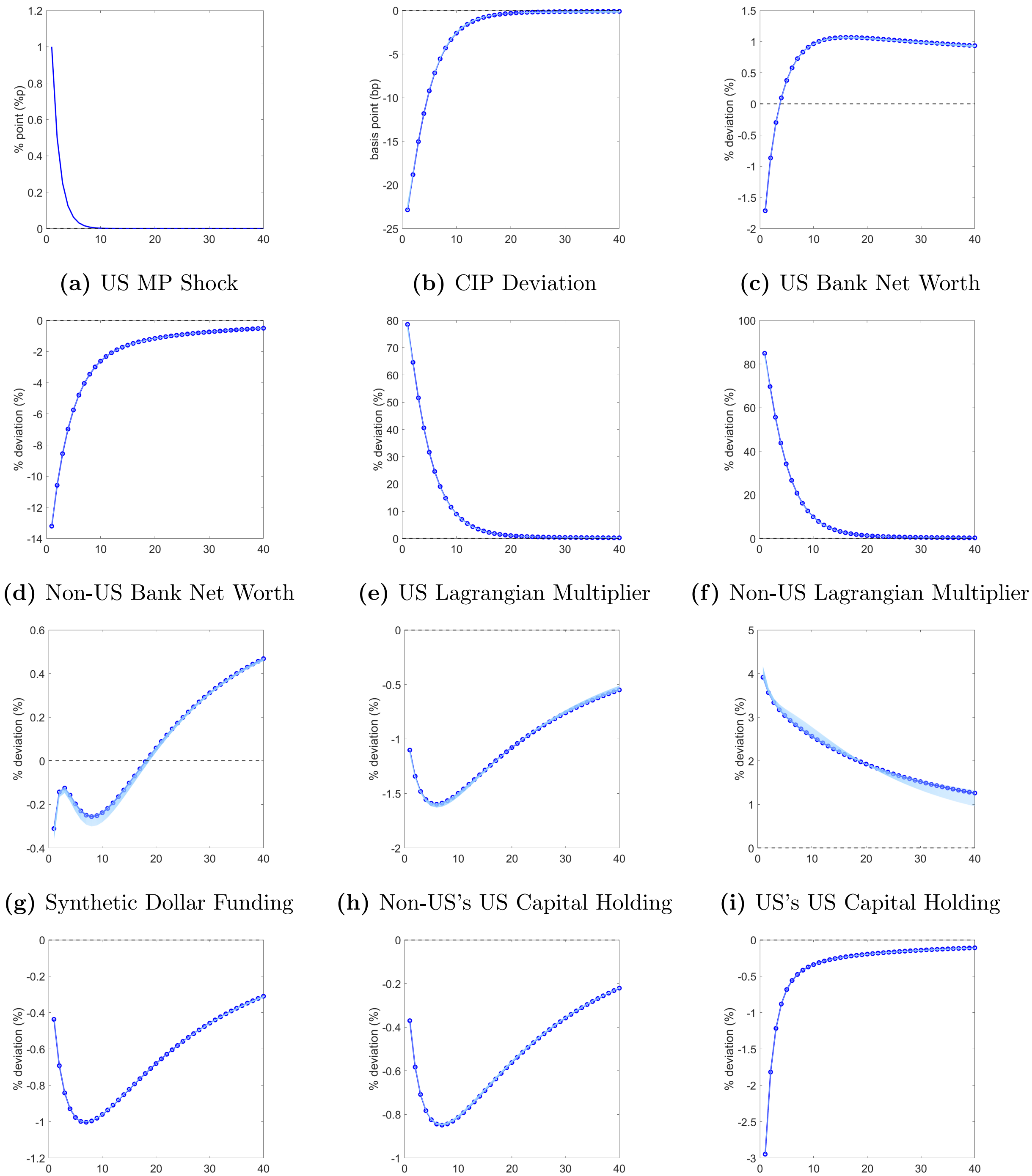
Figure H.2: Impulse Responses to Contractionary US Monetary Policy Shock (Continued)

Note. This figure shows impulse responses to 100bp contractionary US monetary policy shock under dominant currency pricing. 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.

Appendix I Sensitivity Analysis

In this section, we look at whether the choice of quadratic parameters for leverage constraint θ_{H2}, θ_{X2}, θ^*_{F2}, θ^*_{H2}, and θ^*_{X2} affect the results of this model or not. For a computational reason, I change values of θ_{X2} fixing other parameters at 0.005 since the friction in the FX swap market is the main ingredient of this paper. In detail, I choose 100 number of $\theta_{X2} \in (0.001, \theta_{X1}/\bar{x})$. The end point is set at $\theta_{X1}/\bar{x}$ to guarantee positive leverage constraints since the leverage constraint on FX swap is $\theta_{X1}+\theta_{X2}(x_t-\bar{x}) = (\theta_{X1}-\theta_{X2}\bar{x})+\theta_{X2}x_t$. Then, impulse responses are obtained from the model with each value of θ_{X2}. If the baseline model is robust to the choice of θ_{X2}, then the impulse responses from choices of θ_{X2} should not vary substantially.

Figure I.1 shows the impulse responses to 100bp contractionary US monetary policy shock. Blue solid line with dots is the baseline impulse response where $\theta_{X2} = 0.005$ while impulse responses from other choices of θ_{X2} is displayed as skyblue lines. We can see that impulse responses are not mostly affected by, and thus robust to, the choice of θ_{X2}.



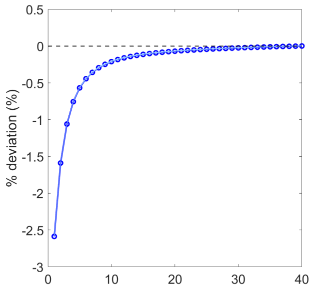
(a) US MP Shock | **(b)** CIP Deviation | **(c)** US Bank Net Worth

(d) Non-US Bank Net Worth | **(e)** US Lagrangian Multiplier | **(f)** Non-US Lagrangian Multiplier

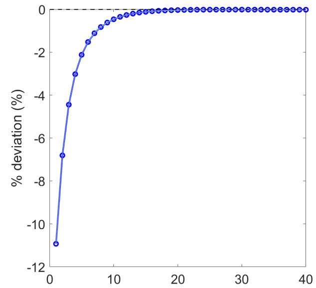
(g) Synthetic Dollar Funding | **(h)** Non-US's US Capital Holding | **(i)** US's US Capital Holding

(j) US Aggregate Capital | **(k)** Non-US Aggregate Capital | **(l)** US Output

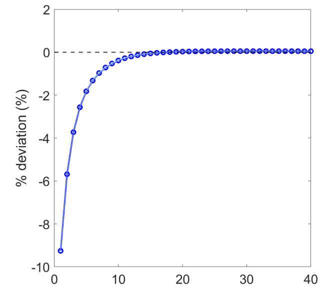
Figure I.1: Impulse Responses to Contractionary US Monetary Policy Shock



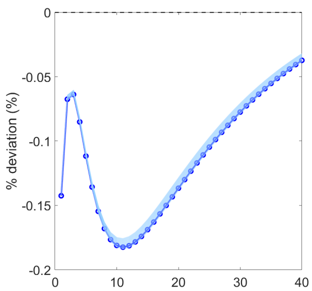
(m) Non-US Output



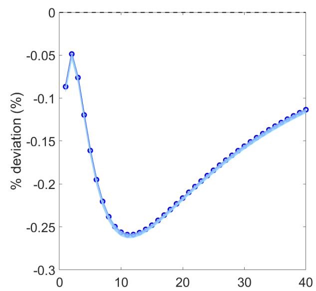
(n) US Investment



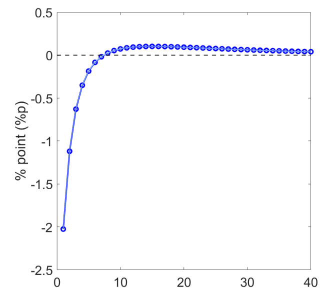
(o) Non-US Investment



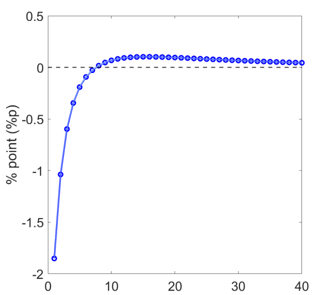
(p) US Consumption



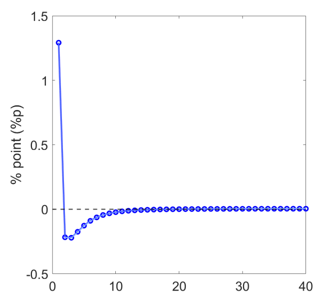
(q) Non-US Consumption



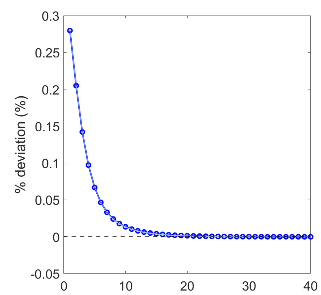
(r) US Inflation



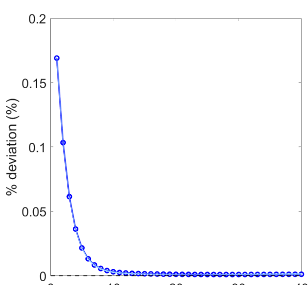
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

Figure I.1: 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 with circle is the baseline impulse response where $\theta_{X2} = 0.005$. Impulse responses from the model with different values of θ_{X2} are displayed in skyblue lines.