The Synthetic Dollar Funding Channel of US Monetary Policy[*]

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Abstract

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

JEL Codes: E52, F41, G15

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

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1 Introduction

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

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

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

Based on the above motivation, I investigate a novel transmission channel of US monetary policy through FX swap markets: the synthetic dollar funding channel. The synthetic dollar funding channel 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 policy affects the external finance premium through bank balance sheets, which in turn amplifies the monetary transmission. CIP deviations in this paper play a similar role as the external finance premium since they are wedges in dollar funding markets and become relevant when direct dollar funding is unavilable. Hence, this paper analyzes effects of US monetary policy on CIP deviations and their implications for amplification of global monetary transmission.

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

First, I estimate responses of CIP deviations to US monetary policy shocks using high-frequency identification. A US monetary policy shock is estimated to have large and significant effects on CIP deviations in the post-GFC (2008-) periods when CIP deviations have emerged. For instance, 3-month CIP deviations widen by 25.5bp 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 the choice of risk-free rate in measuring CIP deviations and to the information effect of US 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 an equilibrium price in the FX swap market.

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

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

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

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

Finally, I investigate 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 et al. (2008), Du and Schreger (2016), Du et al. (2018a), Du et al. (2018b)). Du et al. (2018a) and Cerutti et al. (2021) regress CIP deviations on interest rate differentials and suggest the role of monetary policy, though they do not estimate the causal effects. Jiang et al. (2021) estimate the causal effect of high-frequency identified US monetary policy shocks on Treasury basis. This paper uses LIBOR basis instead since it gauges frictions in interbank dollar funding markets, which are the main focus of this paper, while Treasury basis is more related to convenience yields.

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

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

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

However, all the above papers work on UIP deviations rather than CIP deviations. Even though UIP 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 et al. (2020) and Kekre and Lenel (2021), convenience yields are determined from the demand for safety that USD provides: exogenously given demand function for US government bonds (Jiang et al., 2020) or money-in-the-utility function (Kekre and Lenel, 2021). Bianchi et al. (2022) argue that settlement risk in interbank markets creates the precautionary demand for US dollar and CIP deviations appear as dollar liquidity premium. Unlike these papers, I derive CIP deviations from the limit to arbitrage and demand for currency matching, unrelated to the safety or the liquidity that USD provides.

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

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

2 Empirical Evidence

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

2.1 Empirical Strategy

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

$$\Delta cid^{j}_{t,h} = \alpha_j + \beta_h \Delta mp_t + \epsilon^{j}_{t,h} \tag{2.1}$$

The dependent variable $\Delta cid^{j}_{t,h}$ is the change in CIP deviation between currency j and USD with maturity h. In the right-hand side, α_j is the currency fixed effect, Δmp_t is the change in US monetary policy indicator, and $\epsilon^j_{t,h}$ is the disturbance term. Then, for each maturity h, (2.1) is estimated from the currency panel. β_h is the effect of US monetary policy on CIP deviation for each h, implying that we obtain the term structure of the estimated effects. The currencies used in this regression are G10 currencies while the maturities span from 3-month to 10-year.[2,3] Maturities longer than or equal to 3-month are chosen since they are more related to business cycle frequency, and also not affected by quarter-end effects (see Du et al., 2018a). The sample period starts from February 2000 and ends at April 2021.[4]

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

Regarding the identification of exogenous monetary policy shock, there has been an extensive literature on using high-frequency surprises in interest rate futures as monetary policy shocks (see Gürkaynak et al., 2005; Nakamura and Steinsson, 2018 for example). Those papers measure surprises in the interest rate futures over narrow window, for instance 30 minutes, around each FOMC announcement. Then, they extract one or multiple principal components from the high-frequency surprises and regard those components as direct measures for US monetary policy shocks. The key identifying assumption is that all the information on fundamentals related to monetary policy are priced before the FOMC announcement. This assumption is satisfied since we take the window narrow enough that the monetary policy cannot respond to the changes in fundamentals over that window, implying that the surprises in the interest rate futures are only due to unsystematic part of monetary policy. Hence, the surprises in the interest rate futures only reflect unexpected changes in monetary policy. Following this literature, Δmp_t in this model is identified by high-frequency method. The detailed method and data for this identification will be covered in Section 2.2.

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

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

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

2.2 Measurement and Data

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

$$cid^j_{t,h} \equiv r^\$_{t,h} - (r^j_{t,h} - \rho^j_{t,h})$$

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

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

For maturities longer than or equal to 1-year, the forward premium is inaccurate since the forward market is relatively illiquid. Instead, following Du et al. (2018a), cross-currency basis is directly measured from the cross-currency swap traded in the over-the-counter (OTC) market. Similar to the forward premium above, the mid price of bid and ask for the cross-currency basis is used. As in Du et al. (2018a), we can back out the forward premium by replicating the fixed-for-fixed currency swap. First, an investor pays the fixed-for-floating interest rate swap $r^{irs,j}_{t,h}$ 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 $r^{irs,\$}_{t,h}$. Since this investment strategy replicates the fixed-for-fixed currency swap with the return rate of the forward premium, it can be calculated as

$$\rho^j_{t,h} = r^{irs,j}_{t,h} + cid^j_{t,h} - r^{irs,\$}_{t,h}$$

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

After calculating CIP deviations, I take two-day difference in CIP deviations as $\Delta cid^j_{t,h}$. For

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

[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 et al. (2018b) for details.

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

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

In order to identify the US monetary policy shocks, five interest rate futures are used: federal funds futures immediately following the FOMC announcement (FF1), federal funds futures immediately following the next FOMC announcement (FF4), and 3-month Eurodollar futures at horizons of two, three, four quarters ahead (ED2, ED3, and ED4 respectively). Note that interest rate futures other than FF1 contain information on forward guidance which has become a crucial policy tool since the global financial crisis and the following zero lower bound periods. Then, surprises in these interest rate futures are measured over 30-minute window around each FOMC announcement: changes from 10 minutes before to 20 minutes after the FOMC announcement.

Following Nakamura and Steinsson (2018), one principal component is extracted from surprises in five interest rate futures. This factor is denoted as NS in this paper, and it contains information

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

Table 1: Summary Statistics of CIP Deviations

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

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

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

2.3 Results

2.3.1 Baseline Estimation

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

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

In Table 2, we have results for seven maturities which are denoted as 3M, 1Y, 2Y, 3Y, 5Y, 7Y, and 10Y. For each maturity, there are two columns: the left column is the estimation result when NS is used as the US monetary policy shock whereas the right column is the one when $Target$ and $Path$ are used as proxies for the shock. Standard errors reported in the parentheses are clustered at the currency level since the data are subject to serial correlation within each currency in general. R^2 and N are the R^2 and the number of observations of this baseline estimation respectively.

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

Moreover, we can see that β^h declines in absolute value as maturities get longer, implying that the US monetary policy has less effect on longer-term CIP deviations. This term structure of β_h can be explained by the expectation hypothesis on the relationship between short-term and long-term cross-currency bases. According to the expectation hypothesis, long-term cross-currency bases are the sum of expected future short-term bases (up to first-order). Then, the term structure of β_h implies that the effect of monetary policy shock on expected future short-term bases is decaying over time.

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

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

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

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

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

Note. This table presents the regression results of cross-currency bases on 1%p contractionary US monetary policy shock for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. For each maturity, there are two columns: the left column is the estimation result when NS is used as the US monetary policy shock whereas the right column is the one when $Target$ and $Path$ are used as proxies for the shock. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. R^2 and N denote the R^2 and the number of observations of the regression respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.3.2 Structural Break

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

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

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

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

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

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

On the other hand, β_h's with maturities 3-month, 1-year, 2-year, and 3-year are estimated to be significant for post-GFC periods. Post-GFC effects are much larger than the effects estimated from the whole sample periods due to the insignificant and negligible effects for pre-GFC periods. In particular, 3-month CIP deviation declines by 25.51bp in response to a contractionary NS shock corresponding to the 100bp rise in 1-year US treasury rate. This estimate of 25.51bp is significant not only statistically but also economically; the synthetic dollar funding cost increases 25.51bp more than the direct dollar funding cost does when the US policy rate rises. This implies profound amplification of the effect of US monetary policy on the dollar funding cost through the FX swap market. Comparing with the pre-GFC periods, the differential effects are estimated to be significant for maturities from 3-month to 3-year. $Target$ factor also has a similar effect on CIP deviations, with larger effect on 3-month CIP deviation than the NS shock has. $Path$ factor is mostly insignificant except for 3-month, and the effect on 3-month CIP deviation is 10.69bp. This positive estimate can be due to the intertemporal substitution of the synthetic dollar supply by financial intermediaries.

Expecting future rise in policy rates and future decrease in the supply of synthetic dollar funding, banks can substitute the present supply for the future supply.

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

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

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

2.3.3 Robustness Check

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

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

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

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

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

The effects are larger (in absolute value) than the baseline estimation. This reinforces the argument of this paper that the effect of US monetary policy on CIP deviations works through the balance sheet of banks intermediating the CIP arbitrage. In appendix A.1, Table A.2 shows that these larger effects are mainly due to the higher US risk premium.[11]

Next, I show that the baseline estimation results are robust to the information effect of monetary policy. As in Miranda-Agrippino and Ricco (2021), there are two sources of the information effect: signaling channel and the slow absorption of information. First, monetary policy can signal fundamentals on which the policy rate is based to private decision makers (see Romer and Romer, 2000; Nakamura and Steinsson, 2018 for example). This signaling channel comes from the asymmetric information between the central bank and the market. Observing the policy rate which works as the signal, the private sector extract information on the fundamentals that the central bank may have more information on. For example, if the policy rate rises, then the private sector (households or firms for instance) may think that the economy is stronger than they expect. Then, a high-frequency surprise may not be shock; instead, it can reflect the revision of private sector's expectation on fundamentals. Second, Coibion and Gorodnichenko (2015) show that expectations respond gradually,

[10]Effects on the 7-year OIS basis are estimated as positive, which does not align with the previous baseline results. This may be due to limitations of data since there are not enough data on 7-year OIS rates compared to other maturities.

[11]Drechsler et al. (2018) and Kekre and Lenel (2022) discuss the effects of monetary policy on risk premia.

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

	3M			1Y			2Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	-9.335	-49.74**	-40.40*	7.126	-34.93***	-42.06**	1.709	-29.28***	-30.99***
	(6.527)	(13.34)	(13.70)	(10.31)	(4.914)	(11.62)	(4.442)	(3.712)	(5.568)
R^2			0.063			0.107			0.100
Target	-3.108	-53.82**	-50.71**	3.236	-20.53**	-23.76*	-7.124	-17.99***	-10.86
	(5.862)	(11.08)	(11.70)	(5.769)	(4.158)	(8.094)	(4.328)	(2.126)	(5.938)
Path	-5.840*	1.025	6.865	3.967	-14.72***	-18.68**	6.208	-12.16***	-18.37***
	(1.929)	(3.419)	(3.555)	(5.092)	(1.801)	(4.516)	(2.722)	(1.499)	(2.660)
R^2			0.133			0.118			0.124
N			1097			1026			803

	3Y			5Y			7Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	10.28	-15.10	-25.38**	15.72	-0.122	-15.85*	-	10.09*	-
	(4.607)	(6.543)	(6.461)	(10.14)	(6.179)	(5.595)	-	(4.197)	-
R^2			0.039			0.024			0.059
Target	-0.188	-4.754	-4.566	5.083	0.745	-4.338	-	7.244*	-
	(1.960)	(6.773)	(8.046)	(2.513)	(3.920)	(2.523)	-	(2.911)	-
Path	11.87	-9.891**	-21.76*	12.80	-0.702	-13.51	-	5.110	-
	(6.322)	(2.116)	(6.902)	(8.495)	(3.192)	(5.963)	-	(2.350)	-
R^2			0.042			0.025			0.061
N			781			760			517

	10Y		
	Pre-GFC	Post-GFC	Diff
NS	-	1.041	-
	-	(3.443)	-
R^2			0.018
Target	-	4.373	-
	-	(3.206)	-
Path	-	-0.746	-
	-	(1.718)	-
R^2			0.021
N			622

Note. This table presents the regression results of OIS cross-currency bases on 1%p contractionary US monetary policy shock with structural break around the GFC for each maturity of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year. For each maturity, there are three columns: estimation results for pre-GFC periods (00-07), post-GFC periods (08-), and their differences. The top row is the estimation results when NS is used as the proxy for US monetary policy shock while the bottom rows are the results from using $Target$ and $Path$ as monetary policy shocks. For 7-year and 10-year maturity, only post-GFC estimates are provided since the series of OIS rates does not exist for pre-GFC periods in the data. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. R^2 and N denote the R^2 and the number of observations of the regression respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

rather than instantaneously, to fundamental shocks. This implies that fundamental shocks may not be instantaneously reflected to market prices, even prices in financial markets. In this case, high-frequency surprises may contain information on past fundamental shocks to which an exogenous shock should be orthogonal. In these two cases, Δmp may not be an exogenous "shock", confounding the estimation for β_h. In order to produce estimates robust to the information effect, information-robust monetary policy shocks are constructed and used as the proxy for the monetary policy shock.

As the first step, I test for the signalling channel of the US monetary policy following Miranda-

Agrippino and Ricco (2021). They use Greenbook forecasts as proxies for the Fed's private information since the forecasts contain information on fundamentals for determining the monetary policy but are not open to the public. The forecasts are made for GDP growth rate, inflation, and unemployment rate which determine the systematic part of the monetary policy. These forecasts are published with 5 years of lag, implying that they are the private information of the Fed. In order to control for the Fed's private information, three monetary policy indicators (NS, $Target$, and $Path$) are projected on Greenbook forecasts as

$$\Delta mp_t = \alpha + \sum_{i=-1}^{2} \beta_i' x_{t,i}^f + \sum_{i=-1}^{2} \gamma_i' (x_{t,i}^f - x_{t-1,i}^f) + \Delta \widetilde{mp}_t \tag{2.3}$$

where $x_{t,i}^f$ is the vector of Greenbook forecasts for GDP growth rate, inflation, and unemployment rate. Subscript t is the date of FOMC announcement while subscript i is the forecast horizon: -1 for previous quarter, 0 for current quarter, 1 and 2 for next one and two quarters.[12] For the case of unemployment rate, only contemporaneous forecast is included as in Romer and Romer (2004) due to the multicollinearity. We also have the first-difference term $x_{t,i}^f - x_{t-1,i}^f$ which is the difference between forecasts published in current meeting and previous meeting. The results of (2.3) are reported in Table A.9 of Online Appendix A.3.

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

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

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

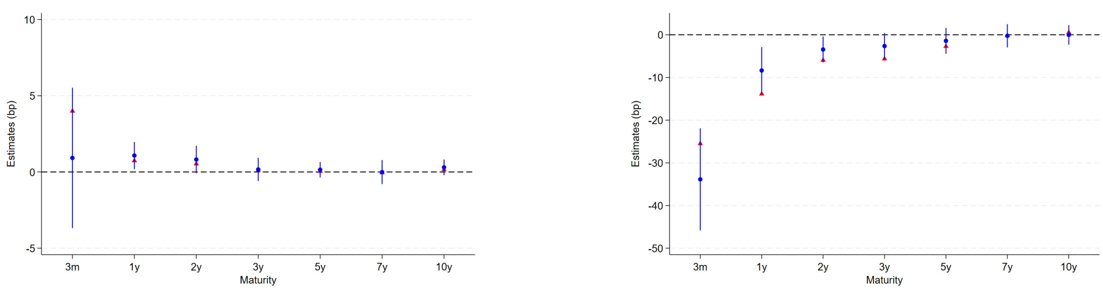
By removing the serially correlated part in futures surprises, we can obtain the residual Δmpi_t for each series of NS, $Target$, and $Path$. This Δmpi_t is used as the information-robust monetary policy shock to estimate the robust effect of US monetary policy shock on CIP deviations:

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

Table 5 shows the information-robust effect of the US monetary policy shock on CIP deviations for pre-GFC and post-GFC periods. Similar to the results in Table 3, effects of monetary policy

[12] 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.

are insignificant for pre-GFC periods while the effects on short-term basis are large and significant for post-GFC periods.[13] Broadly speaking, estimating information-robust effect does not produce qualitatively different estimates, which implies that the potential information effects may not be crucial problems in this analysis. Obviously estimates of the baseline and the information-robust effects are different quantitatively. Figure 1 compares the effects for pre-GFC and post-GFC periods. In each panel (1a) and (1b), red triangles are estimates of β_h from the baseline model. They are displayed across maturities from 3-month to 10-year. On the other hand, blue circles are information-robust effects while the blue line around each circle is the 95% confidence interval. We can see that information-robust effects are more muted for pre-GFC periods. For post-GFC periods, information-robust effects are larger for 3-month maturity while they are more muted for other maturities. However, all differences are not large in the sense that all baseline estimates are within the 95% confidence interval of the information-robust estimates.



(a) Pre-GFC

(b) Post-GFC

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

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

3 The Model

Following Devereux et al. (2023), we study a two-country production economy with nominal price rigidity and limited commitment constraints of financial intermediaries. The two countries are the US and the non-US. Through this model, we can analyze effects of US monetary policy on CIP deviations, synthetic dollar funding, and implications for global economies.[14] The novel contribution of this model is the determination of CIP deviations as general equilibrium objects. As CIP deviations are prices of synthetic dollar funding through the FX swap market, it is determined by the supply

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

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

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

	3M			1Y			2Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.922	-33.86***	-34.78***	1.078*	-8.360**	-9.438**	0.820	-3.442*	-4.262**
	(2.035)	(5.283)	(4.507)	(0.393)	(2.422)	(2.672)	(0.399)	(1.337)	(1.259)
R^2			0.034			0.022			0.011
Target	-0.470	-49.90***	-49.43***	0.636*	-9.793***	-10.43***	0.415	-4.433**	-4.848**
	(1.768)	(7.136)	(7.353)	(0.233)	(1.894)	(2.015)	(0.221)	(1.107)	(1.199)
Path	2.527	13.03*	10.50*	0.360	1.035	0.675	0.377	1.499	1.123
	(1.278)	(4.105)	(3.827)	(0.173)	(2.007)	(2.099)	(0.180)	(1.216)	(1.221)
R^2			0.105			0.049			0.025
N			1377			1319			1345

	3Y			5Y			7Y		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.168	-2.642	-2.809	0.148	-1.416	-1.564	-0.005	-0.234	-0.229
	(0.335)	(1.347)	(1.477)	(0.223)	(1.334)	(1.401)	(0.348)	(1.207)	(1.250)
R^2			0.010			0.011			0.005
Target	0.196	-3.389**	-3.585**	-0.122	-1.312	-1.190	-0.181	-0.652	-0.470
	(0.163)	(0.781)	(0.862)	(0.193)	(0.584)	(0.640)	(0.224)	(0.401)	(0.415)
Path	0.003	1.125	1.122	0.301*	0.553	0.252	0.192	1.111	0.919
	(0.163)	(1.123)	(1.200)	(0.126)	(0.920)	(0.948)	(0.155)	(1.124)	(1.148)
R^2			0.021			0.013			0.007
N			1335			1348			1347

	10Y		
	Pre-GFC	Post-GFC	Diff
NS	0.306	-0.026	-0.332
	(0.227)	(1.008)	(1.083)
R^2			0.015
Target	-0.041	-0.058	-0.017
	(0.217)	(0.562)	(0.682)
Path	0.309	0.527	0.219
	(0.201)	(0.791)	(0.832)
R^2			0.016
N			1334

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

and demand for the synthetic dollar funding. For this purpose, I embed the FX swap market in the general equilibrium model with banks subject to leverage constraints.

3.1 Structure of FX Swap Market

Before moving on to the theoretical analysis, I describe the basic and simplified structure of FX swap contract and FX swap market. US banks and non-US banks are participants and counterparties of each other in the FX swap market, but this simplification summarizes the real world well. Large global banks who can borrow USD from USD-rich households or US MMFs and lend the USD to ultimate borrowers by selling USD in the spot market. This transaction is usually mediated by broker-dealers, but they are mostly part of global banks in the form of subsidiaries for instance. These top-tier global banks are usually US banks, though not always. On the other hand, banks, non-bank financial institutions (such as insurance companies, pension funds, hedge funds), and non-financial firms of non-US countries are main users of FX swap. This paper assumes demand-side of the FX swap market as the banking sector in non-US countries since I focus on the transmission of US monetary policy through interbank markets. When non-US banks hold USD-denominated assets, they are subject to a currency mismatch problem and following currency risks since they usually lack USD-denominated funding. Since banks are heavily penalized on currency mismatches, they buy USD spot and sell USD forward in the FX swap market in order to hedge currency risks. For this reason, it is without loss of generality to set the main players of the FX swap market as US banks and non-US banks. From now on, the currency of the US is denoted as USD (\$) while the non-US currency is denoted as EUR (€) for notational convenience.

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

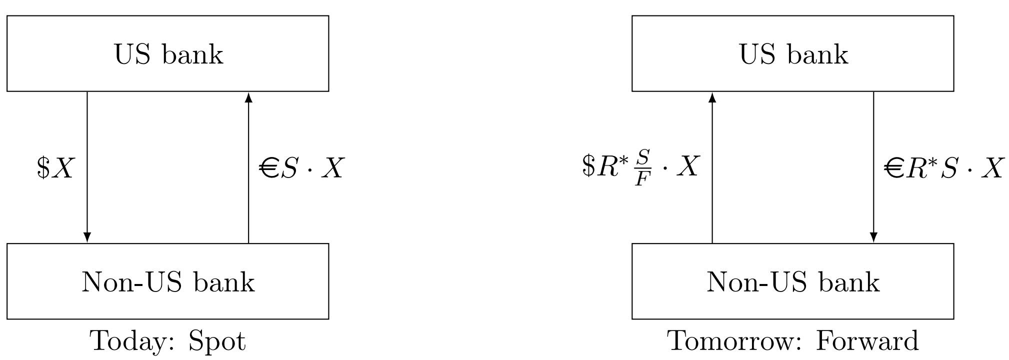


Figure 2: Structure of a FX Swap Contract

In this sense, FX swap is similar to collateralized borrowing where the currency of each party works as the collateral. Here, US bank is the lender of the USD with EUR as collateral since it sells USD and buys EUR in the spot market. The rate of return on this lending is R^*S/F since the forward contract exchanges proceeds R^*S from the EUR-denominated assets into USD at the predetermined forward rate. Thus, $R^*S/F - R$, an excess return on USD lending, is the profit that US banks obtain from supplying the USD in the FX swap market. In the next section, we will see the endogenous determination of $R^*S/F - R$ in the FX swap market with maintaining this simple structure of the FX swap market.

3.2 US Economy

3.2.1 Household

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

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

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

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

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

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

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

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

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 Euler equation for the deposits.

3.2.2 Capital Good Producers

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

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

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

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

Consequently, the following life-time profit maximization problem

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

yields the first-order condition for Q_t as

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

3.2.3 Retailers

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

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

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

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

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

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

and the aggregate price index as

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

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

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

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

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

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

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

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

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

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

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 technology of them are given by

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

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

where ϵ is the elasticity of substitution between varieties.

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

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

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

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.[15]

3.2.5 Firm

A monopolistically competitive firm $j \in [0, 1]$ produces each variety from the production function:[16]

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

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

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

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

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

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

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

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

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

where the nominal marginal cost MC_t is

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

Note that the marginal cost is common across varieties j.

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

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

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

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

yields the following first-order conditions as

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

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

3.2.6 Financial Intermediary

The financial intermediary side is modeled à la Gertler and Kiyotaki (2010). There is a continuum of perfectly competitive financial intermediaries ("banks" for short) with measure one. US banks can source their funds from their retained net worth as well as issuing deposits to US households. From this funding, they can purchase US capitals or arbitrage CIP deviations by lending to non-US banks in the cash market.[17] The detailed intermediation process of US banks is explained below.

Figure 3 displays the timeline of the bank decision problem. At the *beginning* of each period t, the state of time t which includes all shocks as well as stay/exit status of banks is unfolded. Banks exit with probability $1-\sigma$ while they stay as bankers with probability σ.[18] Exiting banks pay out all of their net worth to households as dividends while they are filled with new banks with initial net worth as transfers of ξ fraction of banks' total asset value from the household.

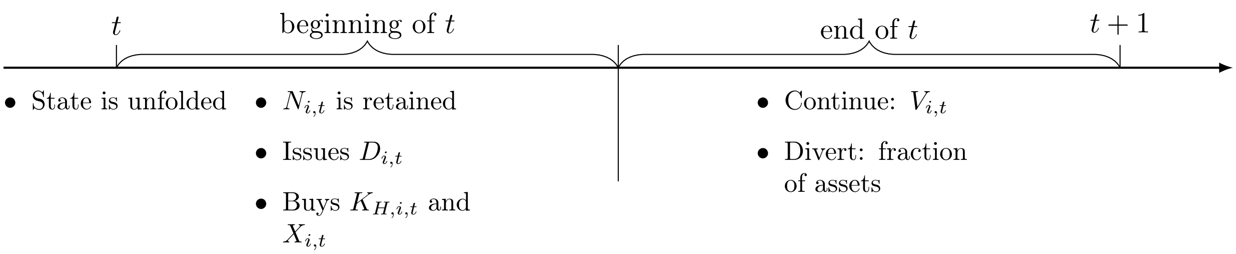


Figure 3: Timeline of Bank i's Decision

After observing the state and conditional on that bank i stays, it retains its net worth $N_{i,t}$ and issues deposits $D_{i,t}$ at gross interest rate R_t.[19] Regarding the asset side, the bank can purchase US capital $K_{H,i,t}$ at price Q_t while it can engage in CIP arbitrage $X_{i,t}$ in the FX swap market.[20,21] $\$X_{i,t}$ is exchanged for €$S_t X_{i,t}$ and lent to non-US banks in the cash market with non-US interest rate of R_t^* while the exchange rate risk is hedged by the swap contract. The balance sheet identity of bank i in terms of USD is then given by

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

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

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

[18] 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.

[19] 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.

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

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

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

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

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

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

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

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

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

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 (3.21), $R_{K,t+1} - R_t$ is the excess return on US capital bond 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[22,23]

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

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

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

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

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

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

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

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

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

Importantly, the leverage constraint is imposed not only on capital but also on CIP arbitrage $X_{i,t}$. This is in line with the change in regulatory framework after the GFC; the calculation of leverage ratio changed from non-risk-weighted basis to risk-weighted basis. Arbitrage contains little risk, so the size of arbitrage was not subject to regulation based on risk-weighted leverage ratio. On the other hand, the regulation on non-risk-weighted leverage ratio puts limit on arbitrage activity. This regulatory reform can be parameterized by non-zero θ_{X1} and θ_{X2} while they have been zero before

[22] CIP deviations are defined following the tradition of cross-currency basis.

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

the GFC. Following Devereux et al. (2023), the quadratic parameters θ_{H2} and θ_{X2} are introduced to induce stationarity. This can be understood as monitoring cost proportional to the scale of asset, making banks easier to divert when they hold larger amount of assets. Note that the quadratic parts depend on the aggregate asset rather than individual bank's asset, so they are exogenous to bank i.

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

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

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

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

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

$$\nu_{N,t} \equiv E_t \left[\Omega_{t,t+1} \right] R_t \tag{3.26}$$

for the stochastic discount factor of bank $\Omega_{t,t+1} \equiv \Lambda_{t,t+1}(1-\sigma+\sigma\nu_{t+1})$.[24] Then, the Bellman equation is simplified as

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

The first-order conditions of the above Bellman equation are

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

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

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

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

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

[24] 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 the SDF of banks.

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

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

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

3.2.7 Monetary Policy

We assume the following Taylor rule type US monetary policy as

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

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

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

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

3.2.8 Fiscal Policy

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

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

3.3 Non-US Economy

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

3.3.1 Financial Intermediary

As the US, there is a continuum of banks with total measure one while they exit with probability $1-\sigma$ in each period. Given its net worth $N^*_{i,t}$, bank i takes deposits $D^*_{i,t}$ from non-US households. Also, there is an additional amount of lending $S_t\tilde{X}^*_{i,t}$ from US banks since they deposit for taking advantage of arbitrage opportunities. This suggests that the total amount of deposits is $D^*_{i,t}+S_t\tilde{X}^*_{i,t}$. Note that $\tilde{X}^*_{i,t}$ is the total amount of lending from US banks that non-US bank i obtains, and it is not necessarily the lending from US bank i. From these sources of funding, bank i can purchase the non-US capital $K^*_{F,i,t}$ at its price Q^*_t and the US capital $K^*_{H,i,t}$ at Q_t. Then, the balance sheet identity of bank i is given by

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

At period $t+1$, bank i earns gross return rate of $R^*_{K,t+1}\equiv(\tilde{R}^*_{K,t+1}+(1-\delta)Q^*_{t+1})/Q^*_t$ from the non-US capital and $R_{K,t+1}$ from the US capital. With these returns and newly issued deposits $D^*_{i,t+1}+S_{t+1}\tilde{X}^*_{i,t+1}$, it purchases $K^*_{F,i,t+1}$ and $K^*_{H,i,t+1}$ and repays $R^*_t(D^*_{i,t}+S_t\tilde{X}^*_{i,t})$.

Since the value of US capital holding $Q_tK^*_{H,i,t}$ is denominated in USD, there is a currency mismatch between the return and the funding cost. In this model, the motive for *currency matching* arises because non-US banks are subject to tighter limit on asset holdings of which currency risks are not hedged, reflected in the leverage constraint (3.34). This simplifies the analysis since we can still use the first-order perturbation method unlike the mean-variance framework.[25] Let bank i fund $x^*_{i,t}\in[0,1]$ share of $Q_tK^*_{H,i,t}$ through the FX swap market, which represents the demand for synthetic dollar funding. Then, €$R^*_tS_tx^*_{i,t}Q_tK^*_{H,i,t}$ is exchanged into \$$R^*_t(S_t/F_t)x^*_{i,t}Q_tK^*_{H,i,t}$ by the forward leg of the FX swap contract. Thus, the budget constraint is

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

Figure 5 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.

There is an implicit assumption that non-US banks cannot approach direct dollar funding market where they can borrow USD at interest rate R_t. Instead, currency matching is only available through the FX swap market. This is the important and distinguishing feature of this model that creates the channel through which CIP deviations can affect cross-border capital flows and asset prices. This assumption is not unrealistic since non-US banks, except for some big global banks,

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

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

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

usually lack access to the direct dollar funding market or they need to pay high premium for the dollar funding (see Ivashina et al., 2015; Du and Schreger, 2022 for instance).[26]

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

$$\begin{aligned} N^*_{i,t+1} = \Bigg[& (R^*_{K,t+1} - R_t^*)\phi^*_{F,i,t} + \frac{S_{t+1}}{S_t} \underbrace{\left(R_{K,t+1} - R_t^* \frac{S_t}{S_{t+1}} \right)}_{\text{Ⓑ}} (1 - x^*_{i,t})\phi^*_{H,i,t} \\ & + \frac{S_{t+1}}{S_t} \underbrace{\left(R_{K,t+1} - R_t^* \frac{S_t}{F_t} \right)}_{\text{Ⓒ}} x^*_{i,t}\phi^*_{H,i,t} + R_t^* \Bigg] N^*_{i,t} \end{aligned} \tag{3.33}$$

for the ratio of each asset to net worth

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

We can see that each asset-to-net-worth ratio is multiplied by the excess return of the asset. Ⓑ 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.[27] It can be expressed as

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

[27] 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

$R_{K,t+1} - (R_t - cid_t)$, so $-cid_t$ is an intermediation fee that the non-US bank has to pay for the synthetic dollar funding.

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

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

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

$$\begin{aligned} V^*_{i,t} \geq \Theta_t \Bigg[& \left(\theta^*_{F1} + \theta^*_{F2} \frac{Q^*_t K^*_{F,t}}{P^*_t} \right) Q^*_t K^*_{F,i,t} + \left(\theta^*_{H1} + \theta^*_{H2} \frac{(1-x^*_t) S_t Q_t K^*_{H,t}}{P^*_t} \right) (1-x^*_{i,t}) S_t Q_t K^*_{H,i,t} \\ & + \left(\theta^*_{X1} + \theta^*_{X2} \frac{x^*_t S_t Q_t K^*_{H,t}}{P^*_t} \right) x^*_{i,t} S_t Q_t K^*_{H,i,t} \Bigg] \end{aligned} \tag{3.34}$$

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

Under the conjecture that $V^*_{i,t} = \nu^*_t N^*_{i,t}$, the optimization problem of continuing bank i is

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

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

$$\nu^*_{F,t} \equiv E_t \left[\Omega^*_{t,t+1} \left(R^*_{K,t+1} - R^*_t \right) \right] \tag{3.35}$$

$$\nu^*_{H,t} \equiv E_t \left[\Omega^*_{t,t+1} \frac{S_{t+1}}{S_t} \left(R_{K,t+1} - R^*_t \frac{S_t}{S_{t+1}} \right) \right] \tag{3.36}$$

$$\nu^*_{X,t} \equiv E_t \left[\Omega^*_{t,t+1} \frac{S_{t+1}}{S_t} \left(R_{K,t+1} - R^*_t \frac{S_t}{F_t} \right) \right] \tag{3.37}$$

$$\nu^*_{N,t} \equiv E_t \left[\Omega^*_{t,t+1} \right] R^*_t \tag{3.38}$$

the steady-state.

The first-order conditions for the above problem are

$$\nu^*_{F,t} = \mu^*_t \Theta_t \left(\theta^*_{F1} + \theta^*_{F2} \frac{Q^*_t K^*_{F,t}}{P^*_t} \right) \tag{3.39}$$

$$\nu^*_{H,t} = \mu^*_t \Theta_t \left(\theta^*_{H1} + \theta^*_{H2} \frac{(1 - x^*_t) S_t Q_t K^*_{H,t}}{P^*_t} \right) \tag{3.40}$$

$$\nu^*_{X,t} = \mu^*_t \Theta_t \left(\theta^*_{X1} + \theta^*_{X2} \frac{x^*_t S_t Q_t K^*_{H,t}}{P^*_t} \right) \tag{3.41}$$

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

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

The demand for synthetic dollar funding $x^*_t Q_t K^*_{H,t}$ is decreasing in $-cid_t$ unless $\mu^*_t = \theta^*_{X1} = \theta^*_{X2} = 0$, and it is displayed as the downward-sloping red line in Figure 6.

The law of motion for the aggregate net worth is

$$\begin{aligned} N^*_{t+1} = \sigma \Bigg[& (R^*_{K,t+1} - R^*_t) \phi^*_{F,t} + \frac{S_{t+1}}{S_t} \left(R_{K,t+1} - R^*_t \frac{S_t}{S_{t+1}} \right) (1 - x^*_t) \phi^*_{H,t} \\ & + \frac{S_{t+1}}{S_t} \left(R_{K,t+1} - R^*_t \frac{S_t}{F_t} \right) x^*_t \phi^*_{H,t} + R^*_t \Bigg] N^*_t + (1 - \sigma) \xi^* \left(\phi^*_{F,t} + \phi^*_{H,t} \right) N^*_t \end{aligned} \tag{3.42}$$

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

3.4 Equilibrium

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

$$X_t = x^*_t Q_t K^*_{H,t} \tag{3.43}$$

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

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

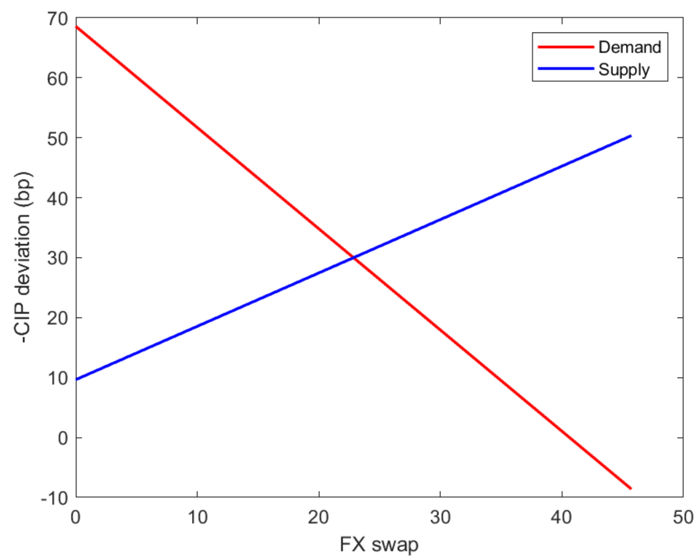


Figure 6: Demand and Supply Function of the FX Swap Market

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

can obtain the US balance of payment as

$$\begin{aligned}
&\left(1-\frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)^2\right)P_{H,t}Y_{H,t}+\left(1-\frac{\psi_P}{2}\left(\frac{P^*_{H,t}}{P^*_{H,t-1}}-1\right)^2\right)\frac{1}{S_t}P^*_{H,t}Y^*_{H,t}\\
&\quad -P_t\Big(C_t+I_t+K_{t-1}\frac{\psi_K}{2}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\Big)\\
&\quad -(R_{K,t}-1)(1-x^*_{t-1})Q_{t-1}K^*_{H,t-1}-\underbrace{\left(R_{K,t}-R^*_{t-1}\frac{S_{t-1}}{F_{t-1}}\right)}_{\text{Ⓓ}}X_{t-1}\\
&=-\left[(1-x^*_t)Q_tK^*_{H,t}-(1-x^*_{t-1})Q_{t-1}K^*_{H,t-1}\right] \qquad (3.44)
\end{aligned}$$

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

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

4 Results

4.1 Calibration

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

For the firm parameters, subsidy s and s^* are set at 0.2 to eliminate the steady-state price distortion while the capital share α is given by a standard value of 1/3. The Rotemberg price adjustment cost ψ_P is calibrated as 159.87 in order to match the Calvo parameter of 0.84.[29] Capital depreciation rate δ is set at 0.04 while the investment adjustment cost ψ_K is set at 4.

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

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

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

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

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

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

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

Table 6: Parameter Values

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

4.2 Impulse Responses

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

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

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

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

In panel (7e) and (7f), the Lagrangian multipliers of US and non-US banks rise about 0.8 log points. This means that the leverage constraints of both US and non-US banks are tightened due to their lower net worth. As implied by the supply function of FX swap (3.28), the increase in the Lagrangian multiplier of the US bank leads to the widening of CIP deviations in panel (7b). US banks reduce supply of synthetic dollar funding through the FX swap market, so CIP deviations as the price of the synthetic dollar funding widen in the equilibrium. Note that the tightening of the non-US banks' leverage constraint brings about the decrease in the demand for FX swap and upward pressure for CIP deviations. In the general equilibrium, the supply-side effect is larger than the demand-side effect so that CIP deviations widen. Comparing with the counterfactual case, the increases in Lagrangian multipliers are larger in the baseline case even though the net worth of the US bank declines less. This difference comes from the additional constraint that US banks face in the baseline economy: leverage constraint on FX swap. Even though the net worth of the US bank decreases more in the counterfactual economy, its leverage is less constrained since it faces no limit on FX swap activity.

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

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

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

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

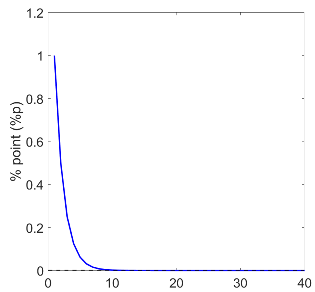
Since CIP deviations are the wedge between the synthetic and the direct dollar funding cost, the synthetic dollar funding cost rises more than the direct cost when CIP deviations widen. Hence, the intermediation by non-US banks is hampered more, reducing not only the US capital holdings but also the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

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

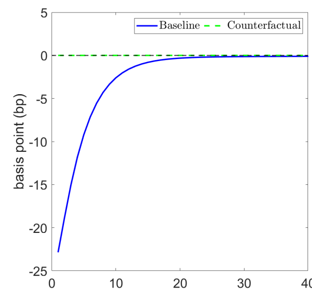
Panel (7p) and (7q) display impulse responses of consumption. Interestingly, US consumption is higher while non-US consumption is lower in the baseline economy than the counterfactual economy. This can be explained by CIP deviations as intermediation fees that US banks obtain from supplying the USD in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

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

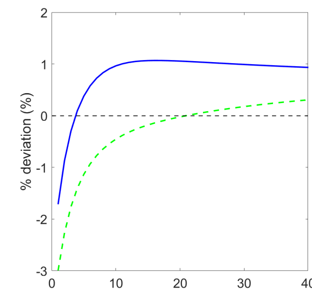
As the conventional theory predicts, USD appreciates in both nominal and real value as in panel (7t) and (7u). This model predicts the amplification of this effect: nominal appreciation rate rises by 1.29%p with amplification of 0.84%p and real appreciation of 0.28% with amplification of 0.19%p. It is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



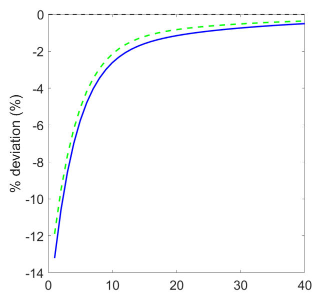
(a) US MP Shock



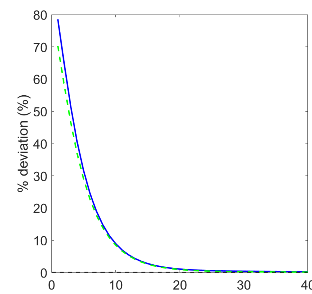
(b) CIP Deviation



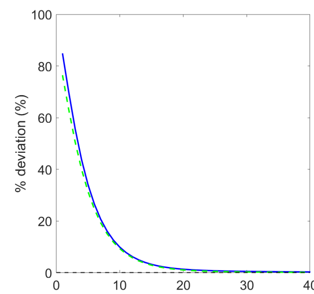
(c) US Bank Net Worth



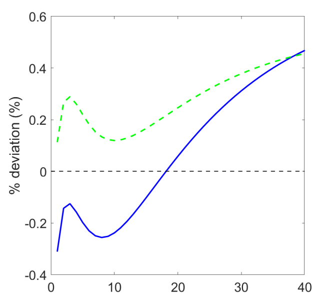
(d) Non-US Bank Net Worth



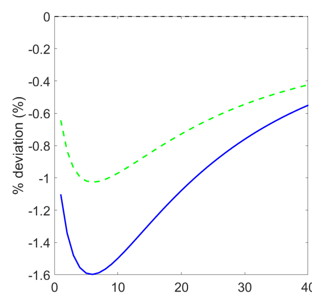
(e) US Lagrangian Multiplier



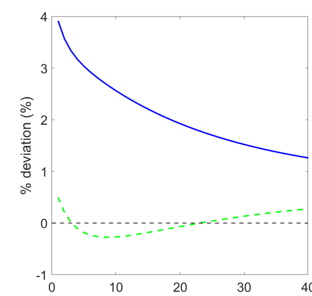
(f) Non-US Lagrangian Multiplier



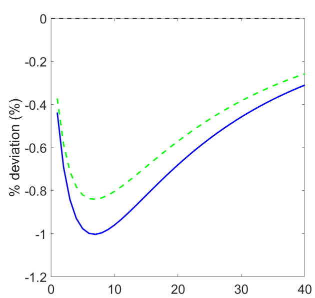
(g) Synthetic Dollar Funding



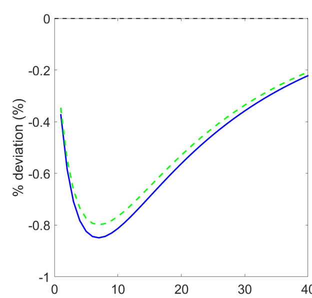
(h) Non-US's US Capital Holding



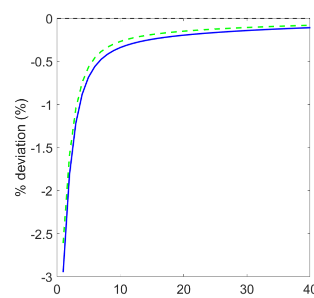
(i) US's US Capital Holding



(j) US Aggregate Capital

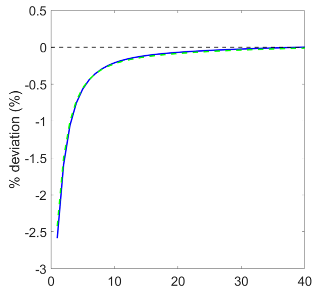


(k) Non-US Aggregate Capital

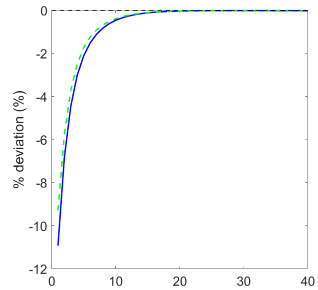


(l) US Output

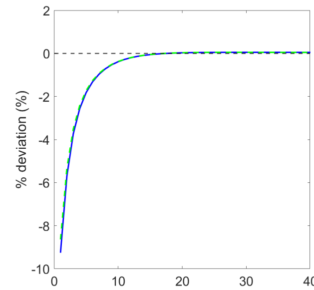
Figure 7: Impulse Responses to Contractionary US Monetary Policy Shock



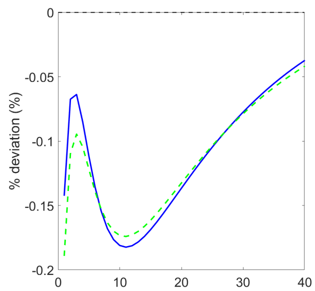
(m) Non-US Output



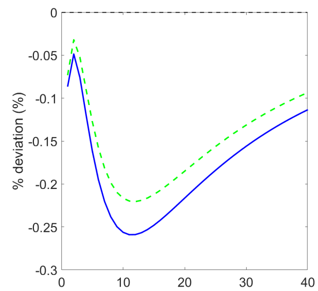
(n) US Investment



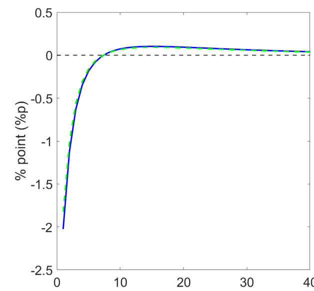
(o) Non-US Investment



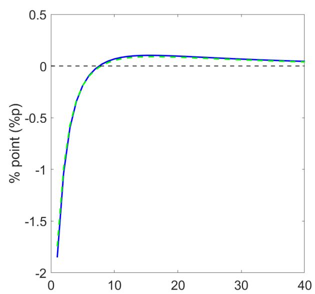
(p) US Consumption



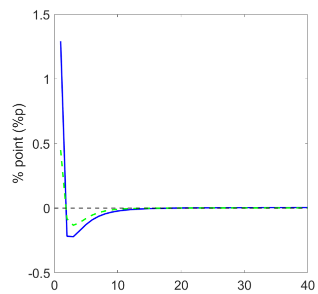
(q) Non-US Consumption



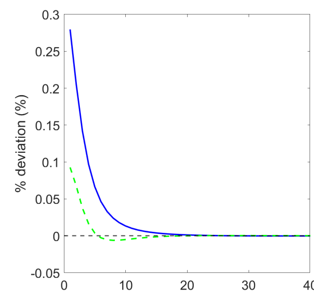
(r) US Inflation



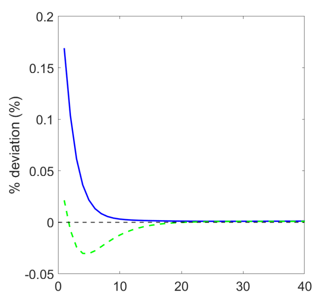
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

Figure 7: Impulse Responses to Contractionary US Monetary Policy Shock (Continued)
Note. This figure shows impulse responses to 100bp contractionary US monetary policy shock. Time periods of the impulse responses are in quarterly frequency. For each panel, blue solid line is the baseline impulse response where US banks are subject to the leverage constraint on FX swap. Impulse responses from the counterfactual economy where there is no leverage constraint on FX swap are displayed in green dotted lines.

4.3 US Monetary Policy and Central Bank Swap Lines

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

Figure 8: Central Bank Swap Lines

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

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

As central bank swap lines provide dollar liquidity into international financial markets, the cost of USD can become lower. According to Bahaj and Reis (2022), the swap line spread ss_t works as 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, lower cases are used to denote net interest rates. cid_t is measured using OIS rates as risk-free rates.

[31] 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.

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

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

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

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

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

$$-cid_t \leq ss_t \tag{4.1}$$

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

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

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

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

$$X_t + X_t^{SL} = x_t^{*}Q_tK_{H,t}^{*} \tag{4.3}$$

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

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

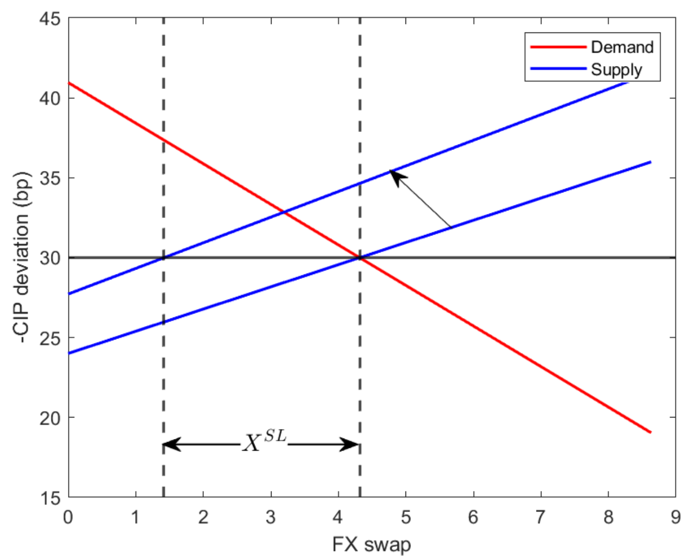


Figure 9: FX Swap Market and Swap Lines

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

Finally, the complementary slackness condition is given by

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

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

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

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

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

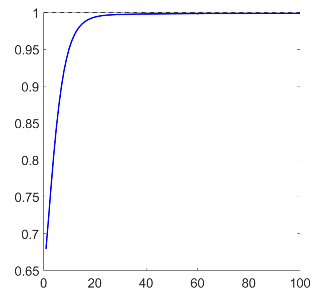
Consequently, in panel (10i) and (10j), both the US and the non-US aggregate capital are larger when there are central bank swap lines. Output and investment of the US and the non-US show similar patterns as the aggregate capital (panel (10k), (10l), (10m), and (10n)). Inflation rates of both countries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

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

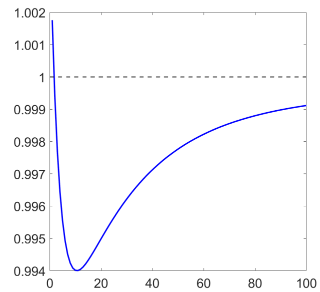
In panel (10s), (10t)) and (10u), USD appreciation rate, real spot exchange rate and real forward exchange rate are lower.

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

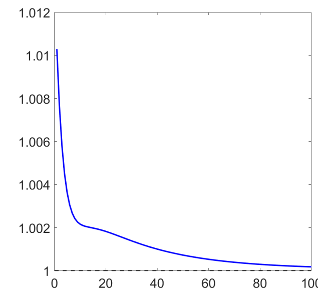
Another related caveat is that we cannot say there is a conflict between the conventional monetary policy and the swap line policy in managing inflation and output gap. When there is a limit on CIP arbitrage and CIP deviations emerge as a consequence, effects of US monetary policy on inflation and output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



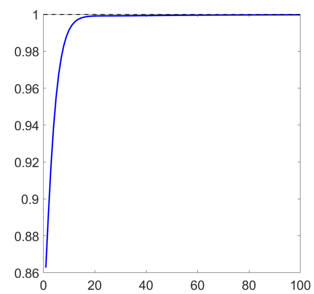
(a) CIP Deviation



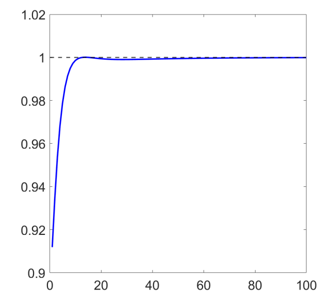
(b) US Bank Net Worth



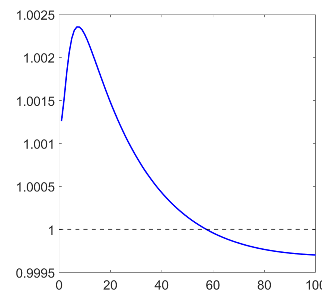
(c) Non-US Bank Net Worth



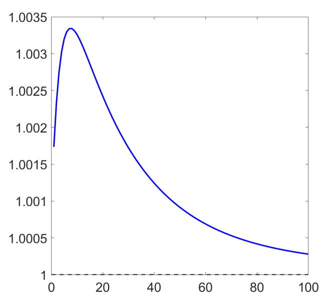
(d) US Lagrangian Multiplier



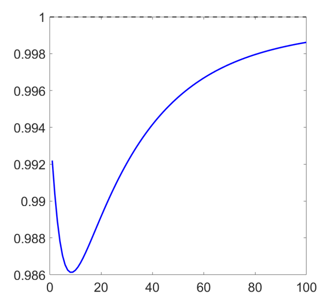
(e) Non-US Lagrangian Multiplier



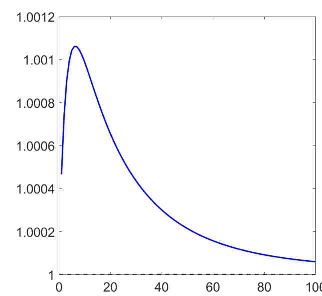
(f) Synthetic Dollar Funding



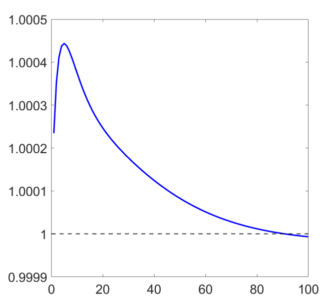
(g) Non-US's US Capital Holding



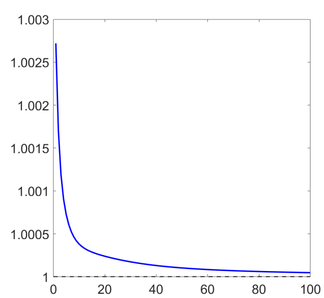
(h) US's US Capital Holding



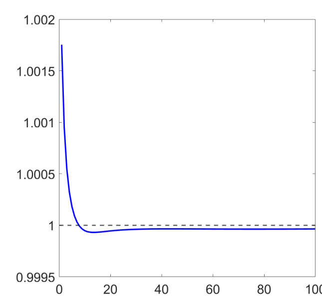
(i) US Aggregate Capital



(j) Non-US Aggregate Capital

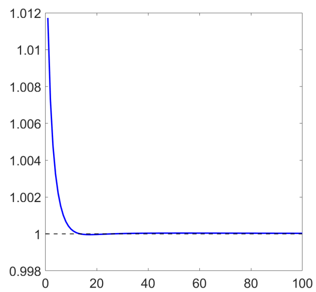


(k) US Output

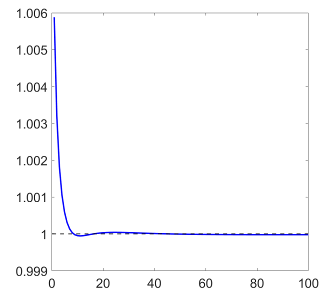


(l) Non-US Output

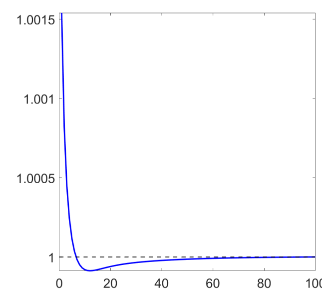
Figure 10: Relative Impulse Responses: With v.s. Without Swap Lines



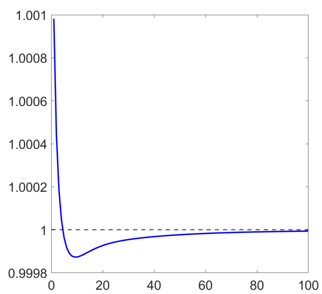
(m) US Investment



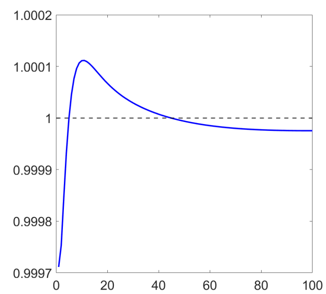
(n) Non-US Investment



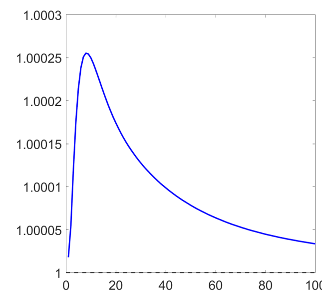
(o) US Inflation



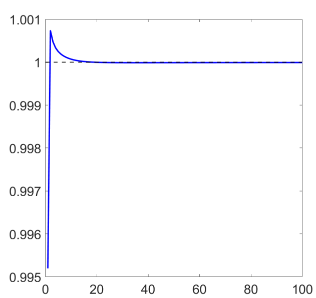
(p) Non-US Inflation



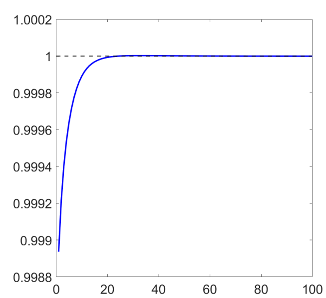
(q) US Consumption



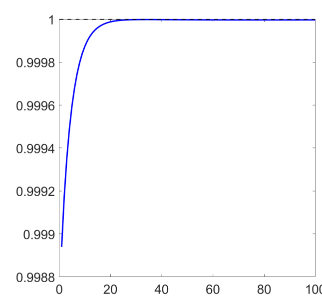
(r) Non-US Consumption



(s) USD Appreciation Rate



(t) Real Spot Exchange Rate



(u) Real Forward Exchange Rate

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

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

5 Conclusion

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

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

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

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

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

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

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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 $cid^j_{t,h} = r^{\$}_{t,h} - (r^j_{t,h} - \rho^j_{t,h})$. 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. Estimates inside parentheses are standard errors clustered across currencies.

First, US LIBOR $\Delta r^{\$}$ reacts less than one-to-one in response to the US monetary policy shock. For instance, NS shock corresponding to 100bp increase in 1-year US treasury rate raises US LIBOR by about 53bp, implying imperfect pass-through of the US monetary policy on interbank rates. On the other hand, changes in the synthetic dollar funding cost $\Delta r^j - \Delta\rho^j$ mostly come from the 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 the change in synthetic dollar funding cost comes from the FX swap market friction. According to Du et al. (2018a), CIP deviations have emerged due to the FX swap market friction since the GFC. The relationship between the effect of US monetary policy on CIP deviations and the FX swap market friction is addressed in Section 2.3.2.

We can do the same decomposition for OIS-based CIP deviations using the fact that the OIS-basis can be decomposed into the LIBOR-basis and LIBOR-OIS spreads of currency j and USD. Decomposition results are reported in in Table A.2. Three panels of Table A.2 indicate the effect of NS, $Target$, and $Path$ respectively. In each panel, the top row is the total effect on OIS-basis. Three rows below are the decomposition which should sum up to the total effect. Note that the effect on Δcid^{libor} is different from the baseline estimates in Table 2 due to the different sample periods. We can see that the effect on the OIS-basis is mostly due to the higher US risk premium (see Drechsler et al., 2018; Kekre and Lenel, 2022). This observation is related to the argument in Jiang et al. (2021) that LIBOR-OIS spreads are negatively correlated with Treasury bases which are CIP deviations for government bond yields. They argue that the Treasury basis widens if the demand for USD increases, which is the case when the LIBOR-OIS spread rises. Hence, the OIS-basis likely reflects the demand for USD.

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	-7.779	-5.223**	-2.177*	-2.264*	-1.092	-1.092	0.310
	(4.826)	(1.487)	(0.833)	(0.751)	(0.570)	(0.570)	(0.576)
$\Delta r^{\$}$	53.05***	60.17***	63.62***	64.74***	61.82***	57.06***	51.87***
	(0.147)	(0.336)	(0.523)	(0.815)	(0.839)	(0.763)	(0.916)
$-\Delta r^j$	-10.61**	-20.88***	-26.43***	-27.05***	-27.96***	-25.37***	-23.46***
	(2.576)	(3.846)	(4.180)	(4.147)	(3.943)	(3.558)	(2.782)
$\Delta\rho^j$	-50.21***	-44.48***	-38.99***	-39.44***	-34.89***	-31.09***	-27.90***
	(6.077)	(4.324)	(3.885)	(3.636)	(3.566)	(3.019)	(2.705)
$Target$	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid	-12.26**	-3.705**	-1.541*	-1.513**	-0.758*	-0.758*	0.049
	(3.131)	(0.795)	(0.509)	(0.394)	(0.295)	(0.295)	(0.252)
$\Delta r^{\$}$	39.60***	35.17***	31.81***	29.44***	29.10***	27.80***	26.30***
	(0.023)	(0.477)	(0.387)	(0.393)	(0.580)	(0.590)	(0.749)
$-\Delta r^j$	-7.87***	-12.53**	-14.13***	-13.73***	-13.12***	-11.09***	-9.95***
	(1.349)	(2.644)	(2.675)	(2.637)	(2.417)	(2.310)	(2.065)
$\Delta\rho^j$	-43.99***	-26.35***	-19.09***	-16.98***	-16.78***	-16.66***	-16.25***
	(4.173)	(2.630)	(2.733)	(2.580)	(2.500)	(2.251)	(2.224)
$Path$	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid	3.570	-1.807	-0.785	-0.886	-0.412	0.030	0.230
	(2.471)	(0.810)	(0.439)	(0.445)	(0.356)	(0.376)	(0.371)
$\Delta r^{\$}$	14.37***	26.03***	32.26***	35.37***	32.75***	29.40***	25.84***
	(0.046)	(0.200)	(0.407)	(0.704)	(0.767)	(0.697)	(0.594)
$-\Delta r^j$	-2.993	-8.799***	-12.74***	-13.67***	-14.98***	-14.32***	-13.50***
	(1.848)	(1.832)	(1.919)	(1.901)	(1.828)	(1.521)	(1.011)
$\Delta\rho^j$	-7.803*	-18.98***	-20.19***	-22.39***	-18.10***	-14.67***	-12.00***
	(2.554)	(2.097)	(1.563)	(1.485)	(1.369)	(1.000)	(0.880)

Note. This table presents the decomposition of regression results of cross-currency bases on each US monetary policy shock. The top panel is the decomposition of the effect of NS shock while the bottom panel is the one of target factor. In each panel, the top row shows the total effect of which estimates are from the previous 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. Standard errors clustered across currencies are reported in the parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.2 Term Structure of the effect 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.3, we can see that the first two PCs explain

Table A.2: Decomposition of the Effect of US Monetary Policy Shock on OIS-Basis

	Full Sample						
NS	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid^{ois}	-30.87**	-15.70*	-19.83**	-11.82	1.944	10.09*	1.041
	(8.600)	(5.858)	(3.852)	(5.675)	(6.725)	(4.197)	(3.443)
Δcid^{libor}	-13.96	-5.159*	-4.099	-4.168	-1.747	2.470*	-0.119
	(8.594)	(2.030)	(1.969)	(2.718)	(2.442)	(0.934)	(2.065)
$\Delta(libor^j - ois^j)$	4.055	8.046	3.258	9.847	9.744	7.827	2.596
	(3.239)	(4.510)	(1.490)	(4.942)	(4.399)	(4.523)	(2.945)
$-\Delta(libor^\$ - ois^\$)$	-21.41***	-18.59***	-18.99***	-17.50***	-6.053**	-0.209	-1.436
	(1.341)	(1.172)	(2.103)	(2.023)	(1.535)	(0.144)	(1.673)
$Target$	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid^{ois}	-28.21**	-10.30*	-15.03***	-4.039	2.003	7.244*	4.373
	(7.329)	(3.016)	(1.297)	(5.085)	(3.613)	(2.911)	(3.206)
Δcid^{libor}	-17.08*	-4.292*	-3.388*	-3.104	-1.350	0.944	-1.324
	(6.153)	(1.488)	(1.280)	(1.422)	(1.486)	(1.177)	(1.878)
$\Delta(libor^j - ois^j)$	4.015	5.030	0.604	10.61	7.807**	5.461	6.087
	(2.683)	(2.318)	(1.136)	(5.025)	(1.941)	(2.830)	(2.878)
$-\Delta(libor^\$ - ois^\$)$	-15.96***	-11.03***	-12.25***	-11.55***	-4.454**	0.838***	-0.391
	(0.681)	(0.664)	(0.708)	(1.141)	(1.071)	(0.088)	(2.202)
$Path$	3M	1Y	2Y	3Y	5Y	7Y	10Y
Δcid^{ois}	-6.285	-6.377	-6.377*	-7.508**	0.379	5.110	-0.746
	(2.918)	(3.008)	(2.507)	(1.917)	(3.781)	(2.350)	(1.718)
Δcid^{libor}	0.930	-1.392	-1.120	-1.445	-0.668	1.421	0.429
	(3.773)	(0.780)	(0.798)	(1.347)	(1.155)	(0.683)	(0.858)
$\Delta(libor^j - ois^j)$	0.447	3.184	2.315	0.745	3.378	4.074	-0.600
	(1.389)	(2.344)	(1.445)	(0.711)	(2.675)	(2.438)	(1.513)
$-\Delta(libor^\$ - ois^\$)$	-6.505***	-8.169***	-7.572***	-6.807***	-2.331**	-0.385**	-0.575
	(0.509)	(0.492)	(1.070)	(0.533)	(0.471)	(0.094)	(0.821)

Note. This table presents the decomposition of regression results of OIS bases on each US monetary policy shock. The top panel is the decomposition of the effect of NS shock, the middle panel is the one of target factor, and the bottom panel is the one of path factor. In each panel, the top row shows the total effect. The below three rows are decomposed effects respectively, and they sum up to the total effect. Units of the estimates are in basis points. Standard errors clustered across currencies are reported in the parentheses. Note that the regression coefficients for Δcid^{libor} are different from the baseline estimation in Table 2 due to the different sample periods. We have less data for the OIS rates than LIBOR rates. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

about 68.5% - 90.9% 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.4 displays factor loadings on PC1 and PC2 for each currency and each maturity. The upper panel of Table A.4 reports the factor loadings on PC1 while the factor loadings on PC2 are 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

Table A.3: Cumulative Explained Variance of Δcid

Δcid	PC1	PC2	PC3	PC4	PC5
AUD	0.6125	0.7636	0.8699	0.9266	0.9621
CAD	0.7151	0.8525	0.9188	0.9496	0.9731
CHF	0.6937	0.8662	0.9289	0.9558	0.9748
DKK	0.5535	0.7017	0.8348	0.8956	0.9366
EUR	0.7538	0.9088	0.9565	0.9747	0.9857
GBP	0.6601	0.8399	0.9050	0.9432	0.9682
JPY	0.7049	0.8784	0.9389	0.9658	0.9821
NOK	0.5298	0.6845	0.7929	0.8587	0.9185
NZD	0.6176	0.7652	0.8859	0.9314	0.9623
SEK	0.6384	0.8058	0.8991	0.9371	0.9630

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

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.4: Factor Loadings on PC1 and PC2 across Maturities

PC1	AUD	CAD	CHF	DKK	EUR	GBP	JPY	NOK	NZD	SEK
3m	0.0429	0.2046	0.2359	0.1391	0.2721	0.2407	0.2248	0.1800	0.0731	0.1738
1y	0.4064	0.3668	0.3563	0.3854	0.3626	0.3351	0.3692	0.3409	0.3472	0.3612
2y	0.4242	0.4064	0.4077	0.4097	0.4092	0.4161	0.4136	0.4256	0.4213	0.3993
3y	0.4557	0.4190	0.4258	0.4107	0.4143	0.4305	0.4314	0.4557	0.4418	0.4211
5y	0.4427	0.4043	0.4069	0.4393	0.4082	0.4301	0.4172	0.4155	0.4423	0.4226
7y	0.3702	0.3989	0.3990	0.3905	0.3924	0.3877	0.3919	0.4026	0.4088	0.4131
10y	0.3353	0.4004	0.3808	0.3875	0.3672	0.3689	0.3582	0.3575	0.3724	0.3915
PC2	AUD	CAD	CHF	DKK	EUR	GBP	JPY	NOK	NZD	SEK
3m	0.8935	0.8354	0.6422	0.4235	0.6581	0.6468	0.6666	0.6813	0.8566	0.6717
1y	0.1975	0.2909	0.4298	0.3300	0.4491	0.4928	0.3733	0.4027	0.3224	0.3954
2y	0.1480	0.1246	0.2271	0.3661	0.1397	0.1405	0.2229	0.1913	0.1440	0.2735
3y	0.0352	-0.0550	0.0130	0.2922	-0.0404	-0.0259	0.0319	0.0833	0.0384	0.0554
5y	-0.0367	-0.1937	-0.2919	-0.1944	-0.2313	-0.2028	-0.2413	-0.2372	-0.1391	-0.2579
7y	-0.2139	-0.2917	-0.3515	-0.4649	-0.3506	-0.3517	-0.3695	-0.3593	-0.2254	-0.3445
10y	-0.3041	-0.2762	-0.3773	-0.4882	-0.4094	-0.3918	-0.4133	-0.3805	-0.2645	-0.3597

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.5 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.5, NS is estimated to have significantly negative effect on PC1, and its effect on PC2 is also negative although it is insignificant.[35] As the baseline estimation results, $Path$ has insignificant effect on both PC1 and PC2 while $Target$ has significantly negative effect on both factors. 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 the loadings on short-term basis were positive while those on long-term basis were negative. Combining these two observations, the decline in short-term Δcid is amplified while the effect on long-term Δcid is dampened due to the two offsetting forces. This makes β_h more negative for short-term CIP deviation and nearly zero for long-term CIP deviation, which sheds light on the term structure of β^h mentioned previously.

Next, principal components of Δcid are extracted for pre-GFC and post-GFC periods separately. Similar to the above argument, principal components for each currency are extracted from Δcid across maturities. Table A.6 shows cumulative explained variance of Δcid up to three factors for pre-GFC and post-GFC periods. In general, cumulative explained variance is larger for post-GFC periods than pre-GFC periods, except NOK, implying that the small number of factors has larger explanatory power for CIP deviations. This suggests the importance of some common factors after the Global Financial Crisis, including the US monetary policy, which reinforces the motivation of this paper.

In Table A.7, loadings on the first and the second principal components are displayed. The upper panel of Table A.7 shows the loadings on PC1 while the loadings on PC2 are shown in the lower panel. Each row of the panel is the maturity while each column is currency. In each column, loadings for pre-GFC and post-GFC periods are displayed separately. As the estimation results from

[35] The p-value of β when PC2 is the dependent variable is 5.1%, which is slightly over the significance level 5%.

Table A.5: Principal Components of Δcid and the US Monetary Policy

	Full Sample			
	PC1		PC2	
	(1)	(2)	(3)	(4)
NS	-2.619*		-1.687	
	(1.033)		(0.751)	
Target		-2.080**		-1.815**
		(0.506)		(0.409)
Path		-0.688		0.035
		(0.629)		(0.434)
R^2	0.012	0.017	0.024	0.043
N	1441	1441	1441	1441

Note. This table presents the regression results of principal components of Δcid on 1%p contractionary US monetary policy shock. For each principal component, there are two columns: the left column is the estimation result when NS is used as the US monetary policy shock whereas the right column is the one when $Target$ and $Path$ are used as proxies for the shock. Standard errors clustered across currencies are reported in the parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.6: Cumulative Explained Variance of Δcid: Pre-GFC v.s. Post-GFC

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

Note. This table presents cumulative explained variance in Δcid. For each currency, principal components of Δcid with maturities of 3-month, 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year are extracted for pre-GFC (00-07) and post-GFC (08-) periods separately. Three principal components are displayed in this table for simplicity.

the whole sample period, PC1 and PC2 are level and slope factor respectively for both pre-GFC and post-GFC periods. Regarding the level factor, loadings on this factor do not show stark difference between the two periods. What is remarkable in this table is that the slope of the slope factor is much steeper for post-GFC periods than pre-GFC periods. Considering that the term structure of β_h comes from the level factor, this helps explain the term structure shown in Table 3.

In Table A.8, US monetary policy shock does not have significant effects on PC1 and PC2

Table A.7: Factor Loadings on PC1 and PC2 across Maturities: Pre-GFC v.s. Post-GFC

PC1	AUD		CAD		CHF		DKK		EUR	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	-0.0017	0.0471	0.0735	0.2177	-0.0079	0.2402	0.0875	0.1443	0.1004	0.2803
1y	0.1996	0.4132	0.3654	0.3669	0.1820	0.3563	0.3697	0.3855	0.2896	0.3626
2y	0.3827	0.4247	0.4162	0.4052	0.2995	0.4079	0.4173	0.4090	0.3708	0.4082
3y	0.4338	0.4562	0.4342	0.4173	0.3320	0.4287	0.4444	0.4099	0.3487	0.4136
5y	0.4556	0.4447	0.4348	0.4018	0.4999	0.4046	0.4327	0.4389	0.4561	0.4067
7y	0.4599	0.3638	0.4143	0.3967	0.5082	0.3973	0.4182	0.3899	0.4765	0.3909
10y	0.4542	0.3293	0.3723	0.4011	0.5086	0.3790	0.3491	0.3881	0.4604	0.3662
	GBP		JPY		NOK		NZD		SEK	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	0.0886	0.2455	0.0597	0.2387	-0.0266	0.2055	-0.0221	0.0867	-0.0225	0.1841
1y	0.2741	0.3344	0.3077	0.3707	0.3604	0.3424	0.3157	0.3454	0.2211	0.3609
2y	0.3992	0.4154	0.3939	0.4136	0.4028	0.4266	0.4591	0.4165	0.3647	0.3970
3y	0.4636	0.4303	0.4442	0.4298	0.4198	0.4565	0.3990	0.4431	0.3988	0.4204
5y	0.4695	0.4287	0.4500	0.4146	0.4255	0.4115	0.5167	0.4369	0.4461	0.4233
7y	0.3990	0.3884	0.4398	0.3886	0.4207	0.3975	0.4305	0.4071	0.4883	0.4122
10y	0.4039	0.3683	0.3916	0.3562	0.4157	0.3504	0.2785	0.3831	0.4703	0.3905
PC2	AUD		CAD		CHF		DKK		EUR	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	0.5154	0.9041	0.6797	0.8265	0.1650	0.6450	0.2441	0.4190	0.4848	0.6502
1y	0.6870	0.1765	0.3540	0.3010	0.5585	0.4279	0.4763	0.3293	0.5726	0.4539
2y	0.3342	0.1354	0.3136	0.1178	0.5755	0.2218	0.4604	0.3660	0.3574	0.1383
3y	0.0664	0.0284	0.1289	-0.0650	0.3456	0.0080	0.1350	0.2945	0.1896	-0.0453
5y	-0.1469	-0.0263	-0.1975	-0.1959	-0.1538	-0.2952	-0.2231	-0.1961	-0.2154	-0.2342
7y	-0.2146	-0.2133	-0.3207	-0.3020	-0.3009	-0.3507	-0.4229	-0.4676	-0.3183	-0.3539
10y	-0.2804	-0.2934	-0.3949	-0.2804	-0.3099	-0.3760	-0.5048	-0.4882	-0.3545	-0.4122
	GBP		JPY		NOK		NZD		SEK	
	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC	Pre-GFC	Post-GFC
3m	0.1510	0.6473	0.7657	0.6554	0.9983	0.6550	-0.0082	0.8741	-0.0281	0.6912
1y	0.4210	0.4962	0.4221	0.3732	0.0036	0.4091	-0.3567	0.3111	0.6261	0.3853
2y	0.4097	0.1363	0.2576	0.2219	-0.0237	0.1891	-0.2287	0.1277	0.5125	0.2616
3y	0.3840	-0.0350	0.0402	0.0295	-0.0094	0.0786	-0.4442	0.0114	0.2489	0.0364
5y	-0.1932	-0.2041	-0.1717	-0.2473	0.0313	-0.2486	0.0442	-0.1463	-0.2169	-0.2566
7y	-0.4639	-0.3493	-0.2496	-0.3776	0.0279	-0.3762	0.4410	-0.2162	-0.3283	-0.3392
10y	-0.4817	-0.3890	-0.2753	-0.4211	0.0327	-0.3979	0.6532	-0.2338	-0.3574	-0.3509

Note. This table presents factor loadings on the first two principal components for each currency and for pre-GFC (00-07) and post-GFC (08-) periods. The first panel shows the factor loadings on the first principal component while the second panel displays those on the second principal component. Each column indicates factor loadings for each G10 currency. In a column, there are two subcolumns: left subcolumn is the factor loadings for pre-GFC periods while the right subcolumn is the ones for post-GFC periods. Elements of subcolumns are factor loadings for each maturity from 3-month to 10-year.

during pre-GFC periods while the effect is significant during post-GFC periods. This is obvious since the effect on CIP deviations is also significant only for post-GFC periods, and principal components summarize overall information in CIP deviations. In response to US monetary policy shock, both PC1 and PC2 declines during post-GFC periods. As PC1 is the level factor and the loadings are positive, β_h declines almost uniformly across all maturities. On the other hand, the decline in PC2 leads to lower β_h for short-term maturities while higher β_h for long-term maturities since PC2 is the slope factor. Combining the effects from PC1 and PC2, the effect on short-term basis becomes strengthened while the effect on long-term basis is muted. Moreover, since the slope of the slope factor is steeper for post-GFC periods, the difference between short-term and long-term β_h is starker for post-GFC periods than the whole sample period.

Table A.8: Principal Components and the US Monetary Policy: Pre-GFC v.s. Post-GFC

	PC1			PC2		
	Pre-GFC	Post-GFC	Diff	Pre-GFC	Post-GFC	Diff
NS	0.450	-6.768*	-7.218*	0.490	-4.652*	-5.143**
	(0.322)	(2.608)	(2.669)	(0.303)	(1.603)	(1.502)
R^2			0.026			0.051
Target	0.155	-5.519**	-5.673**	0.321	-5.360***	-5.681***
	(0.305)	(1.369)	(1.501)	(0.207)	(0.973)	(0.957)
Path	0.293	-1.266	-1.559	0.186	0.823	0.638
	(0.148)	(1.486)	(1.461)	(0.221)	(0.908)	(0.861)
R^2			0.038			0.113
N			1441			1441

Note. This table presents the regression results of principal components of Δcid on 1%p contractionary US monetary policy shock for pre-GFC (00-07) and post-GFC (08-) periods. For each principal component, there are three columns: estimation results for pre-GFC periods, post-GFC periods, and their differences. The top row is the estimation results when NS is used as the proxy for US monetary policy shock while the bottom rows are the results from using $Target$ and $Path$ as monetary policy shocks. Standard errors clustered across currencies are reported in the parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.3 Signalling Channel of US Monetary Policy

The results of (2.3) are reported in Table A.9. 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 0.14 - 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 0.533, so the signaling channel does not exist for the target factor. Nevertheless, information-robust version of $Target$ will be used in order to compare the information-robust shock with the baseline shock.

Table A.9: Signaling Channel of US Monetary Policy

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

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. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix B 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

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

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

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

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

$$\nu_{H,t} \equiv E_t\left[\Omega_{t,t+1}\left(R_{K,t+1} - R_t\right)\right] \tag{B.2}$$

$$\nu_{X,t} \equiv E_t\left[\Omega_{t,t+1}\right]\left(R_t^*\frac{S_t}{F_t} - R_t\right) \tag{B.3}$$

$$\nu_{N,t} \equiv E_t\left[\Omega_{t,t+1}\right] R_t \tag{B.4}$$

the Bellman equation becomes

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

Then, we can obtain the first-order conditions as

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

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

for the Lagrangian multiplier μ_t of the leverage constraint.

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

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

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,

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

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

Aggregating the leverage constraint (3.22) over all banks, we can obtain the relationship between leverage ratios and the franchise value as

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

The proof for non-US banks are the same. From (3.39), (3.40), (3.41), and (3.34),

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

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,

$$\phi_{F,t}^* = \frac{Q_t^* K_{F,t}^*}{N_t^*} \tag{B.12}$$

$$\phi_{H,t}^* = \frac{S_t Q_t K_{H,t}^*}{N_t^*} \tag{B.13}$$

$$\nu_t^* = \frac{1}{\mu_t^*}\left(\nu_{F,t}^* \phi_{F,t}^* + \nu_{H,t}^* (1 - x_t^*) \phi_{H,t}^* + \nu_{X,t}^* x_t^* \phi_{H,t}^*\right) \tag{B.14}$$

Appendix C 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.

C.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

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

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

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

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

for the SDF of the household defined as

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

C.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

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

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

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

we can get the optimality condition as

$$Q_t^* = P_t^* \left(1 + \psi_K \left(\frac{I_t^*}{K_{t-1}^*} - \delta \right) \right) - E_t \left[\Lambda_{t,t+1}^* P_{t+1}^* \psi_K \left(\frac{I_{t+1}^*}{K_t^*} - \delta \right) \frac{I_{t+1}^*}{K_t^*} \right] \tag{C.6}$$

C.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

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

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

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,

$$P_{H,t}^* = P_t^* \left[\omega T_t^{*1-\nu} + 1 - \omega\right]^{-\frac{1}{1-\nu}} \tag{C.9}$$

$$P_{F,t}^* = P_t^* \left[\omega + (1-\omega) T_t^{*-(1-\nu)}\right]^{-\frac{1}{1-\nu}} \tag{C.10}$$

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:

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

Then, we can obtain the following demand functions:

$$I_{F,t}^* = \omega\Big(\frac{P_{F,t}^*}{P_t^*}\Big)^{-\nu}\Big[I_t^* + K_{t-1}^* \frac{\psi_K}{2}\Big(\frac{I_t^*}{K_{t-1}^*} - \delta\Big)^2\Big] \tag{C.11}$$

$$I_{H,t}^* = (1-\omega)(\frac{P_{H,t}^*}{P_t^*}\Big)^{-\nu}\Big[I_t^* + K_{t-1}^* \frac{\psi_K}{2}\Big(\frac{I_t^*}{K_{t-1}^*} - \delta\Big)^2\Big] \tag{C.12}$$

C.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

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

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

C.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

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

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

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

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

for the marginal cost MC_t^* given by

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

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 (C.13) and (C.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:

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

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

C.6 Non-US Monetary Policy

Monetary policy of the EU is

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

where

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

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

C.7 Non-US Fiscal Policy

As the US, the fiscal policy of the EU is

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

C.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,

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

$$\mathcal{E}_t^F = \mathcal{E}_t^H \frac{T_t}{T_t^*} \tag{C.25}$$

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

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

$$K_t^* = K_{F,t}^* \tag{C.27}$$

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),

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

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

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

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

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

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

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

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

Appendix D Equilibrium Equations

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

Here, we converted nominal variables into real variables as

$$\mathcal{E}_t \equiv \frac{S_t P_t}{P^*_t} \quad , \quad f_t \equiv \frac{F_t P^*_t}{P_t}$$
$$\Pi_t \equiv \frac{P_t}{P_{t-1}} \quad , \quad \Pi^*_t \equiv \frac{P^*_t}{P^*_{t-1}} \quad , \quad \Pi^S_t \equiv \frac{S_t}{S_{t-1}}$$
$$p_{H,t} \equiv \frac{P_{H,t}}{P_t} \quad , \quad p_{F,t} \equiv \frac{P_{F,t}}{P_t}$$
$$p^*_{H,t} \equiv \frac{P^*_{H,t}}{P^*_t} \quad , \quad p^*_{F,t} \equiv \frac{P^*_{F,t}}{P^*_t}$$
$$n_t \equiv \frac{N_t}{P_t} \quad , \quad n^*_t \equiv \frac{N^*_t}{P^*_t}$$
$$x_t \equiv \frac{X_t}{P_t} \quad , \quad q_t \equiv \frac{Q_t}{P_t} \quad , \quad q^*_t \equiv \frac{Q^*_t}{P^*_t}$$
$$w_t \equiv \frac{W_t}{P_t} \quad , \quad w^*_t \equiv \frac{W^*_t}{P^*_t}$$
$$\tilde{r}_t \equiv \frac{\tilde{R}_t}{P_t} \quad , \quad \tilde{r}^*_t \equiv \frac{\tilde{R}^*_t}{P^*_t}$$
$$mc_t \equiv \frac{MC_t}{P_t} \quad , \quad mc^*_t \equiv \frac{MC^*_t}{P^*_t}$$
$$tr_t \equiv \frac{TR_t}{P_t} \quad , \quad tr^*_t \equiv \frac{TR^*_t}{P^*_t}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\nu_{X,t} = E_t\left[\Omega_{t,t+1}\right]\left(R_t^* \frac{\mathcal{E}_t}{f_t} - R_t\right) \tag{D.18}$$

$$\nu_{N,t} = E_t\left[\Omega_{t,t+1}\right] R_t \tag{D.19}$$

$$\nu_{H,t} = \mu_t \Theta_t (\theta_{H1} + \theta_{H2} q_t K_{H,t}) \tag{D.20}$$

$$\nu_{X,t} = \mu_t \Theta_t (\theta_{X1} + \theta_{X2} x_t) \tag{D.21}$$

$$\nu_t = \frac{\nu_{N,t}}{1 - \mu_t} \tag{D.22}$$

$$\phi_{H,t} = \frac{q_t K_{H,t}}{n_t} \tag{D.23}$$

$$\phi_{X,t} = \frac{x_t}{n_t} \tag{D.24}$$

$$\nu_t = \frac{1}{\mu_t}(\nu_{H,t}\phi_{H,t} + \nu_{X,t}\phi_{X,t}) \tag{D.25}$$

$$n_{t+1} = \sigma \left[(R_{K,t+1} - R_t)\phi_{H,t} + \left(R_t^* \frac{\mathcal{E}_t}{f_t} - R_t \right) \phi_{X,t} + R_t \right] \frac{n_t}{\Pi_{t+1}}$$

$$+ (1-\sigma)\xi(\phi_{H,t} + \phi_{X,t}) \frac{n_t}{\Pi_{t+1}} \tag{D.26}$$

$$\nu_{F,t}^* = E_t \left[\Omega_{t,t+1}^* (R_{K,t+1}^* - R_t^*) \right] \tag{D.27}$$

$$\nu_{H,t}^* = E_t \left[\Omega_{t,t+1}^* \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{1}{\Pi_{t+1}^S} \right) \right] \tag{D.28}$$

$$\nu_{X,t}^* = E_t \left[\Omega_{t,t+1}^* \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{\mathcal{E}_t}{f_t} \right) \right] \tag{D.29}$$

$$\nu_{N,t}^* = E_t \left[\Omega_{t,t+1}^* \right] R_t^* \tag{D.30}$$

$$\nu_{F,t}^* = \mu_t^* \Theta_t (\theta_{F1}^* + \theta_{F2}^* q_t^* K_{F,t}^*) \tag{D.31}$$

$$\nu_{H,t}^* = \mu_t^* \Theta_t (\theta_{H1}^* + \theta_{H2}^* (1 - x_t^*) \mathcal{E}_t q_t K_{H,t}^*) \tag{D.32}$$

$$\nu_{X,t}^* = \mu_t^* \Theta_t (\theta_{X1}^* + \theta_{X2}^* x_t^* \mathcal{E}_t q_t K_{H,t}^*) \tag{D.33}$$

$$\nu_t^* = \frac{\nu_{N,t}^*}{1 - \mu_t^*} \tag{D.34}$$

$$\phi_{F,t}^* = \frac{q_t^* K_{F,t}^*}{n_t^*} \tag{D.35}$$

$$\phi_{H,t}^* = \frac{\mathcal{E}_t q_t K_{H,t}^*}{n_t^*} \tag{D.36}$$

$$\nu_t^* = \frac{1}{\mu_t^*} (\nu_{F,t}^* \phi_{F,t}^* + \nu_{H,t}^* (1 - x_t^*) \phi_{H,t}^* + \nu_{X,t}^* x_t^* \phi_{H,t}^*) \tag{D.37}$$

$$n_{t+1}^* = \sigma \Bigg[(R_{K,t+1}^* - R_t^*)\phi_{F,t}^* + \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{1}{\Pi_{t+1}^S} \right) (1 - x_t^*) \phi_{H,t}^*$$

$$+ \Pi_{t+1}^S \left(R_{K,t+1} - R_t^* \frac{\mathcal{E}_t}{f_t} \right) x_t^* \phi_{H,t}^* + R_t^* \Bigg] \frac{n_t^*}{\Pi_{t+1}^*} + (1-\sigma)\xi^* (\phi_{F,t}^* + \phi_{H,t}^*) \frac{n_t^*}{\Pi_{t+1}^*} \tag{D.38}$$

$$K_t = I_t + (1-\delta) K_{t-1} \tag{D.39}$$

$$K_t^* = I_t^* + (1-\delta) K_{t-1}^* \tag{D.40}$$

$$q_t = 1 + \psi_K \Big(\frac{I_t}{K_{t-1}} - \delta \Big) - E_t \Big[\Lambda_{t,t+1} \Pi_{t+1} \psi_K \Big(\frac{I_{t+1}}{K_t} - \delta \Big) \frac{I_{t+1}}{K_t} \Big] \tag{D.41}$$

$$q_t^* = 1 + \psi_K \big(\frac{I_t^*}{K_{t-1}^*} - \delta \big) - E_t \Big[\Lambda_{t,t+1}^* \Pi_{t+1}^* \psi_K \Big(\frac{I_{t+1}^*}{K_t^*} - \delta \Big) \frac{I_{t+1}^*}{K_t^*} \Big] \tag{D.42}$$

$$w_t = (1-\alpha) mc_t \frac{Y_t}{L_t} \tag{D.43}$$

$$\tilde{r}_{K,t} = \alpha mc_t \frac{Y_t}{K_{t-1}} \tag{D.44}$$

$$mc_t = \frac{1}{Z_t} \frac{w_t^{1-\alpha} \tilde{r}_{K,t}^{\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}} \tag{D.45}$$

$$w_t^* = (1-\alpha)mc_t^* \frac{Y_t^*}{L_t^*} \tag{D.46}$$

$$\tilde{r}_{K,t}^* = \alpha mc_t^* \frac{Y_t^*}{K_{t-1}^*} \tag{D.47}$$

$$mc_t^* = \frac{1}{Z_t^*} \frac{w_t^{*1-\alpha} \tilde{r}_{K,t}^{*\alpha}}{(1-\alpha)^{1-\alpha}\alpha^\alpha} \tag{D.48}$$

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \Pi_t^{\phi_\pi(1-\rho_R)} \epsilon_{R,t} \tag{D.49}$$

$$\frac{R_t^*}{\bar{R}^*} = \left(\frac{R_{t-1}^*}{\bar{R}^*}\right)^{\rho_R} \Pi_t^{*\phi_\pi(1-\rho_R)} \epsilon_{R,t}^* \tag{D.50}$$

$$tr_t + s\left(p_{H,t}Y_{H,t} + \frac{1}{\mathcal{E}_t} p_{H,t}^* Y_{H,t}^*\right) = 0 \tag{D.51}$$

$$tr_t^* + s^*(p_{F,t}^* Y_{F,t}^* + \mathcal{E}_t p_{F,t} Y_{F,t}) = 0 \tag{D.52}$$

$$\begin{aligned}(1+s)(\epsilon-1) &= \epsilon \frac{mc_t}{p_{H,t}} - \psi_P\Big(\frac{p_{H,t}}{p_{H,t-1}}\Pi_t - 1\Big)\frac{p_{H,t}}{p_{H,t-1}}\Pi_t \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\Big(\frac{p_{H,t+1}}{p_{H,t}}\Pi_{t+1} - 1\Big)\Big(\frac{p_{H,t+1}}{p_{H,t}}\Pi_{t+1}\Big)^2\Big(\frac{Y_{H,t+1}}{Y_{H,t}}\Big)\right]\end{aligned} \tag{D.53}$$

$$\begin{aligned}(1+s)(\epsilon-1) &= \epsilon \frac{\mathcal{E}_t mc_t}{p_{H,t}^*} - \psi_P\Big(\frac{p_{H,t}^*}{p_{H,t-1}^*}\Pi_t^* - 1\Big)\frac{p_{H,t}^*}{p_{H,t-1}^*}\Pi_t^* \\ &+ E_t\left[\Lambda_{t,t+1}\psi_P\Big(\frac{p_{H,t+1}^*}{p_{H,t}^*}\Pi_{t+1}^* - 1\Big)\Big(\frac{p_{H,t+1}^*}{p_{H,t}^*}\Pi_{t+1}^*\Big)^2\Big(\frac{1}{\Pi_{t+1}^S}\Big)\Big(\frac{Y_{H,t+1}^*}{Y_{H,t}^*}\Big)\right]\end{aligned} \tag{D.54}$$

$$\begin{aligned}(1+s^*)(\epsilon-1) &= \epsilon \frac{mc_t^*}{p_{F,t}^*} - \psi_P\Big(\frac{p_{F,t}^*}{p_{F,t-1}^*}\Pi_t^* - 1\Big)\frac{p_{F,t}^*}{p_{F,t-1}^*}\Pi_t^* \\ &+ E_t\left[\Lambda_{t,t+1}^*\psi_P\Big(\frac{p_{F,t+1}^*}{p_{F,t}^*}\Pi_{t+1}^* - 1\Big)\Big(\frac{p_{F,t+1}^*}{p_{F,t}^*}\Pi_{t+1}^*\Big)^2\Big(\frac{Y_{F,t+1}^*}{Y_{F,t}^*}\Big)\right]\end{aligned} \tag{D.55}$$

$$\begin{aligned}(1+s^*)(\epsilon-1) &= \epsilon \frac{mc_t^*}{\mathcal{E}_t p_{F,t}} - \psi_P\Big(\frac{p_{F,t}}{p_{F,t-1}}\Pi_t - 1\Big)\frac{p_{F,t}}{p_{F,t-1}}\Pi_t \\ &+ E_t\left[\Lambda_{t,t+1}^*\psi_P\Big(\frac{p_{F,t+1}}{p_{F,t}}\Pi_{t+1} - 1\Big)\Big(\frac{p_{F,t+1}}{p_{F,t}}\Pi_{t+1}\Big)^2\Pi_{t+1}^S\Big(\frac{Y_{F,t+1}}{Y_{F,t}}\Big)\right]\end{aligned} \tag{D.56}$$

$$\Big[1 - \frac{\psi_P}{2}\Big(\frac{p_{H,t}}{p_{H,t-1}}\Pi_t - 1\Big)^2\Big]Y_{H,t} = \omega p_{H,t}^{-\nu}\Big(C_t + I_t + \frac{\psi_K}{2}K_{t-1}\Big(\frac{I_t}{K_{t-1}} - \delta\Big)^2\Big) \tag{D.57}$$

$$\Big[1 - \frac{\psi_P}{2}\Big(\frac{p_{H,t}^*}{p_{H,t-1}^*}\Pi_t^* - 1\Big)^2\Big]Y_{H,t}^* = (1-\omega)p_{H,t}^{*-\nu}\Big(C_t^* + I_t^* + \frac{\psi_K}{2}K_{t-1}^*\Big(\frac{I_t^*}{K_{t-1}^*} - \delta\Big)^2\Big) \tag{D.58}$$

$$Y_t = Y_{H,t} + Y_{H,t}^* \tag{D.59}$$

$$\Big[1 - \frac{\psi_P}{2}\Big(\frac{p_{F,t}^*}{p_{F,t-1}^*}\Pi_t^* - 1\Big)^2\Big]Y_{F,t}^* = \omega p_{F,t}^{*-\nu}\Big(C_t^* + I_t^* + \frac{\psi_K}{2}K_{t-1}^*\Big(\frac{I_t^*}{K_{t-1}^*} - \delta\Big)^2\Big) \tag{D.60}$$

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

$$Y_t^* = Y_{F,t} + Y_{F,t}^* \tag{D.62}$$

$$x_t = x_t^* q_t K_{H,t}^* \tag{D.63}$$

$$K_t = K_{H,t} + K_{H,t}^* \tag{D.64}$$

$$K_t^* = K_{F,t}^* \tag{D.65}$$

$$\begin{aligned}
&p_{H,t}Y_{H,t}\left[1-\frac{\psi_P}{2}\left(\frac{p_{H,t}}{p_{H,t-1}}\Pi_t-1\right)^2\right]+\frac{1}{\mathcal{E}_t}p_{H,t}^*Y_{H,t}^*\left[1-\frac{\psi_P}{2}\left(\frac{p_{H,t}^*}{p_{H,t-1}^*}\Pi_t^*-1\right)^2\right]\\
&-\left(C_t+I_t+\frac{\psi_K}{2}K_{t-1}\Big(\frac{I_t}{K_{t-1}}-\delta\Big)^2\right)-(R_{K,t}-1)\frac{q_{t-1}(1-x_{t-1}^*)K_{H,t-1}^*}{\Pi_t}\\
&-\left(R_{K,t}-R_{t-1}^*\frac{\mathcal{E}_{t-1}}{f_{t-1}}\right)\frac{x_{t-1}}{\Pi_t}=-\left((1-x_t^*)q_tK_{H,t}^*-(1-x_{t-1}^*)\frac{q_{t-1}K_{H,t-1}^*}{\Pi_t}\right)
\end{aligned} \tag{D.66}$$

$$\mathcal{E}_t = \mathcal{E}_{t-1}\frac{\Pi_t^S \Pi_t}{\Pi_t^*} \tag{D.67}$$

$$\log Z_t = \rho_z \log Z_{t-1} + \sigma_z \epsilon_{zt} \tag{D.68}$$

$$\log Z_t^* = \rho_z^* \log Z_{t-1}^* + \sigma_z^* \epsilon_{zt}^* \tag{D.69}$$

$$\log \Theta_t = \rho_\theta \log \Theta_{t-1} + \sigma_\theta \epsilon_{\theta,t} \tag{D.70}$$

$$\log \epsilon_{R,t} = \rho_m \log \epsilon_{R,t-1} + \epsilon_{m,t} \tag{D.71}$$

$$\log \epsilon_{R,t}^* = \rho_m \log \epsilon_{R,t-1}^* + \epsilon_{m,t}^* \tag{D.72}$$

Appendix E 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

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

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

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

$$\mathcal{E} = \mathcal{E}^H \left[\frac{\omega + (1-\omega)T^{1-\nu}}{\omega T^{*1-\nu} + 1 - \omega} \right]^{\frac{1}{1-\nu}} \tag{E.4}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\nu_X = \Omega \left(R^* \frac{\mathcal{E}}{f} - R \right) \tag{E.18}$$

$$\nu_N = \Omega R \tag{E.19}$$

$$\nu_H = \mu(\theta_{H1} + \theta_{H2} q K_H) \tag{E.20}$$

$$\nu_X = \mu(\theta_{X1} + \theta_{X2} x) \tag{E.21}$$

$$\nu = \frac{\nu_N}{1 - \mu} \tag{E.22}$$

$$\phi_H = \frac{q K_H}{n} \tag{E.23}$$

$$\phi_X = \frac{x}{n} \tag{E.24}$$

$$\nu = \frac{1}{\mu}(\nu_H \phi_H + \nu_X \phi_X) \tag{E.25}$$

$$n = \sigma \left[(R_K - R)\phi_H + \left(R^* \frac{\mathcal{E}}{f} - R \right) \phi_X + R \right] n + (1-\sigma)\xi(\phi_H + \phi_X) n \tag{E.26}$$

$$\nu_F^* = \Omega^*(R_K^* - R^*) \tag{E.27}$$

$$\nu_H^* = \Omega^*(R_K - R^*) \tag{E.28}$$

$$\nu_X^* = \Omega^* \left(R_K - R^* \frac{\mathcal{E}}{f} \right) \tag{E.29}$$

$$\nu_N^* = \Omega^* R^* \tag{E.30}$$

$$\nu_F^* = \mu^*(\theta_{F1}^* + \theta_{F2}^* q^* K_F^*) \tag{E.31}$$

$$\nu_X^* = \mu^*(\theta_{H1}^* + \theta_{H2}^*(1 - x^*)\mathcal{E} q K_H^*) \tag{E.32}$$

$$\nu_X^* = \mu^*(\theta_{X1}^* + \theta_{X2}^* x^* \mathcal{E} q K_H^*) \tag{E.33}$$

$$\nu^* = \frac{\nu_N^*}{1 - \mu^*} \tag{E.34}$$

$$\phi_F^* = \frac{q^* K_F^*}{n^*} \tag{E.35}$$

$$\phi_H^* = \frac{\mathcal{E} q K_H^*}{n^*} \tag{E.36}$$

$$\nu^* = \frac{1}{\mu^*}(\nu_F^* \phi_F^* + \nu_H^*(1 - x^*)\phi_H^* + \nu_X^* x^* \phi_H^*) \tag{E.37}$$

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

$$+ (1-\sigma)\xi(\phi_F^* + \phi_H^*) n^* \tag{E.38}$$

$$I = \delta K \tag{E.39}$$

$$I^* = \delta K^* \tag{E.40}$$

$$q = 1 \tag{E.41}$$

$$q^* = 1 \tag{E.42}$$

$$w = (1-\alpha) mc \frac{Y}{L} \tag{E.43}$$

$$\tilde{r}_K = \alpha mc \frac{Y}{K} \tag{E.44}$$

$$mc = \frac{w^{1-\alpha} \tilde{r}_K^{\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}} \tag{E.45}$$

$$w^* = (1-\alpha) mc^* \frac{Y^*}{L^*} \tag{E.46}$$

$$\tilde{r}_K^* = \alpha mc^* \frac{Y^*}{K^*} \tag{E.47}$$

$$mc^* = \frac{w^{*1-\alpha} \tilde{r}_K^{*\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}} \tag{E.48}$$

$$R = \bar{R} \tag{E.49}$$

$$R^* = \bar{R}^* \tag{E.50}$$

$$tr + s\left(p_H Y_H + \frac{1}{\mathcal{E}} p_H^* Y_H^*\right) = 0 \tag{E.51}$$

$$tr^* + s^*(p_F^* Y_F^* + \mathcal{E} p_F Y_F) = 0 \tag{E.52}$$

$$(1+s)(\epsilon - 1) = \epsilon \frac{mc}{p_H} \tag{E.53}$$

$$(1+s)(\epsilon - 1) = \epsilon \frac{\mathcal{E} mc}{p_H^*} \tag{E.54}$$

$$(1+s^*)(\epsilon - 1) = \epsilon \frac{mc^*}{p_F^*} \tag{E.55}$$

$$(1+s^*)(\epsilon - 1) = \epsilon \frac{mc^*}{\mathcal{E} p_F} \tag{E.56}$$

$$Y_H = \omega p_H^{-\nu}(C + I) \tag{E.57}$$

$$Y_H^* = (1-\omega) p_H^{*-\nu}(C^* + I^*) \tag{E.58}$$

$$Y = Y_H + Y_H^* \tag{E.59}$$

$$Y_F^* = \omega p_F^{*-\nu}(C^* + I^*) \tag{E.60}$$

$$Y_F = (1-\omega) p_F^{-\nu}(C + I) \tag{E.61}$$

$$Y^* = Y_F + Y_F^* \tag{E.62}$$

$$x = x^* q K_H^* \tag{E.63}$$

$$K = K_H + K_H^* \tag{E.64}$$

$$K^* = K_F^* \tag{E.65}$$

$$p_H Y_H + \frac{1}{\mathcal{E}} p_H^* Y_H^* - C - I - (R_K - 1)(1 - x^*) q K_H^* - \left(R_K - R^* \frac{\mathcal{E}}{f}\right) x = 0 \tag{E.66}$$

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 (E.13) and (E.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. (E.6) - (E.9) show that price variables are functions of T. Also, the spot exchange rate $\mathcal{E}$ is expressed in terms of T in (E.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 (E.43) - (E.45) and (E.46) - (E.48), 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 NFA in this model is $-(1 - x^*)K_H^*$, the final bullet point of the five empirical moments implies

$$x^* = 1 - \frac{0.185 * 4 * Y}{K_H^*}$$

Then, the balance of payment equation (E.66) 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 (E.59) with resource constraints (E.57) and (E.58),

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

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 (E.57), (E.58), (E.60), and (E.61). The steady-state real forward exchange rate is

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

Real wage w and w^* are obtained from (E.43) and (E.46) 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 (E.51) and (E.52) 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 (E.26) and (E.38),

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

(E.17), (E.18), and (E.19) imply that marginal values of b_H, x and net worth are functions of the US bank's SDF Ω. Plugging these into (E.19) and (E.25), 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 (E.27), (E.28), (E.29) are functions of Ω^*, (E.34) and (E.37) yield

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

(E.15) and (E.16) suggest that Ω is a function of ν while Ω^* is a function of ν^*. From (E.26) and (E.38),

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

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 (E.17)-(E.19). Also, ν_F^*, ν_H^*, ν_X^*, and ν_N^* follow directly from (E.27)-(E.30).

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 et al. (2023). Then, θ_{H1}, θ_{X1}, θ^*_{F1}, θ^*_{H1}, and θ^*_{X1} are calibrated as

$$
\begin{aligned}
\theta_{H1} &= \frac{\nu_H}{\mu} - \theta_{H2} q K_H \\
\theta_{X1} &= \frac{\nu_X}{\mu} - \theta_{X2} x \\
\theta^*_{F1} &= \frac{\nu^*_F}{\mu^*} - \theta^*_{F2} q^* K^*_F \\
\theta^*_{H1} &= \frac{\nu^*_H}{\mu^*} - \theta^*_{H2}(1 - x^*)\mathcal{E} q K^*_H \\
\theta^*_{X1} &= \frac{\nu^*_X}{\mu^*} - \theta^*_{X2} x^* \mathcal{E} q K^*_H
\end{aligned}
$$

Appendix F 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.

F.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

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

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

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

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

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 (F.1) and (F.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

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

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 (F.3) and (F.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:

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

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

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

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

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

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

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

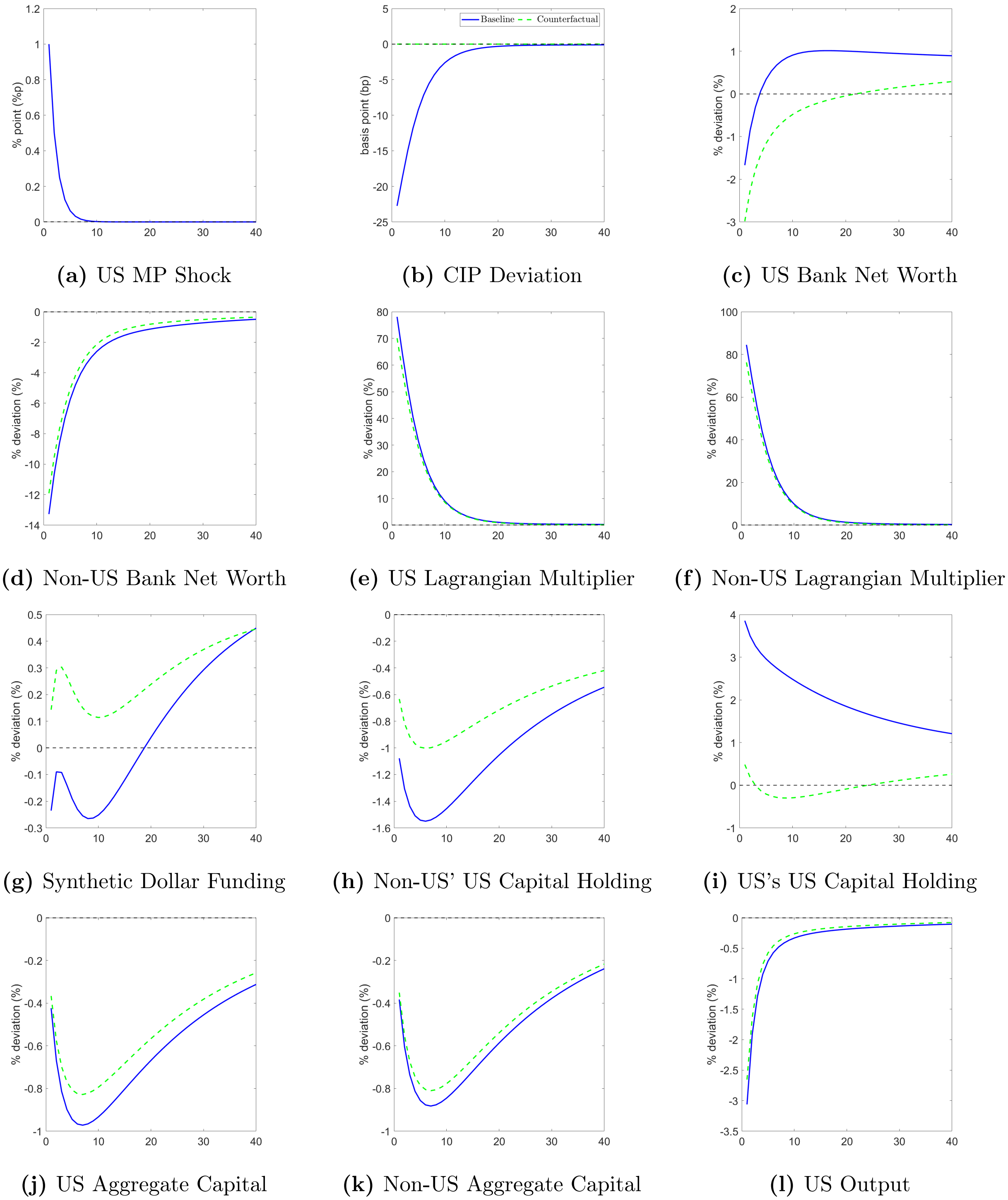
$$\left[1 - \frac{\psi_P}{2}\left(\frac{P^*_{F,t}}{P^*_{F,t-1}} - 1\right)^2\right] Y_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t}\right)^{-\nu} \left(C_t + I_t + K_{t-1}\frac{\psi_K}{2}\Big(\frac{I_t}{K_{t-1}} - \delta\Big)^2\right) \tag{F.11}$$

while the balance of payment equation becomes

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

Figure F.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.



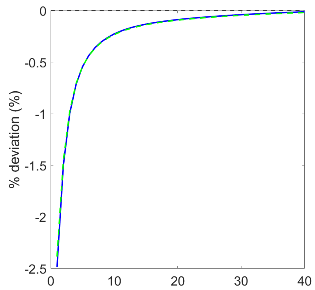
(a) US MP Shock (b) CIP Deviation (c) US Bank Net Worth

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

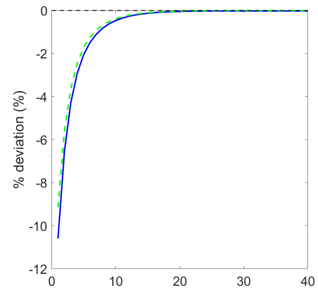
(g) Synthetic Dollar Funding (h) Non-US' US Capital Holding (i) US's US Capital Holding

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

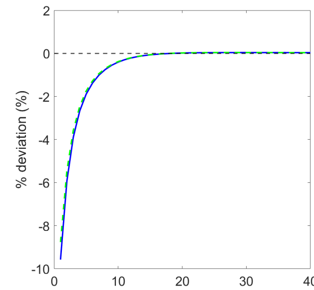
Figure F.1: Impulse Responses to Contractionary US Monetary Policy Shock



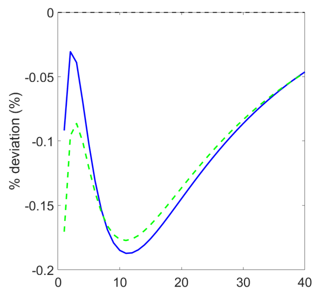
(m) Non-US Output



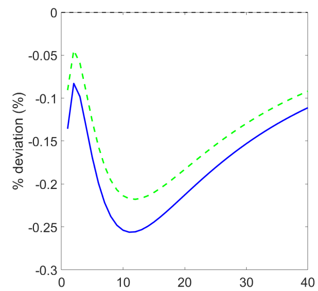
(n) US Investment



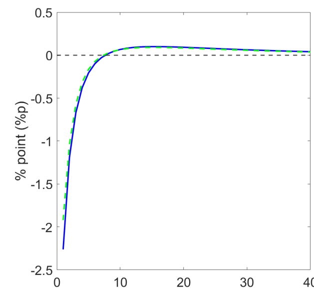
(o) Non-US Investment



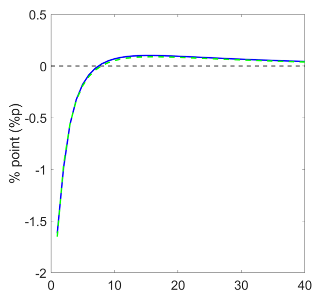
(p) US Consumption



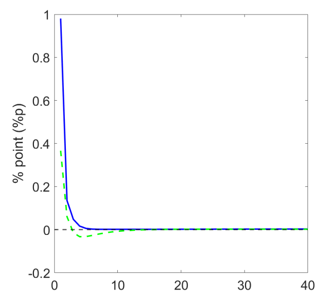
(q) Non-US Consumption



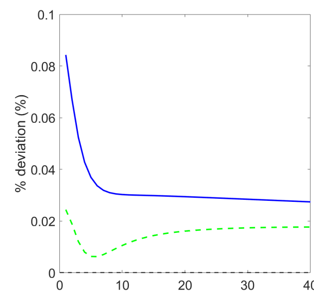
(r) US Inflation



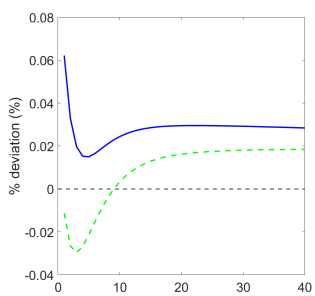
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

Figure F.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.

F.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

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

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

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

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

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

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

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

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:

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

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

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

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

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

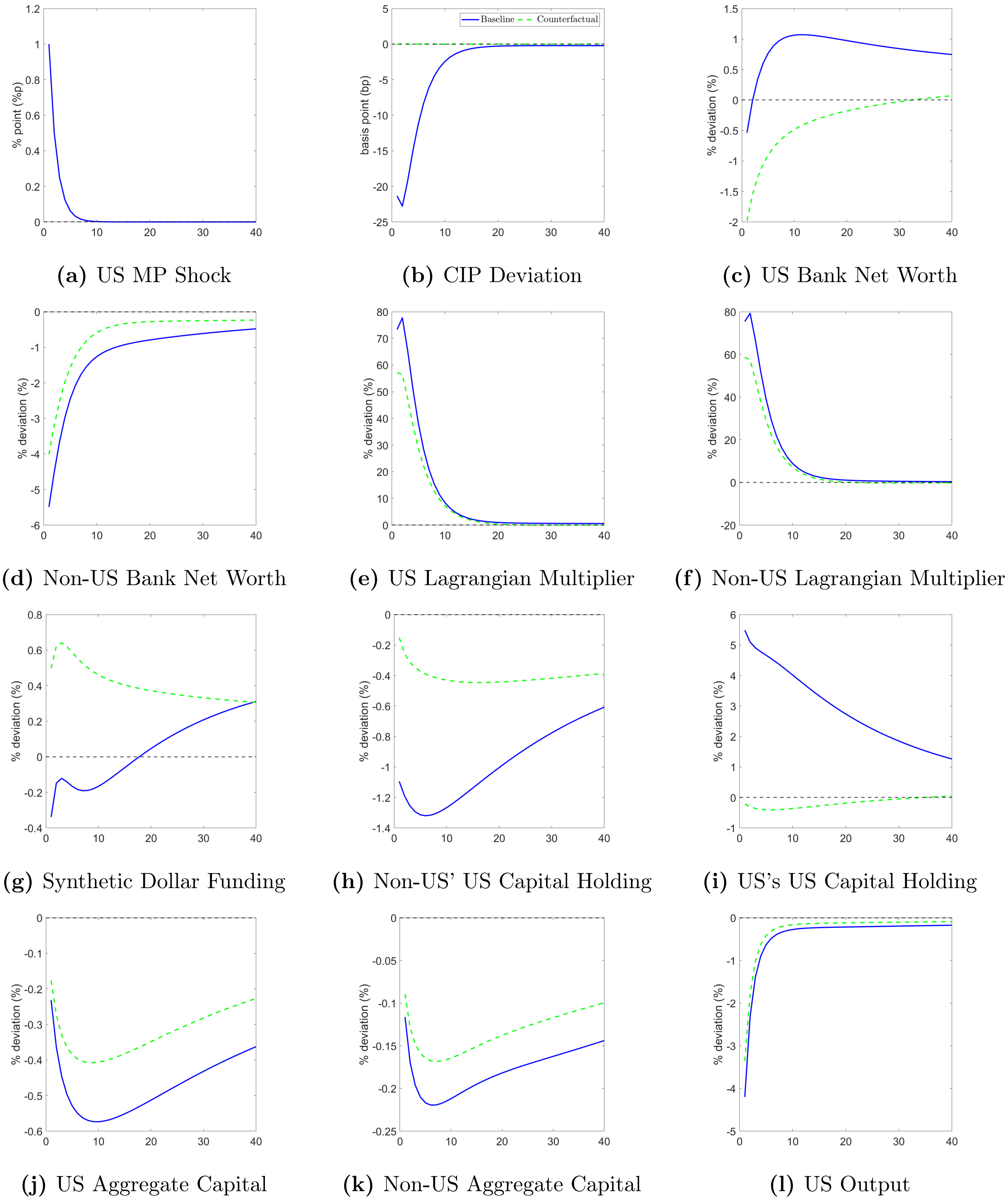
$$\left[1-\frac{\psi_P}{2}\left(\frac{P_{F,t}^*}{P_{F,t-1}^*}-1\right)^2\right]Y_{F,t}^* = \omega\left(\frac{P_{F,t}^*}{P_t^*}\right)^{-\nu}\left(C_t^*+I_t^*+K_{t-1}^*\frac{\psi_K}{2}\left(\frac{I_t^*}{K_{t-1}^*}-\delta\right)^2\right) \tag{F.22}$$

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

while the balance of payment equation is

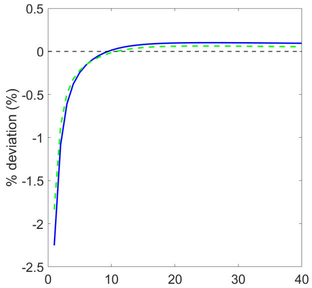
$$\begin{aligned}&\left(1-\frac{\psi_P}{2}\left(\frac{P_{H,t}}{P_{H,t-1}}-1\right)^2\right)P_{H,t}Y_t - P_t\left(C_t+I_t+K_{t-1}\frac{\psi_K}{2}\left(\frac{I_t}{K_{t-1}}-\delta\right)^2\right)\\ &\quad -(R_{K,t}-1)Q_{t-1}(1-x_{t-1}^*)K_{H,t-1}^* - \left\{R_{K,t}-\left(\frac{S_{t-1}}{S_t}R_{t-1}^*+\frac{S_t-F_{t-1}}{S_t}\right)\right\}X_{t-1}\\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

In Figure F.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.

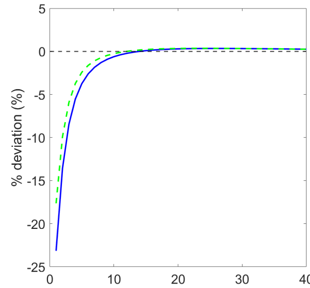


(a) US MP Shock
(b) CIP Deviation
(c) US Bank Net Worth
(d) Non-US Bank Net Worth
(e) US Lagrangian Multiplier
(f) Non-US Lagrangian Multiplier
(g) Synthetic Dollar Funding
(h) Non-US' US Capital Holding
(i) US's US Capital Holding
(j) US Aggregate Capital
(k) Non-US Aggregate Capital
(l) US Output

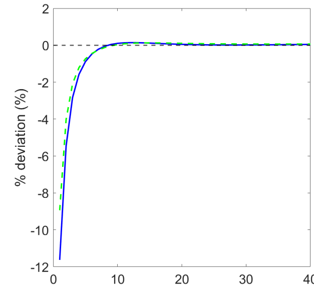
Figure F.2: Impulse Responses to Contractionary US Monetary Policy Shock



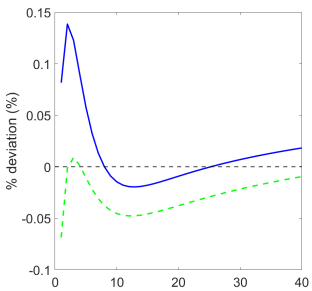
(m) Non-US Output



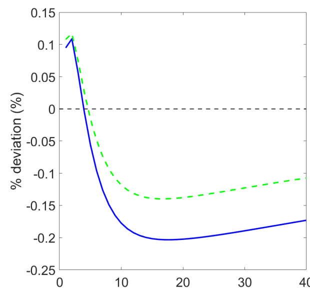
(n) US Investment



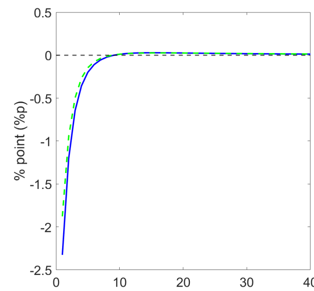
(o) Non-US Investment



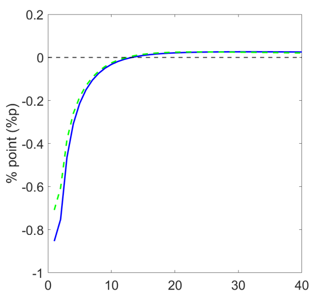
(p) US Consumption



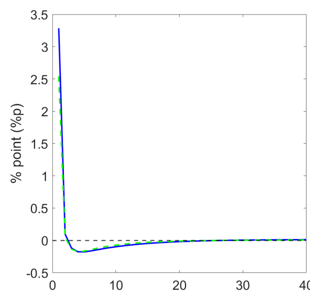
(q) Non-US Consumption



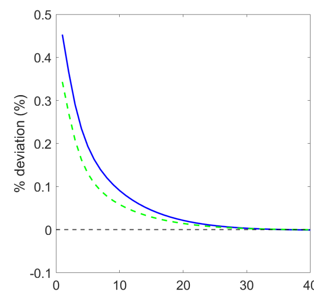
(r) US Inflation



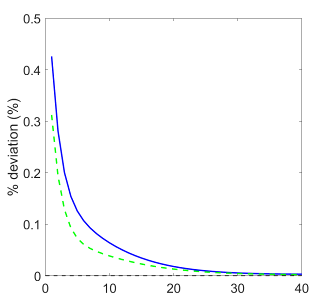
(s) Non-US Inflation



(t) USD Appreciation Rate



(u) Real Spot Exchange Rate



(v) Real Forward Exchange Rate

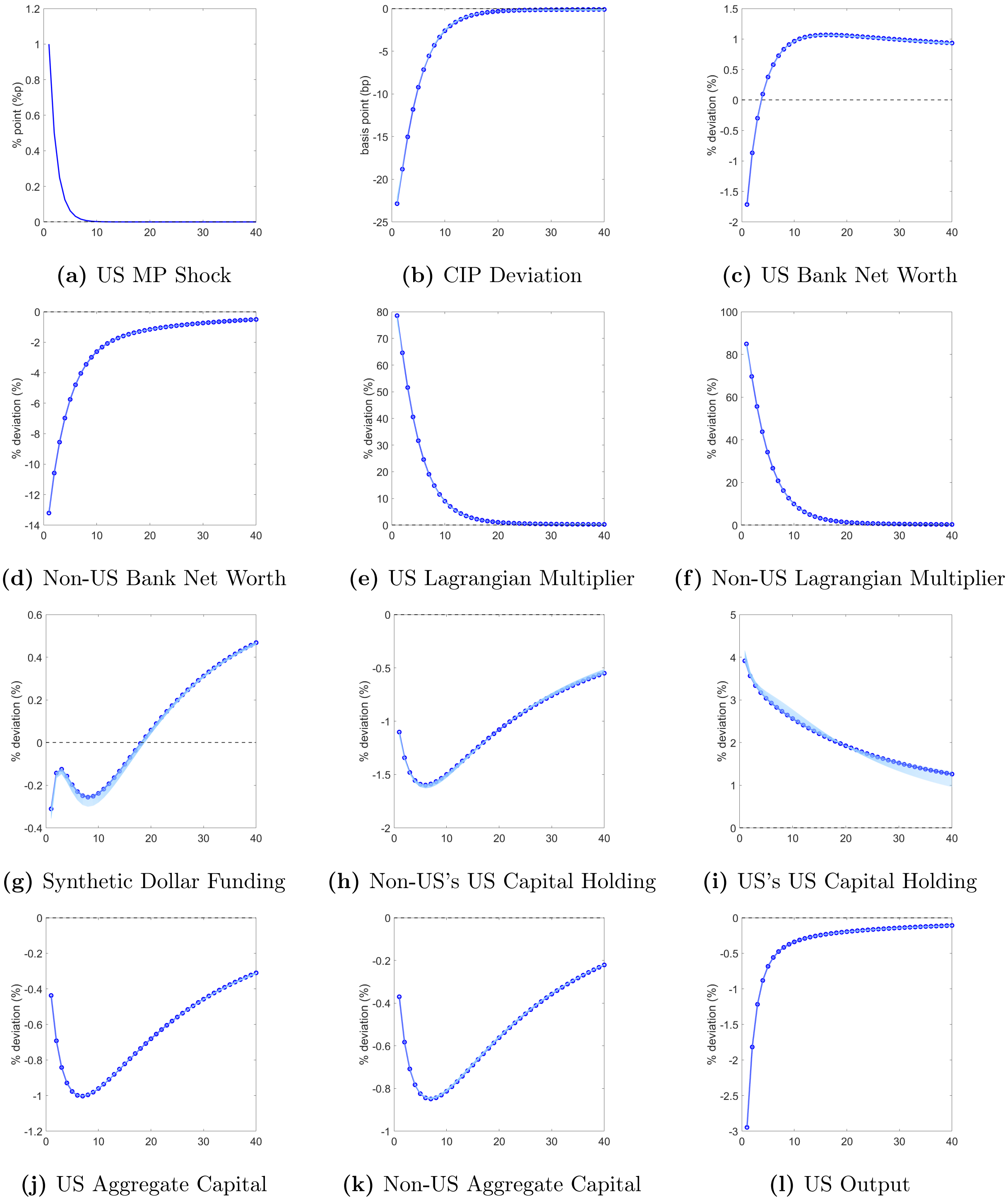
Figure F.2: Impulse Responses to Contractionary US Monetary Policy Shock (Continued)

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 G 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 G.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

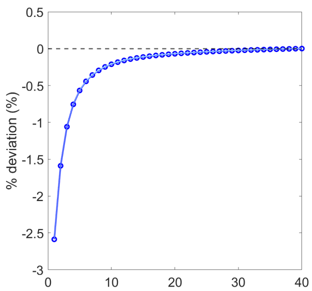
(i) US's US Capital Holding

(j) US Aggregate Capital

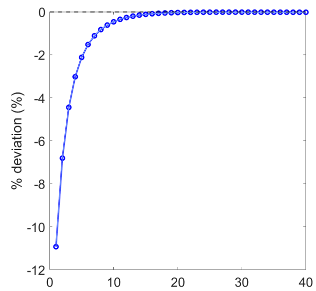
(k) Non-US Aggregate Capital

(l) US Output

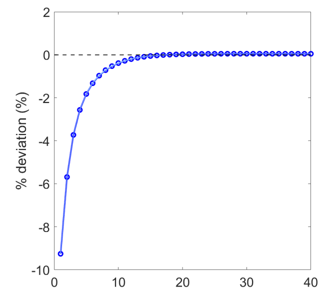
Figure G.1: Impulse Responses to Contractionary US Monetary Policy Shock



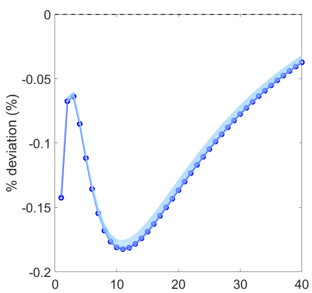
(m) Non-US Output



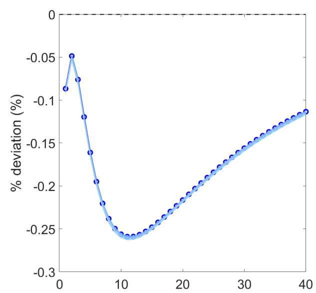
(n) US Investment



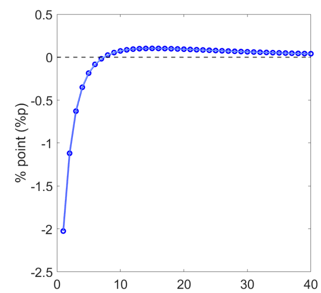
(o) Non-US Investment



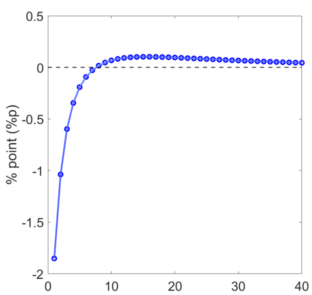
(p) US Consumption



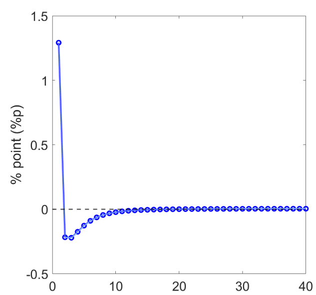
(q) Non-US Consumption



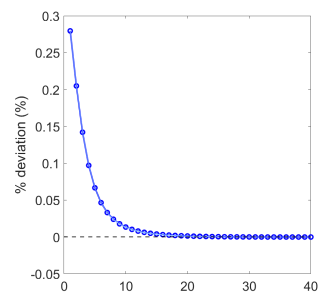
(r) US Inflation



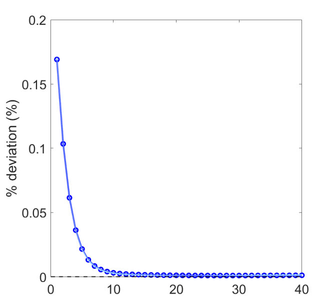
(s) Non-US Inflation



(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. 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.