Dollar Funding Fragility and non-US Global Banks*

Philippe Bacchetta
University of Lausanne, Swiss Finance Institute, and CEPR

J. Scott Davis
Federal Reserve Bank of Dallas

Eric van Wincoop
University of Virginia and NBER

July 15, 2026

Abstract

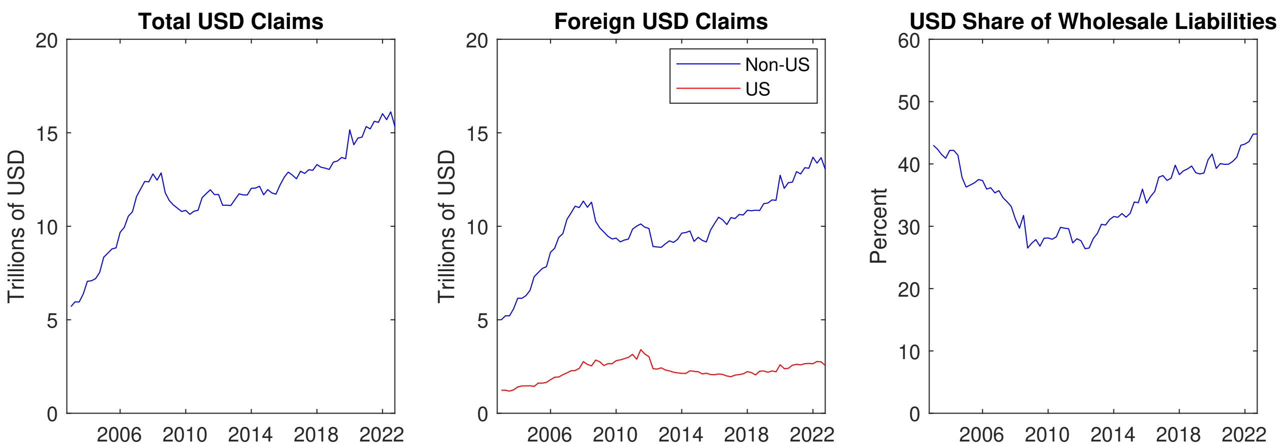
Global non-US banks have significant dollar exposure both on and off their balance sheet. We develop a model to analyze their adjustment to dollar funding shocks, whether from reduced direct lending or external dollar shortages. The model provides insight into banks' responses through borrowing, lending, and FX swap positions, as well as the impact on their net worth, their probability of default and CIP deviations. Implications of the model are confronted with data on the behavior of non-US global banks around major dollar funding contraction episodes. We examine the benefits of central bank dollar swap lines or local currency lending by the central bank.

*We would like to thank Patrick McGuire for guidance with regards to the dollar component of G-SIB balance sheets. We also thank Beata Javorcik (discussant) and seminar participants at Peking University, Fudan University, the Bank of England, the Swiss National Bank, the ECFIN-JIE Global Macro conference, and the BSE Forum for comments. We gratefully acknowledge financial support from the Bankard Fund for Political Economy. This paper represents the views of the authors, which are not necessarily the views of the Federal Reserve Bank of Dallas or the Federal Reserve System.

1 Introduction

Non-US global banks play a central role in global dollar markets and in the international transmission of dollar funding shocks. Figure 1 illustrates three salient facts. First, non-US banks hold more than $15 trillion in dollar-denominated assets as of 2022, a quantity that has increased steadily over time. Second, non-US banks account for the dominant share of cross-border dollar claims worldwide. Third, focusing on non-US Global Systemically Important Banks (G-SIBs), more than 40 percent of wholesale liabilities are denominated in US dollars. These liabilities are typically short term and must be rolled over frequently.

Figure 1: USD Claims of US and Non-US Banks



Notes: USD claims of non-US banks in the first two panels are calculated from the BIS International Banking Statistics using the method described in McGuire and von Peter (2012) and Aldasoro and Ehlers (2018). The foreign USD claims of US banks is from the BIS Locational Banking Statistics. Foreign claims include a bank's cross-border claims and the local claims of foreign affiliates. The USD share of wholesale liabilities is based on data for 40 non-US G-SIB banks that is discussed in Section 4 and the Online Appendix.

The reliance of global banks on dollar funding has been viewed as a potential source of vulnerability for the international financial system, particularly during episodes of dollar shortages or market stress (IMF Global Financial Stability Report, 2019). Such shortages may originate either within the banking sector—through a contraction in wholesale dollar funding to non-US banks—or outside the banking system, for instance through disruptions to FX swap markets external to banks. In this paper, we study how non-US global banks are affected by these different sources of dollar funding stress. Closely related, we analyze whether and under what circumstances central bank dollar swap lines or domestic liquidity provision can mitigate the resulting vulnerabilities.

This paper makes two main contributions. First, while detailed bank-level data on the currency composition of global banks' balance sheets are not publicly available, we construct quarterly, country-level measures of dollar assets, liabilities, and synthetic dollar funding of non-US G-SIB banks. We do so by combining country-level banking data from the BIS with bank-level balance sheet information from public financial filings. This approach delivers consistent measures of aggregate dollar exposure at the country level—the level at which dollar liquidity risks are typically monitored by policymakers—and allows us to document systematic balance-sheet responses of global banks to episodes of dollar funding stress.

Second, we develop a model of non-US global banks to analyze two distinct dollar funding shocks. The first is a dollar liquidity shock that tightens the supply of wholesale dollar funding to banks. The second is an external dollar shortage shock that raises the cost of synthetic dollar funding through FX swap markets. The first dollar funding shock reduces the *quantity* of available dollar funding, while the second raises the *price* of synthetic dollar funding. These shocks have very different implications for bank balance sheets, funding costs, default risk, and CIP deviations.

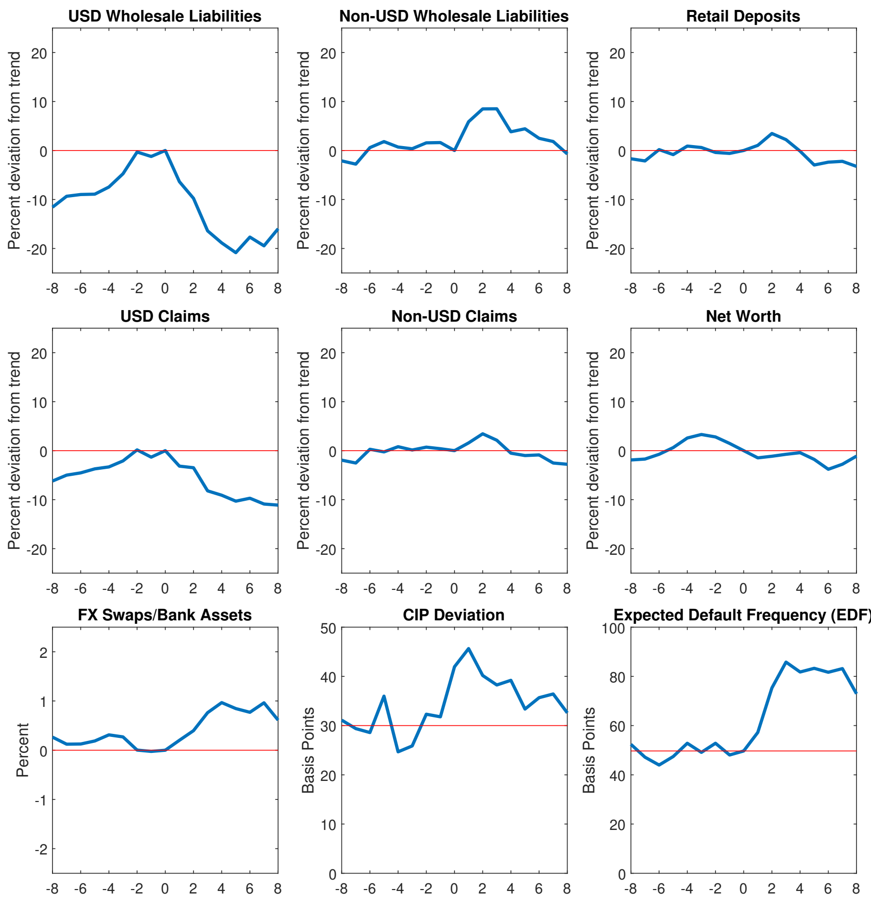
We use our constructed balance-sheet measures to document a set of stylized facts about episodes of large dollar funding contraction. Figure 2 plots the average behavior of non-US G-SIB banks around episodes of sharp contractions in dollar liabilities. In a panel of banks across 14 countries from 2003 to 2022, we identify 22 episodes in which the four-quarter sum of dollar liabilities of a country's banking system fell by more than 10 percent relative to the preceding four quarters. Seven of these episodes occurred during 2007–2008, and another seven during the European sovereign debt crisis of 2010–2012.

Figure 2 shows that wholesale dollar liabilities decline sharply—by close to 20 percent—during these episodes, while retail deposits remain broadly stable and non-dollar balance-sheet components adjust only modestly. Banks significantly reduce dollar lending, although somewhat less than the decline in dollar liabilities. There is also an increase in synthetic dollar borrowing through FX swaps. At the same time, CIP deviations and market-based default probabilities increase.

We show that dollar liquidity shocks in our model are consistent with these stylized facts, both qualitatively and quantitatively. By contrast, external dollar funding shocks, operating through the price rather than quantity mechanism, are inconsistent with these facts. Other shocks that do not relate specifically to the dollar funding market are also unlikely to account for these facts.[1]

[1] For example, a broad deleveraging shock would tend to generate comparable contractions in dollar and non-dollar assets and liabilities. A deterioration in asset quality would raise default risk, which would lead to an across-the-board drop in wholesale funding across all currencies, a pattern we do not observe during our 22 empirical episodes. In the same context, Ivashina et al. (2015) assume that domestic currency liabilities are

Figure 2: Large Dollar Funding Contractions and Bank Balance-sheet Adjustment



Notes: USD claims and liabilities are based on BIS International Banking Statistics. Net worth and deposits are constructed using bank balance sheet data from S&P Capital IQ. Non-USD claims and liabilities are constructed using bank balance sheet data from S&P Capital IQ and BIS International Banking Statistics. The CIP deviation is the 3-month OIS CIP deviation and is calculated with data from Bloomberg. EDF is from Moody's Analytics. Details about the data are discussed in the Online Appendix.

We develop a three-period model of non-US global banks with assets and liabilities denominated in dollars and the domestic currency. Banks hold long-term assets that are costly to liquidate prior to maturity and fund themselves using a combination of stable retail deposits and short-term wholesale funding in both the domestic currency and dollars. They hedge their net on-balance sheet dollar exposure using FX swaps, which are subject to regulatory and balance sheet costs.[2] Crucially, the probability of bank default is endogenous and depends on asset liquidation losses, wholesale funding rates, and expected asset payoffs in both currencies.

Several findings arise from this framework. First, a dollar liquidity shock that reduces access to wholesale dollar funding is consistent with the stylized facts as long as banks cannot easily replace the reduced dollar funding with domestic currency funding. If they could, they would simply replace the decline in wholesale dollar funding with synthetic dollar funding (increased domestic currency borrowing swapped into dollars). Dollar lending would then be little affected, inconsistent with Figure 2.[3]

Second, external dollar funding shocks that give rise to a higher CIP deviation (price shock) have limited effects on the bank under a binding dollar borrowing constraint. It has little effect on bank borrowing and lending, net worth, the swap market position and default probability. This is the case even for implausibly large changes in the CIP deviation. When the dollar borrowing constraint is not binding, the higher CIP deviation leads to standard CIP arbitrage: increased on-balance sheet dollar borrowing, combined with increased synthetic dollar lending. But even there, there is no effect on bank net worth, the probability of default and domestic and foreign currency lending. It is also clear that such shocks cannot account for the episodes of large dollar funding contractions documented in Figure 2. Dollar borrowing is either unchanged or rises.

Third, we find that for both shocks the impact on the bank default probability is quantitatively modest. This is consistent with the absence of widespread failures of non-US global banks in recent decades.[4] At the same time, the model highlights an important nonlinearity:

backed by a government bailout subsidy in the event of a default. Consequently, their framework implies that domestic currency lending rises as much as dollar lending drops, while direct domestic currency borrowing rises as much as direct dollar borrowing drops. This also does not line up with our 22 events of large dollar funding contractions. While dollar liquidity shocks are surely not the only shocks that occurred during these episodes, our model demonstrates that they are uniquely consistent with the stylized facts we document.

[2]On balance sheet wholesale dollar funding is fundamentally different from synthetic dollar funding through FX swaps. As we will discuss further in Section 2.2, most of on-balance sheet dollar funding is unsecured. By contrast, FX swaps are a form of collateralized funding as both parties exchange currencies.

[3]One special case is where the cost of asset liquidation is close to zero, so that assets are almost perfectly liquid. Banks then reduce dollar lending substantially even without constraints in terms of domestic currency borrowing. But even that version of the model is inconsistent with the data in Figure 2 as the probability of default is then unaffected and domestic currency borrowing rises a lot.

[4]One exception is Credit Suisse, which failed in 2023 and was absorbed by another global bank, UBS. However, the fall of Credit Suisse is due to mismanagement problems rather than dollar shortages (e.g., see

sufficiently large dollar liquidity shocks can trigger sharp increases in default risk through endogenous feedback between net worth and funding costs. If the shock is sufficiently large, we find that there only exists a bank-run equilibrium. Small average effects on financial stability therefore co-exist with significant tail risks.

Finally, we examine the role of central bank interventions. Dollar liquidity provision through swap lines offsets the impact of a negative dollar liquidity shock. It therefore leads to increased dollar lending by the bank and lowers the CIP deviation. Domestic currency liquidity provision also increases dollar lending, but can be detrimental by raising the CIP deviation. In terms of financial stability, measured in terms of net worth and probability of default, we find that dollar liquidity provision is most useful in extreme cases of very large dollar liquidity shocks or to stave off bank-run equilibria. We find that with external dollar shortage shocks that raise the CIP deviation, providing dollar liquidity to banks is inefficient, while domestic currency liquidity provision is ineffective.

1.1 Related Literature

Various papers describe dollar activities of non-US banks, mainly based on BIS data. The BIS report by the Committee on the Global Financial System (CGFS) (2020), the IMF Global Financial Stability Report (GFSR) (2019) and Aldasoro and Ehlers (2018) describe vulnerabilities associated with dollar funding of non-US banks. The problem of dollar shortages faced by non-US global banks during the GFC is discussed in McGuire and von Peter (2009), McGuire and von Peter (2012) and McCauley and McGuire (2009). Similar periods of dollar shortages are described by Ivashina et al. (2015) during the European debt crisis, by Anderson et al. (2025) and Iida et al. (2018) for the 2016 US money market reform episode and by Eren et al. (2020) during the Covid crisis.

As described in the CGFS and GFSR reports, the vulnerability of non-US banks to dollar liquidity shocks has improved since the GFC as a result of new regulations. One important new regulation is the LCR (Liquidity Coverage Ratio), which gradually went into effect starting in 2015, being fully in effect by 2019. It requires that banks hold high-quality liquid assets at least equal to 100 percent of the expected net cash outflows during a 30-day stress scenario. The GFSR report shows that liquidity ratios have indeed increased in most countries between 2008 and 2018. But the LCR applies to all currencies combined. Barajas et al. (2020) show that dollar liquidity ratios are much lower than for other currencies and half of all countries have dollar liquidity ratios below 100%.

Limited data on FX swap positions of banks makes it difficult to evaluate off-balance sheet dollar positions of non-US banks. It is generally assumed, based on supervisory guidance,

Lengwyler and Weder di Mauro, 2023)

that banks use off-balance sheet derivatives to balance out their net on-balance sheet dollar positions (e.g., Aldasoro et al., 2020; Kloks et al., 2023). We make that assumption as well, both in the empirical analysis and in the model. Aldasoro et al. (2020) show that the implied net positions in the swap market vary across countries, with Canada and Japan on net buying dollar swaps (borrowing dollars through the swap market) and Australia selling dollar swaps (lending dollars through the swap market). They also discuss the need for central bank swap lines when short-term dollar borrowing from money market funds and through FX swaps is not rolled over.[5]

Some papers use actual data of swap and forward market positions of banks that are settled via the CLS cash settlement system. These data have good coverage of interbank swap market positions, but capture only a small fraction of swap market positions with non-bank customers. Kloks et al. (2023) obtain an estimate of net positions with non-bank customers by combining interbank CLS positions with the overall net swap market positions obtained by assuming that off-balance sheet positions fully hedge the on-balance sheet positions.

The large literature on CIP deviations stresses the role of global banks and their more limited CIP arbitrage after the GFC. However, much of the emphasis is on US global banks, which are suppliers of global dollars, starting with the seminal paper of Du et al. (2018). Interesting recent papers using US bank-level data include Anderson et al. (2025), Barbiero et al. (2024), and Moskowitz et al. (2026). More closely related to our analysis, Khetan (2024) examines the impact of reductions in direct US dollar lending by US money market funds (MMFs), a major source of wholesale dollar financing for non-US global banks. Using CLS data, he shows that these reductions lead to an increase in synthetic dollar borrowing by global banks and an increase in CIP deviations.[6]

Using data for non-US banks, several papers show that dollar shortages negatively affect dollar lending. Ivashina et al. (2015) show that European banks decreased their syndicated dollar loans during the European debt crisis, when MMFs reduced their dollar funding. Eguren-Martin et al. (2024) show that an increase in the CIP deviation reduces cross-border lending by UK banks, while Keller (2024) shows that it reduces bank credit by Peruvian banks. Barajas et al. (2020) present evidence showing that a rise in CIP deviations reduces cross-border lending by non-US banks and increases their probability of default. Iida et al. (2018) also present evidence of a link between CIP deviations and the probability of bank default for non-US banks.

[5]There is a vast literature describing central bank swap lines and documenting that they lower CIP deviations. See for example Bahaj and Reis (2022), Cerutti et al. (2021), Rime et al. (2022), Ferrara et al. (2022), Goldberg and Ravazzolo (2022) and Kekre and Lenel (2025).

[6]Empirical analyses using bank-level data on non-US banks include Abbassi and Bräuning (2020) and Kloks et al. (2024), who analyze the impact of non-US banks on the FX swap market at quarter ends.

While most of the literature is empirical, Ivashina et al. (2015) present a model that is related to our framework as they analyze the impact of funding shocks on the balance sheet of non-US banks. They consider a shock to the exogenous default probability of banks, which affects their dollar borrowing and lending. They also allow for synthetic dollar borrowing and show that shocks to non-US banks affect CIP deviations. Iida et al. (2018) develop a similar model and analyze a wider set of shocks. Bahaj and Reis (2022) also develop a closely related model and consider dollar liquidity shocks as we do. We draw a more detailed comparison to their model in Section 4.3.5.

Our model differs from these analyses in several ways. We explicitly distinguish between stable retail deposits and short-term wholesale funding that is not necessarily rolled over. The cost of wholesale funding and the probability of bank default are endogenous. This enables an analysis of bank vulnerability, in addition to introducing richer mechanisms through endogenous default premia and borrowing costs. We make a distinction between short-term liabilities and long-term assets that can only be liquidated at a cost. We consider the importance of local currency funding constraints. Finally, a major difference from previous analyses is that we calibrate the model to get a sense of the magnitude of the effects.[7]

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 discusses analytical results based on a linearized version of the model. Section 4 presents the numerical analysis based on a calibrated version of the model and Section 5 concludes.

2 Model Description

There is a continuum of non-US banks on the interval [0,1]. We will describe a representative bank. There are three periods. Our main focus will be on period 1. Period 0 is the past. We take the bank balance sheet from period 0 and interest rates from period 0 as given. There are two currencies, the domestic currency and the dollar. Although we will apply the model to non-US global banks from all over the world, for simplicity we refer to the domestic currency as the euro.

Apart from non-US banks, there are also US banks, wholesale lenders to non-US banks and agents that have an exogenously given demand for synthetic dollar funding. Since non-US banks are the focus of our analysis, most of the time we simply refer to them as "banks". The only role of US banks is to conduct CIP arbitrage, which non-US banks will do as well. Wholesale lenders provide dollar and euro funding to banks. They demand interest rates that depend on the risk of default of the bank. They may also impose borrowing constraints

[7] Bohorquez (2023) analyzes the amplifying role of dollar appreciation in self-fulfilling crises. The exchange rate plays a limited role in our analysis, as non-US global banks hedge exchange rate risk. In a model without banks, Bacchetta et al. (2026) analyze the impact of offshore dollar funding shocks on the exchange rate.

on the bank.

We take exchange rates and interest rates on safe dollar and euro assets as given. One can think of the interest rates as set by the central banks. Assume that the safe interest rate for both currencies is i^s. Its level will not be important in what follows. Although there is uncertainty about the period 2 exchange rate, this will not affect banks as they are assumed to balance out any on-balance sheet net dollar exposure with an off-balance sheet net dollar position through the swap market. We assume that the exchange rate (dollars per euro) is 1 in both periods 0 and 1.

2.1 Bank Assets

Consider a representative non-US bank. The bank has long-term (illiquid) euro and dollar assets. These are two-period loans made in period 0. The interest rates on the euro and dollar loans are $i_0^{€,l}$ and $i_0^{\$,l}$. Interest is paid in period 1 and 2, while the principal is due at time 2. The value of euro and dollar loans is $L_0^{€}$ and $L_0^{\$}$.

The bank does not make any new loans in period 1, but can sell some of its loans. However, since these are illiquid assets, the loans are sold at a discount. Specifically, the prices that the bank receives for selling respectively a one euro and one dollar loan in period 1 are

$$p_1^{€} = 1 - \nu_e \left(L_0^{€} - L_1^{€} \right) \tag{1}$$

$$p_1^{\$} = 1 - \nu_d \left(L_0^{\$} - L_1^{\$} \right) \tag{2}$$

The values of euro and dollar loans not sold in period 1 are $L_1^{€}$ and $L_1^{\$}$. The bank therefore sells $L_0^{€} - L_1^{€}$ euro loans and $L_0^{\$} - L_1^{\$}$ dollar loans. Since all banks are identical in the model, in equilibrium they will all sell the same number of loans. However, the prices of these loans are determined by the aggregate sale of euro and dollar loans by all banks. Therefore, the bank takes these prices as given.[8]

When banks sell very few loans, the prices are close to 1, so the discount is very small. However, the more loans banks sell in period 1, the higher the discount at which they are sold. One can also interpret this as banks first selling their most liquid assets and then increasingly illiquid assets at higher discounts. The parameters ν_e and ν_d are important, as they determine the size of the bank's losses from selling loans at a discount.[9]

[8] We will not explicitly model the agents who buy the loans. In Gertler and Kiyotaki (2015) the bank sells the assets to households, who have an inferior technology of managing them. In their model the price of the assets is also a negative linear function of the number of assets that banks sell (that households buy).

[9] We assume that the prices are linear in the number of loans sold as opposed to depending on the percentage of bank loans that are sold. What matters is the absorptive capacity of these assets by the market rather than their share of total bank loans.

We assume that there is a stochastic period 2 default rate on the principal of euro and dollar loans of $d_2^{€}$ and $d_2^{\$}$. Define d and σ^2 as the mean and variance of these default rates. They are the same for euro and dollar loans. The two default rates are assumed to have independent Gamma distributions $\Gamma(k, \theta)$, where the shape parameter is $k = (d/\sigma)^2$ and the scale parameter is $\theta = \sigma^2/d$.[10] The payments in period 2 on euro and dollar loans are $(1 + i_0^{€} - d_2^{€})L_0^{€}$ and $(1 + i_0^{\$} - d_2^{\$})L_0^{\$}$.

2.2 Bank Liabilities

On the liability side of the bank balance sheet are retail euro deposits, as well as wholesale euro and dollar borrowing. Retail deposits are $B^{€}$. These remain the same in period 1 as in period 0, capturing the difficulty of quickly expanding this source of funding when a sudden funding need arises. These retail deposits are guaranteed by deposit insurance. Since they are safe assets, the interest rate is the safe interest rate i^s.

Wholesale funding in both currencies is short-term (one-period). Wholesale euro and dollar liabilities are $B_t^{€,w}$ and $B_t^{\$,w}$ in period $t = 0, 1$. We assume that the bank's on-balance sheet dollar funding is unsecured.[11] The period 1 interest rates are[12]

$$i_1^{€} = i^s + p_D \tag{3}$$

$$i_1^{\$} = i^s + p_D \tag{4}$$

Here p_D is the probability of default of the bank in period 2. Lenders are assumed to be risk neutral and therefore demand interest rates that are equal to the safe rate plus the probability of default. This assumes that there is no recovery. The probability of default of the bank is endogenous and will be discussed below. In Section 4.6 we will discuss two extensions to this framework, one where the lenders are risk averse and one where there is a partial bailout of wholesale lenders in case of bank default.

The bank's balance sheet is given by:

$$L_1^{€} + L_1^{\$} = W_1 + B^{€} + B_1^{€,w} + B_1^{\$,w} \tag{5}$$

[10]As an alternative, we have also considered log normal distributions instead of Gamma distributions for the default rates. This has no effect on any of the results.

[11]Only a small share of direct dollar funding comes from repos, which are collateralized. According to a recent report from the Office of Financial Research (Friedrichs et al., 2026), secured repo lending from US lenders to foreign bank borrowers totaled \$1.1 trillion at the end of 2025, or about 6-7% of the total dollar liabilities of foreign banks as reported in Figure 1. This proportion is likely to be smaller at the beginning of our sample.

[12]More precisely, $1 + i_1^{€} = (1 + i^s)/(1 - p_D)$ and analogously for the dollar. While we use these precise expressions when solving the model in Section 4, this makes virtually no difference except for one extreme case we will discuss in which the probability of bank default can asymptote to a very high level.

where $B^{€}$ is exogenous and the determination of the other variables is described below.

2.3 Off-Balance Sheet Activity

Apart from these on-balance sheet assets and liabilities, the bank is also active off balance sheet in the FX swap market. We describe it for period 1, though it is analogous for period 0.

One unit of a dollar swap market position is defined as follows. An agent who buys one dollar swap at time 1 receives one dollar at time 1 in exchange for 1 euro (the spot exchange rate is 1) and at time 2 receives 1 euro in exchange for F_1 dollars. Here F_1 is the period 1 forward rate (dollars per euro). Buying a dollar swap therefore implies that the agent is net short in forward dollars as it has an obligation to pay F_1 dollars at time 2. By analogy, a seller of dollar swaps is net long in forward dollars. We assume that the swap contract is perfectly enforced. The only risk is that two things happen simultaneously: one of the parties reneges on the forward leg of the contract and the exchange rate moves adversely for the other party. In practice the swap contract is enforced through collateral that is a small fraction (1-3%) of the swap contract. We abstract from this here.

Let S_1 be the dollar swap market position of the representative bank. As discussed in the literature review, it is generally assumed, based on supervisory guidance, that banks use off-balance sheet derivatives to balance out their net on-balance sheet dollar positions. The models in Ivashina et al. (2015), Iida et al. (2018) and Bahaj and Reis (2022) all assume this as well. Accordingly, we assume that the bank's net dollar exposure through the swap market exactly offsets its net on-balance sheet dollar exposure:

$$S_1 = L_1^{\$} - B_1^{\$,w} \tag{6}$$

When $S_1 > 0$, the bank is net short dollars off balance sheet. It will then be equally net long dollars on the balance sheet through dollar lending minus dollar borrowing. This implies that when $B_1^{\$,w}$ drops as a result of a dollar liquidity shock, the bank must adjust through a combination of reduced dollar lending and an increased dollar swap market position.

From (5)-(6) we can also write

$$S_1 = B^{€} + B_1^{€,w} + W_1 - L_1^{€} \tag{7}$$

Setting aside net worth effects, a higher dollar swap market position implies that the bank must either borrow more euros wholesale or reduce euro lending.

When the bank buys S_1 dollar swaps in period 1, in period 2 it receives S_1 euros and pays $F_1 S_1$ dollars. Converted to euros, the period 2 profit on these dollar swaps is then

$$\left(1 - \frac{F_1}{E_2}\right) S_1 \tag{8}$$

Here E_2 is the period 2 spot exchange rate. The analogous period 1 profit on dollar swaps bought at time 0 is $(1 - F_0)S_0$, using that $E_1 = 1$.

We assume that there is a quadratic cost to the bank of swap market positions, equal to

$$0.5\eta S_1^2 \tag{9}$$

One can think of these costs as related to regulations that limit CIP arbitrage. Specifically for G-SIB banks, capital surcharges are imposed depending on the G-SIB score. One element of the G-SIB score is the complexity score, which is related to off-balance sheet derivatives such as FX swaps. The cost can also be related to other post-GFC regulations that affect CIP arbitrage, such as the leverage ratio requirement and the liquidity coverage ratio.[13]

2.4 Bank Net Worth and Probability of Default

In period 0 the net worth W_0 of the bank is equal to the value of its assets minus liabilities:

$$W_0 = L_0^{€} + L_0^{\$} - B^{€} - B_0^{€,w} - B_0^{\$,w} \tag{10}$$

We assume that in period 1 the bank pays out a dividend equal to its regular net profits, excluding any losses from selling loans. This dividend is equal to

$$i_0^{€,l} L_0^{€} + i_0^{\$,l} L_0^{\$} - i^s B^{€} - i_0^{€} B_0^{€,w} - i_0^{\$} B_0^{\$,w} + (1 - F_0)S_0 \tag{11}$$

These profits include interest on assets and liabilities and the profit on the FX swap position.

When the bank does not sell loans in period 1, its net worth remains the same as in period 0: $W_1 = W_0$. More generally, if the bank does sell loans at a discount, its period 1 net worth is

$$W_1 = W_0 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \tag{12}$$

In Online Appendix A we derive the following expression for the net worth of the bank

[13] These regulations affect the supply of FX swaps in response to changes in the CIP deviation, but to the extent that non-US banks are on the demand side of the swap market, they can also affect the demand for FX swaps. For evidence on how post-GFC regulations have affected CIP deviations, see Du et al. (2018), Cenedese et al. (2021) and Borio et al. (2018).

at time 2:[14]

$$W_2 = \left(i_0^{€,l} - i_1^{€} - d_2^{€}\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$} - d_2^{\$}\right) L_1^{\$} + (1+i_1^{€})W_0 + (i_1^{€} - i^s)B^{€}$$
$$+ \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 - (1-p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1-p_1^{€})(L_0^{€} - L_1^{€}) \quad (13)$$

The last two terms of (13) capture the losses that the bank suffers from selling assets in period 1 at a discount, which also reduces the period 2 net worth. Most other terms in (13) are excess returns. For example, the first two terms are the return from lending euros or dollars minus the interest rate on euro or dollar wholesale borrowing. The term $i_1^{\$} - i_1^{€} + e_1 - f_1$ is equal to the difference between the interest rate on wholesale dollar borrowing and synthetic dollar borrowing (euro borrowing swapped into dollars). The interest rate on synthetic dollar borrowing is $i_1^{€} + f_1 - e_1$. Here f_1 and e_1 are the log forward and spot rates (we assumed $e_1 = 0$). $f_1 - e_1$ is the forward discount. We also refer to it as the swap rate. We can think of $\left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1$ as a CIP arbitrage profit.

Given the Gamma distributions of $d_2^{€}$ and $d_2^{\$}$, we can then compute the probability of default, which is the probability that the net worth of the bank is negative in period 2:

$$p_D = Prob(W_2 < 0) \quad (14)$$

The Online Appendix discusses the details associated with computing the default probability.

2.5 Bank Maximization Problem

The bank problem that we now describe assumes that the bank remains alive in period 1, so that it is able to make portfolio decisions that pay off in period 2. In Section 2.8 below we discuss that a standard bank-run equilibrium is possible in period 1, where none of the wholesale dollar and euro funding from period 0 is rolled over into period 1. Such an equilibrium is feasible when ν is sufficiently large. In that case, the cost of liquidating assets is so large that the bank is unable to fully repay period 0 wholesale lenders in the absence of rollovers, no matter how many assets they liquidate. However, our main focus in this paper is on rollover equilibria where the bank continues to operate in period 1. The description of the bank maximization problem that follows assumes that this is the case.

The bank maximizes

$$EW_2 - 0.5\frac{\gamma}{W_0}var(W_2) - 0.5\eta S_1^2 \quad (15)$$

The first two terms are the risk-adjusted portfolio return of the bank. We normalize risk-

[14]The precise expression shown in Online Appendix A multiplies the last two terms by $1 + i_1^{€}$. This adds a third-order component that we abstract from in what follows, but we allow for it in the numerical analysis in Section 4.

aversion γ by W_0, so that γ can be thought of as a rate of relative risk-aversion. We subtract the cost of swap market positions. The bank then solves a simple mean-variance portfolio problem.

The bank operates under four constraints. We have already discussed two of them. The bank cannot increase its loan portfolio at time 1. It can only sell assets. Therefore,

$$L_1^{€} \leq L_0^{€} \tag{16}$$
$$L_1^{\$} \leq L_0^{\$} \tag{17}$$

In addition we assume that the bank is subject to borrowing constraints on short-term wholesale euro and dollar borrowing in period 1:

$$B_1^{€,w} \leq \bar{B}^{€} \tag{18}$$
$$B_1^{\$,w} \leq \bar{B}^{\$} \tag{19}$$

These borrowing constraints can be motivated by a familiar contract enforcement problem. The bank can divert a portion of the funds that it has borrowed. If it does so, it faces a penalty of $\bar{B}^{€}$ for euro borrowing and $\bar{B}^{\$}$ for dollar borrowing, for example imposed by the courts.[15] The constraints (18)-(19) may also be motivated by regulations. For example, Khetan (2024) reports that US money market funds have strict regulatory concentration limits, restricting how much they can lend to any institution. Assuming that (19) is binding, we will refer to a drop in $\bar{B}^{\$}$ as a dollar liquidity shock, which reduces the ability of non-US banks to borrow wholesale dollars.

When (18)-(19) hold, the lenders are not concerned that the bank will default other than in times where its net worth is negative. So default of the bank in period 2 happens due to inability to pay (negative net worth) rather than unwillingness to pay.

Let the Lagrange multipliers associated with the constraints (16)-(17) be μ_e and μ_d. The Lagrange multipliers associated with the constraints (18)-(19) are l_e and l_d. These Lagrange multipliers are zero when the constraints do not bind and positive when they do bind. So we must impose $l_d\left(B_1^{\$,w} - \bar{B}^{\$}\right) = 0$ and $l_d \geq 0$ and similarly for the other constraints. The bank maximizes the Lagrangian

$$\begin{aligned} &EW_2 - 0.5\frac{\gamma}{W_0}var(W_2) - 0.5\eta S_1^2 \\ &-l_e\left(B_1^{€,w} - \bar{B}^{€}\right) - l_d\left(B_1^{\$,w} - \bar{B}^{\$}\right) - \mu_e\left(L_1^{€} - L_0^{€}\right) - \mu_d\left(L_1^{\$} - L_0^{\$}\right) \end{aligned} \tag{20}$$

[15]Technically, payments on the left-hand side of these expressions should include the interest payments. This will make little difference for the results. For simplicity we assume that concerns about default relate to the principal, not the interest that is due.

From (6)-(7), $B_1^{\$,w} = L_1^{\$} - S_1$ and $B_1^{€,w} = L_1^{€} - B^{€} - W_1 + S_1$. Substituting these into (20), the bank maximizes with respect to $L_1^{€}$, $L_1^{\$}$ and S_1. Together with the complementary slackness conditions, this gives the optimal on-balance sheet and off-balance sheet positions.

2.6 Optimal Decisions by Bank

The first-order condition with respect to S_1 is (see Online Appendix for details)

$$S_1 = \frac{\left(i_1^{\$} + l_d\right) - \left(i_1^{€} + l_e + f_1 - e_1\right)}{\eta} \tag{21}$$

One can think of this as the CIP arbitrage position of non-US banks. The numerator is equal to the cost of borrowing dollars from wholesale lenders minus the cost of borrowing synthetic dollars. The former is $i_1^{\$} + l_d$. It includes both the dollar wholesale funding rate and the dollar Lagrange multiplier. The latter is zero when the dollar borrowing constraint does not bind. When it binds, $l_d > 0$ and $i_1^{\$} + l_d$ is the effective cost to the bank of borrowing dollars.

The cost of borrowing synthetic dollars is $i_1^{€} + l_e + f_1 - e_1$. It is the cost of borrowing euros from wholesale lenders, swapped into dollars. The effective cost to the bank of borrowing euros is $i_1^{€} + l_e$. When the euro borrowing constraint binds, so that $l_e > 0$, this effective cost of borrowing euros is larger than the interest rate on wholesale euro borrowing.

The larger η, the larger the cost to the bank of conducting swap market transactions. This reduces CIP arbitrage. It leads to smaller swap market positions in response to a difference between the (effective) costs of wholesale dollar borrowing and synthetic dollar borrowing.

The first-order conditions with respect to $L_1^{€}$ and $L_1^{\$}$ lead to expressions for period 1 euro and dollar lending that depend on the prices $p_1^{€}$ and $p_1^{\$}$ at which the bank is able to sell euro and dollar loans. An individual bank takes these prices as given. But the prices depend on the aggregate sales of euro and dollar loans as in (1)-(2). Using that equilibrium euro and dollar lending is the same in all banks and equal to aggregate euro and dollar lending, the Online Appendix derives expressions for $L_1^{€}$ and $L_1^{\$}$ after substituting the expressions for the prices into the first-order conditions. This gives

$$L_1^{€} = \frac{i_0^{€,l} - d - i_1^{€} - l_e - \mu_e + (1 + l_e)\nu_e L_0^{€}}{\gamma\sigma^2 + (1 + l_e)\nu_e W_0} W_0 \tag{22}$$

$$L_1^{\$} = \frac{i_0^{\$,l} - d - i_1^{\$} - l_d - \mu_d + (1 + l_e)\nu_d L_0^{\$}}{\gamma\sigma^2 + (1 + l_e)\nu_d W_0} W_0 \tag{23}$$

Consider, for example, euro lending $L_1^{€}$. It can be written as a weighted average of a standard mean-variance portfolio and period 0 lending $L_0^€$. The mean-variance portfolio is

$$\frac{\left(i_0^{€,l} - d - \mu_e\right) - \left(i_1^€ + l_e\right)}{\gamma\sigma^2} W_0$$

The numerator is the effective expected return on lending euros minus the effective cost of borrowing euros. The weight on this mean-variance portfolio is $\gamma\sigma^2/[\gamma\sigma^2 + (1 + l_e)\nu_e W_0]$. This weight is smaller, and the weight on period 0 lending is larger, the bigger the cost of selling euro loans as captured by ν_e.

2.7 FX Swap Market Equilibrium

Three types of agents take positions in the swap market: US banks, non-US banks and non-banks. For non-banks we simply assume an exogenous demand of u for dollar swaps. They can, for example, be non-US firms that have limited access to the US dollar funding market and instead borrow dollars by borrowing euros that they swap into dollars. Alternatively, they can be non-US institutional investors that hold US dollar assets and wish to hedge the exchange rate risk by buying dollar swaps. We will refer to an increase in u as an external dollar shortage shock. Dollar shortages external to banks lead to an increased demand for synthetic dollar funding and therefore a demand for dollar swaps. Such dollar shortages can for example arise as a result of reduced lending by US financial institutions or increased demand for hedging services when non-US investors buy US assets.

US banks have a demand for dollar swaps of

$$S_1^{US} = -\frac{f_1 - e_1}{\eta} \tag{24}$$

This corresponds exactly to the demand for dollar swaps (21) by non-US banks when their dollar and euro borrowing rates are equal (which is the case for non-US banks as well) and they do not face a borrowing constraint in the currency in which they wish to borrow for CIP arbitrage (generally the dollar).

Since we will not model US banks, we can simply think of them as CIP arbitrageurs that can borrow and lend in safe dollar and euro assets. Assume that they borrow B_1 dollars, lend B_1 euros and swap these into dollars by selling B_1 dollar swaps. Therefore $S_1^{US} = -B_1$. This delivers a profit of $(f_1 - e_1)B_1 = -(f_1 - e_1)S_1^{US}$. Assuming a quadratic cost of swap market transactions analogous to non-US banks, this delivers the optimal swap market position of (24).[16]

[16]Even if we assumed that US banks do not have access to safe borrowing and lending rates (e.g. Libor is not completely safe), (24) remains the optimal swap market position when the risk premia are identical for

Swap market equilibrium is then

$$S_1 + S_1^{US} + u = 0 \tag{25}$$

This implies a swap rate of

$$f_1 - e_1 = 0.5\eta u + 0.5\left[\left(i_1^{\$} + l_d\right) - \left(i_1^{€} + l_e\right)\right] \tag{26}$$

We will refer to $f_1 - e_1$ as the CIP deviation. It is equal to the (safe) synthetic dollar interest rate $i^s + f_1 - e_1$ minus the (safe) cash dollar interest rate i^s.

2.8 Solution

We solve equilibria as follows. The endogenous variables we solve are the wholesale funding rates $i_1^{€}$ and $i_1^{\$}$ and the four Lagrange multipliers l_e, l_d, μ_e and μ_d. To solve these, we impose $i_1^{€} = i_1^{\$} = i^s + p_D$ and the four complementary slackness conditions. The probability of default and the complementary slackness conditions depend on other variables that ultimately can be written as functions of the 6 variables that we solve. These include bank loans $L_1^{€}$ and $L_1^{\$}$ (eqns (22)-(23)), the bank swap market position S_1 (eqn (21)), the swap rate $f_1 - e_1$ (eqn (26)), the prices of bank loans $p_1^{€}$ and $p_1^{\$}$ (eqns (1)-(2)) and wholesale euro and dollar funding. For the latter we use that $B_1^{\$,w} = L_1^{\$} - S_1$ and $B_1^{€,w} = L_1^{€} - B^{€} - W_1 + S_1$.

In the Online Appendix, we check the equilibria graphically by assuming a given probability of default p_D, solving the model under that assumed probability of default and then mapping that into the realized probability of default $p_D = Prob(W_2 < 0)$ implied by the solution of the model. In general there are two fixed points of this mapping.[17] This is familiar from the literature on sovereign default models. A high probability of default leads to high period 1 wholesale funding rates for the bank. This reduces the period 2 net worth, which increases the probability of default. A high probability of default can then be self-fulfilling. However, the equilibrium with a high probability of default and high interest rates is unstable. We therefore focus the analysis on the singular stable equilibrium.

We can describe the equilibrium just discussed as a rollover equilibrium as wholesale dollar and euro funding is rolled over into period 1, subject to the borrowing constraints. But when ν is sufficiently large, there can also be non-rollover equilibria, where none of the wholesale funding is rolled over into period 1. We discuss these non-rollover equilibria in the Online Appendix. The most standard type is a classic self-fulfilling bank-run equilibrium. This is an equilibrium when, in the absence of rollovers, the bank is unable to repay all of

the dollar and euro assets used for arbitrage.

[17] When ν is sufficiently small, there is just one fixed point.

the period 0 wholesale lenders, no matter how much of the dollar and euro loan portfolio they liquidate in period 1. When the parameter ν that captures the cost of loan liquidation is above a certain threshold, say ν_1, the bank faces a liquidity problem where it is unable to turn the assets into sufficient liquid resources to repay all debt.

A less familiar non-rollover equilibrium is feasible as well. In this case again none of the wholesale lending is rolled over into period 1. The bank is still able to repay the period 0 wholesale lenders by liquidating sufficient assets. But the cost of liquidating loans is sufficiently high that second period net worth is negative even in the most favorable case where there are no loan defaults in period 2. The probability of period 2 default p_D is then 1, so that it is indeed optimal for wholesale lenders not to roll over any credit. This equilibrium can happen when ν is in an intermediate range $[\nu_2, \nu_1]$ with $\nu_1 > \nu_2 > 0$.[18]

In most of the analysis we focus on rollover equilibria. But as we discuss further in Section 4, different types of liquidity policy, including central bank swap lines, can play an important role in avoiding self-fulfilling non-rollover equilibria that may or may not be accompanied by dollar liquidity shocks.

2.9 Pre-Shock Equilibrium

Before introducing shocks to the model, we first solve a pre-shock equilibrium. In this equilibrium period 1 variables (wholesale interest rates, forward discount, swap market position, bank lending and borrowing and net worth) are identical to period 0 variables. It is therefore a type of pre-shock steady state. We set $\bar{B}^{€} = B_0^{€,w}$ and $\bar{B}^{\$} = B_0^{\$,w}$ and $u = 0$ in the pre-shock equilibrium. The period zero balance sheet variables, and therefore also S_0, are taken as given and calibrated in Section 4. As we will see, non-US banks overall have slightly higher dollar assets than liabilities. This would imply a positive swap market position of non-US banks. But we set period 0 dollar assets equal to dollar liabilities in the main analysis, so that $S_0 = 0$. In one of the extensions in Section 4.6, we show that non-zero values of S_0 yield little quantitative difference in the results.

We discuss the pre-shock equilibrium in more detail in Appendix B. The borrowing and lending constraints do not bind, so that $l_e = l_d = 0$ and $\mu_e = \mu_d = 0$.[19] The pre-shock swap rate (CIP deviation) is zero. We set σ to target a given pre-shock default probability, which determines wholesale dollar and euro funding rates. From (22)-(23), equating period 1 to

[18] We will discuss these cutoffs for ν in the context of the calibrated model in Section 4.

[19] We consider an extension in Section 4.6 where the dollar borrowing constraint is strictly binding in the pre-shock equilibrium, so that $l_d > 0$.

period 0 loan levels and setting $l_e = l_d = 0$ then implies

$$i_0^{€,l} = d + i_0^{€} + \gamma\sigma^2 L_0^{€}\frac{1}{W_0} \tag{27}$$

$$i_0^{\$,l} = d + i_0^{\$} + \gamma\sigma^2 L_0^{\$}\frac{1}{W_0} \tag{28}$$

where $i_0^{€}$ and $i_0^{\$}$ are the pre-shock euro and dollar wholesale funding rates that are equal in periods 0 and 1. This determines the interest rates on bank loans, which are set in period 0 for the next two periods.

3 Analytical Implications of the Model

In this section we derive a set of analytical results by taking derivatives at the point of the pre-shock equilibrium. These are therefore small shocks. We consider large shocks in Section 4. For large shocks we need to solve the model numerically as there is no closed form solution to the probability of default. As shown in the Online Appendix, for marginal shocks at the pre-shock equilibrium, the derivative of the probability of default with respect to the shocks is zero. The key to this is that the derivative of W_1 with respect to shocks is zero at the pre-shock equilibrium. This is immediate from (12), using that in the pre-shock equilibrium the asset prices are 1 and period 0 and 1 loan volumes are identical. In Section 4 we will see that with large shocks the net worth and the probability of default will change, but for now we abstract from this.

We consider four scenarios for the shocks. The first two involve a dollar liquidity shock in the form of a tightening of the wholesale dollar borrowing constraint. In the pre-shock equilibrium, period 1 wholesale dollar borrowing is equal to period 0 wholesale dollar borrowing, $B_0^{\$,w}$. The shock we consider is one where the period 1 borrowing constraint is tightened, so that banks can borrow a marginal ϵ^b less: $\bar{B}^{\$} = B_0^{\$,w} - \epsilon^b$. We consider two versions of this. One assumes no euro slackness. This means that $\bar{B}^{€} = B_0^{€,w}$. Banks cannot make up for the dollar liquidity shock by borrowing more euros than they did in period 0. The other scenario is one where euro borrowing is slack. This means that $\bar{B}^{€}$ is sufficiently large that banks are not euro-borrowing constrained and therefore $l_e = 0$.

The next two scenarios involve an external dollar shortage shock, which raises demand for synthetic dollar funds. It takes the form of an increase in u by ϵ^u. Since this shock will raise the cost of synthetic dollar borrowing for the bank (euro borrowing swapped into dollars), banks wish to reduce euro borrowing in equilibrium. The euro borrowing constraint therefore will not bind and $l_e = 0$. But the dollar borrowing constraint may be binding as the bank wishes to borrow dollars wholesale and lend dollars synthetically. We both consider the case where $\bar{B}^{\$} = B_0^{\$,w}$, so that banks are unable to borrow more dollars than in period 0, and the case of dollar slackness, where banks are not dollar-borrowing constrained. This means that $\bar{B}^{\$}$ is sufficiently high such that $l_d = 0$.

We can also think of euro and dollar slackness (the borrowing constraints not binding) as being a result of central bank liquidity policy. When the central bank provides sufficient liquidity in the domestic currency in case of a dollar liquidity shock, the euro borrowing constraint is non-binding and $l_e = 0$. When the central bank provides sufficient liquidity in dollars (e.g., through central bank swap lines) in case of an external dollar shortage shock, the dollar borrowing constraint is non-binding and $l_d = 0$.

Table 1: Model Results

	\$ liquidity shock no euro slackness	\$ liquidity shock euro slackness	u-shock no dollar slackness	u-shock dollar slackness
$\Delta L_1^{€}$	$\frac{-0.5\tilde{\nu}}{\eta W_0+\tilde{\nu}}\epsilon^b$	0	0	0
$\Delta L_1^{\$}$	$-\frac{\eta W_0+0.5\tilde{\nu}}{\eta W_0+\tilde{\nu}}\epsilon^b$	$\frac{-\eta W_0}{\eta W_0+0.5\tilde{\nu}}\epsilon^b$	$\frac{-0.5\eta W_0}{\eta W_0+0.5\tilde{\nu}}\epsilon^u$	0
$\Delta B_1^{€,w}$	0	$\frac{0.5\tilde{\nu}}{\eta W_0+0.5\tilde{\nu}}\epsilon^b$	$\frac{-0.5\eta W_0}{\eta W_0+0.5\tilde{\nu}}\epsilon^u$	$-0.5\epsilon^u$
$\Delta B_1^{\$,w}$	$-\epsilon^b$	$-\epsilon^b$	0	$0.5\epsilon^u$
ΔS_1	$\frac{0.5\tilde{\nu}}{\eta W_0+\tilde{\nu}}\epsilon^b$	$\frac{0.5\tilde{\nu}}{\eta W_0+0.5\tilde{\nu}}\epsilon^b$	$\frac{-0.5\eta W_0}{\eta W_0+0.5\tilde{\nu}}\epsilon^u$	$-0.5\epsilon^u$
$\Delta(f_1 - e_1)$	$\frac{0.5\eta\tilde{\nu}}{\eta W_0+\tilde{\nu}}\epsilon^b$	$\frac{0.5\eta\tilde{\nu}}{\eta W_0+0.5\tilde{\nu}}\epsilon^b$	$0.5\frac{\eta W_0+\tilde{\nu}}{W_0+(0.5/\eta)\tilde{\nu}}\epsilon^u$	$0.5\eta\epsilon^u$

The analytical results discussed here are derived in the Online Appendix based on marginal shocks ϵ^b and ϵ^u. Table 1 provides a summary of the results for the four scenarios. We set $\nu_d = \nu_e = \nu$. The parameter $\tilde{\nu} = \gamma\sigma^2 + \nu W_0$ is linearly related to ν. Since the probability of default does not change to the first order, wholesale dollar and euro funding rates do not change either. They are therefore not reported. As shown in Table 1, the results depend importantly on ν and η, which capture, respectively, the cost of selling loans and conducting swap market transactions.

3.1 Dollar Liquidity Shock

The results in the first two columns of Table 1 can be summarized as follows.

Result 1 *Assume a dollar liquidity shock reduces dollar lending to banks by ϵ^b.*

- *When there is no euro slackness, banks sell both euro loans and dollar loans, totaling ϵ^b. The resulting net long dollar position is offset by buying dollar swaps. This raises the swap rate and CIP deviation.*

- *When there is euro slackness, banks borrow more euros. The additional borrowing reduces the need to sell loans. Banks do not sell euro loans and sell fewer dollar loans than in the absence of euro slackness. They have a larger net long dollar position on the balance sheet than in the absence of euro slackness. This leads to a larger increase in demand for dollar swaps, a larger increase in the swap rate and CIP deviation.*

- *The extent of these changes is significantly affected by the cost of selling loans, ν, and the cost of conducting swap market operations, η.*

Since banks have a zero net dollar exposure, they have two ways to adjust to reduced dollar funding. They can reduce dollar lending or buy dollar swaps. To the extent that they buy dollar swaps, the balance sheet implies that they will need to increase euro borrowing or reduce euro lending.

First consider the case without euro slackness. Banks then have two choices. They can sell dollar loans or buy dollar swaps in combination with an equal drop in euro loans. In both cases the cost rises with ν. In addition, buying dollar swaps has a direct cost that rises with η and an indirect cost in the form of a higher CIP deviation that also rises with η.

When ν is large relative to η, the drop in dollar loans is close to the increase in the dollar swap position. This is because the liquidation cost rises the more loans in a particular currency the banks sells. They therefore sell close to an equal amount of dollar and euro loans. The main cost of buying dollar swaps in this case is the liquidation cost associated with selling euro loans.

When ν is small relative to η, the tradeoff changes significantly. Assume that $\nu = 0$ for transparency. While in that case there is no liquidation cost of selling dollar loans, there is a small cost in terms of loan diversification as selling only dollar loans makes the loan portfolio less diversified. This diversification cost depends on $\gamma\sigma^2$. If it is small relative to η, banks will mostly sell dollar loans and not buy a lot of dollar swaps.

The response by banks is quite different when there is euro slackness. To the extent that banks buy dollar swaps, it will then be combined with increased euro borrowing instead of selling euro loans. The main cost of selling dollar loans remains associated with the asset liquidation cost that depends on ν. The cost associated with buying dollar swaps no longer depends on ν as the bank borrows more euros instead of selling euro loans. It rises as η increases.

In this case, when ν is large relative to η, the bank mostly buys dollar swaps and sells few dollar loans. If instead η is large relative to ν, the bank mostly sells dollar loans and buys few dollar swaps.

3.2 External Dollar Shortage Shock

The results in the last two columns of Table 1 can be summarized as follows.

Result 2 *Assume that an external dollar shortage shock (rise in u) raises demand for synthetic dollar funding and therefore demand for dollar swaps.*

- *Both with and without dollar slackness the increased demand for dollar swaps raises the swap rate and CIP deviation. Banks sell dollar swaps as a result, creating a long dollar forward position.*
- *Without dollar slackness banks offset the off-balance sheet long dollar position by reducing dollar lending and reducing euro borrowing.*
- *In the presence of dollar slackness banks offset the off-balance sheet long dollar position by increasing dollar borrowing and reducing euro borrowing, without changing dollar or euro lending. The swap rate and CIP deviation rise less than without dollar slackness.*
- *The cost of selling dollar loans and the cost of conducting swap market operations affect changes in on and off balance sheet positions without dollar slackness, but not with dollar slackness.*

This shock is very different as it originates outside the banks. The rise in the CIP deviation is then essentially exogenous to banks. The higher dollar swap rate incentivizes banks to sell dollar swaps. This makes banks net long in forward dollars off the balance sheet.

Without dollar slackness, banks offset this by selling dollar loans and borrowing fewer euros. A higher cost of selling dollar loans makes this less attractive. The sale of dollar loans and reduction in euro borrowing are then smaller and banks sell fewer dollar swaps. As a result, the swap rate and CIP deviation rise more. A higher cost of conducting swap market transactions leads to a higher equilibrium CIP deviation. Even though the cost of conducting swap market transactions is higher, as a result of the higher CIP deviation banks sell more dollar swaps and dollar loans.

When there is dollar slackness, the Lagrange multipliers for both dollar and euro borrowing are zero. This implies that the demand for dollar swaps is the same for US and non-US banks, equal to $-(f_1 - s_1)/\eta$. As a result, the increase in demand for dollar swaps by ϵ^u external to the banks implies that in equilibrium both US and non-US banks sell $0.5\epsilon^u$ dollar swaps. This leads to a net dollar forward position of $0.5\epsilon^u$, which banks offset by borrowing $0.5\epsilon^u$ more dollars and equally reducing euro borrowing. Both on-balance sheet and off-balance sheet transactions are then unaffected by the cost of selling loans and conducting swap market transactions.

4 Numerical Results

The analytical solution provides useful insights for small shocks. In this section, we quantify the impact of dollar funding shocks with a numerical solution of the model. In this case, shocks are no longer small and have implications for the net worth of banks and the probability of default. The probability of default also affects bank borrowing rates. In addition, a drop in net worth has an amplifying effect on the balance sheet of banks, forcing banks to sell off more loans than the decline in its wholesale borrowing would imply. This may also lead to bank-runs.

The first step towards a numerical solution is to calibrate the model parameters. We first describe data that we use to calibrate on- and off-balance sheet positions of the non-US banks. After that we discuss the calibration of some of the other parameters. We then present the quantitative impact of a dollar liquidity shock on on- and off-balance sheet positions, the CIP deviation and the probability of default. We compare the results with the data for the 22 episodes discussed in the Introduction. We also discuss the quantitative impact of an external dollar shortage shock. In Section 4.6 we also consider an extension where both shocks are combined.

4.1 Calibration

4.1.1 Bank Balance Sheet

We use bank balance sheet data both for the calibration of the model and for the event study in Figure 2. In both cases we use balance sheet data for the 40 largest non-US and non-Chinese G-SIB banks, which are headquartered in 14 countries.[20] The calibration is based on aggregate balance sheet data across all these 40 banks in Q4, 2022, while the event study is based on quarterly data from 2003 to 2022 and aggregates the banks by country. Here we provide a quick sketch of how the balance sheets of these banks are constructed, leaving full details to the Online Appendix.

The 40 banks are G-SIB banks for which the BIS has collected data as part of its annual G-SIB assessment since it started doing so in 2013. These are banks that have appeared on the BIS G-SIB main sample list every year from 2013 to 2022. For individual G-SIB banks we obtain data about total assets, net worth, retail deposits and wholesale liabilities (total liabilities minus retail deposits) from S&P Global CapitalIQ. We will treat the retail deposits as being entirely in the local currency. Even though the local currency varies by country, we will continue to refer to it as the euro for simplicity.

[20]The 14 countries are Germany, Spain, Finland, France, Italy, the Netherlands, Australia, Canada, Switzerland, Denmark, the UK, Japan, Singapore, and India. We exclude Chinese banks because China only started reporting to the BIS International Banking Statistics in Q4, 2015.

While we can observe the total assets and liabilities of these global banks, the currency composition of those assets and liabilities is not observable. We therefore need to approximate the currency composition of the balance sheet. For this we turn to the BIS International Banking Statistics, which reports data at the country level. Total claims and liabilities, as well as the USD-denominated claims and liabilities, are calculated using a combination of the BIS Locational Banking Statistics by nationality (LBSN) and the Consolidated Banking Statistics (CBS), following the methodology described in McGuire and von Peter (2012) and Aldasoro and Ehlers (2018).

Since the BIS International Banking Statistics data are available at the country-level, we do not have data on the dollar assets and liabilities of individual banks. We approximate the share of a country's dollar assets and liabilities that are held by the G-SIB banks. We exploit the fact that 80-90% of a country's dollar assets and liabilities reported by the BIS are cross-jurisdictional (either cross-border assets and liabilities or locally booked by a bank's foreign affiliates).

We observe the cross-jurisdictional assets and liabilities of individual G-SIB banks from the annual G-SIB assessment by the BIS. These are totals across all currencies. We observe from the BIS International Banking Statistics the cross-jurisdictional assets and liabilities of all banks headquartered in a country. At the country level we can then compute the share of total cross-jurisdictional claims and liabilities booked by the G-SIBs headquartered in that country. This share varies from close to 100% in countries like the UK, Canada, Australia, and Spain to as low as 50% in Japan. On average across our 14 countries this share is around 73%.

For each country, we approximate the share of the USD claims and liabilities from the BIS International Banking Statistics that is held by G-SIB banks. Since the vast majority of USD denominated claims and liabilities are cross-jurisdictional, we assume that this share is equal to the share of total cross-jurisdictional claims and liabilities in that country booked by the G-SIB banks. This gives us the dollar assets and wholesale dollar liabilities of G-SIB banks in each country. Non-dollar assets and liabilities are the residual.

This gives us quarterly data from 2003 to 2022 of balance sheets of the aggregate of the G-SIB banks in each of the 14 countries, which we use for the event study in Figure 2. In addition, for Q4, 2022, we sum the data across all 40 G-SIB banks to calibrate the model. This is reported in Table 2.[21]

We assume that the balance sheet in Table 2 is representative for all G-SIB banks. We

[21] Dollar assets in 2022 in Table 2 are \$8.8T. We can compare this to total dollar assets of all non-US banks in 2022 of \$15.4T, as shown in Figure 1. There are two differences. First, Table 2 applies to non-US banks of 14 countries. There are an additional \$3.4T dollar claims by non-US banks in other countries, including \$1.4T dollar claims by Chinese banks. Second, Table 2 refers to non-US G-SIB banks. Dollar claims by all non-US banks in these 14 countries amount to \$12T in 2022, of which 73 percent are held by G-SIB banks.

use these balance sheet data (converted to trillions of dollars) to calibrate the first seven model parameters in Table 3, with one modification. For now we will assume that in period 0 (and the pre-shock equilibrium in period 1) dollar assets are equal to dollar liabilities and euro assets are equal to total assets minus dollar assets. Banks then have a zero swap market position. In Section 4.6 we consider an extension where we vary the pre-shock net dollar position (and therefore swap market position), but for now we assume that dollar assets are simply equal to dollar liabilities.

Table 2: Balance Sheet non-US G-SIB banks, Q4 2022 ($bln.)

Assets		Liabilities	
$L^{€}$: euro assets	38651	W: net worth	2579
$L^{\$}$: dollar assets	8801	$B^{€}$: € retail deposits	25326
		$B^{€,w}$: € wholesale borrowing	11565
		$B^{\$,w}$: $ wholesale borrowing	7982
Total	47452	Total	47452

Note: For data description see Section 4.1.1.

4.1.2 Other Parameters

Table 3 also reports the values of other model parameters. We set d, the mean default rate on bank loans, equal to 0.03. This corresponds to the annual default rate of entrepreneurs in Bernanke et al. (1999).

We set σ, the standard deviation of the default rate on loans, to match a probability of bank default of 0.005. This 50 basis point bank default probability is based on Moody's daily EDF (expected default frequency) for the 40 banks. For each bank we take the average over the 2003-2022 sample, after which we average over the banks.

As discussed in Section 2.9, we set $u = 0$, which also implies a zero swap rate in the pre-shock equilibrium. We set the rate of risk aversion γ of banks at 2 and the interest rate on safe assets at 0.02.

We set $\eta = 0.0025$ and $\nu = \nu_d = \nu_e = 0.2$, such that the model is consistent with the rise in the CIP deviation and probability of bank default observed for the 22 episodes of dollar funding contraction discussed in the introduction. We do this for the case of a binding euro borrowing constraint as the model's performance without a euro borrowing constraint (euro slackness) is inconsistent with the data. A comparison of the model results to the data for these 22 episodes is discussed in Section 4.3.3. Section 4.6 discusses an extension where

Table 3: Model Parameters

$L_0^{€}$	39.5	period 0 euro loans
$L_0^{\$}$	8	period 0 dollar loans
W_0	2.6	period 0 net worth
$B^{€}$	25.3	euro retail deposits
$B_0^{€,w}$	11.6	period 0 wholesale euro borrowing
$B_0^{\$,w}$	8	period 0 wholesale dollar borrowing
S_0	0	period 0 demand for dollar swaps by non-US banks
d	0.03	default rate on euro and dollar loans
σ	0.0222	standard deviation default rate euro and dollar loans
u	0	exogenous demand for dollar swaps
γ	2	bank risk-aversion
i^s	0.02	interest rate on safe euro and dollar assets
$f_0 - e_0$	0	period 0 swap rate=CIP deviation
η	0.0025	sensitivity demand dollar swaps to swap rate
$\nu_d = \nu_e$	0.2	parameter that captures cost of selling loans

$\nu_d \neq \nu_e$.[22]

4.2 Endogenous Default Probability

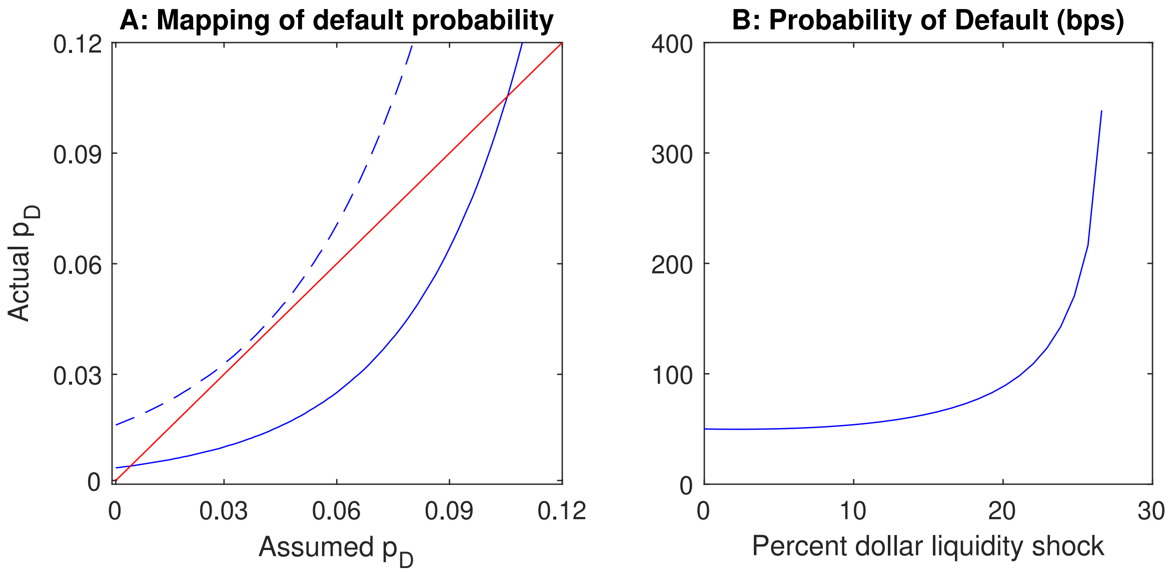
In Section 3 we derived closed-form solutions for the change in the bank's balance sheet variables, its swap position, and the CIP deviation following a shock. However, to be analytically tractable, we assumed very small shocks, so that the bank probability of default remains unchanged. We now consider large shocks that lead to an endogenous change in the bank's probability of default.

For the rollover equilibrium, the bank's probability of default can be found as the solution to a fixed point problem, where an assumed probability of default p_D determines the bank's interest rates on wholesale borrowing, which then affects the bank's balance sheet and its actual probability of default $p_D = Prob(W_2 < 0)$. For our calibrated parameters, and assuming a fixed euro borrowing constraint, the mapping from this assumed probability of default to the bank's actual probability of default is shown in panel A in Figure 3. The solid blue line is the mapping in the pre-shock state before any shock to dollar liquidity.

Panel A in Figure 3 shows that in the pre-shock state there are two fixed points in this mapping from the assumed to the actual probability of default. A high probability of default

[22] As we show in section 4.3, this calibration implies that in our benchmark model, the bank faces about a 15% discount when selling loans after a shock. This is consistent with the evidence on typical haircuts applied to collateral securities in secured lending transactions, as collected by a Study Group of the BIS Committee on the Global Financial System (CGFS) (2010).

Figure 3: Default Probability



Notes: Chart A shows a mapping from the assumed p_D to the implied actual p_D for the benchmark parameterization. The solid blue line assumes no dollar liquidity shock. In the lower equilibrium the default probability is 50 basis points. In the higher equilibrium it is 10.7 percent. The dashed line represents the mapping after a 27% dollar liquidity shock. It no longer intersects the 45 degree line, implying that a rollover equilibrium no longer exists. Chart B shows the probability of bank default p_D as a function of the size of the dollar liquidity shock. The maximum size is 26.6%. After that there is no longer a solution.

leads to high period 1 wholesale funding rates for the bank. This reduces the period 2 net worth, which increases the probability of default. However, the equilibrium with a higher probability of default is unstable. Any small perturbation in the assumed probability of default will cause the actual probability to move away from the fixed point. The only stable rollover equilibrium is the fixed point on the left with a default probability of around 50 basis points.

Dollar liquidity shocks shift the solid blue line in panel A up, leading to an increase in the bank default probability. How this default probability changes as a function of the size of the shock is shown in panel B of the Figure. For small and moderate sized dollar liquidity shocks the default probability remains small. The probability of default starts to rapidly increase when dollar liquidity shocks are above 20 percent, to well over 300 basis points.

This rapid increase in the probability of default is partly the result of a feedback loop between the wholesale funding rates and the probability of default. As the shock becomes larger, there are larger bank losses associated with the liquidation of assets. This raises the probability of default in period 2. This raises the wholesale dollar and euro funding rates, which then in turn further raises the probability of default.

This escalating feedback mechanism continues until the rollover equilibrium no longer exists. This is illustrated by the dashed-line mapping between the assumed and actual probability of default in panel A. This dashed line is drawn for a dollar liquidity shock of 27%. Here the mapping no longer intersects the 45-degree line and there is no longer a rollover equilibrium. This is further highlighted in panel B, where the probability of default as a function of the shock size asymptotes when the size of the shock approaches 26.6%.

As discussed in Section 2.8, non-rollover equilibria can exist as well, where none of the period 0 wholesale lending is rolled over in period 1. In the illustration above, when the rollover equilibrium no longer exists for dollar liquidity shocks larger than 26.6%, there only exists a non-rollover equilibrium in the form of a standard bank-run equilibrium. Non-rollover equilibria are feasible even in the absence of a dollar liquidity shock. This can lead to bank default either in period 1 or in period 2. As discussed in the Online Appendix, a bank-run equilibrium with default in period 1 can occur when $\nu > 0.0195$ under the benchmark parameterization. Since we set $\nu = 0.2$, such bank-run equilibria are feasible in the model even without any shock. A delayed default equilibrium is also possible, where default occurs with predictable certainty in period 2. This can happen for ν in the intermediate range $[0.0126, 0.0195]$ within the benchmark parameterization.

4.3 Dollar Liquidity Shock

We now discipline the size of the direct dollar funding shock using the average contraction in wholesale dollar liabilities observed in the event-study episodes shown in Figure 2. Based on 22 episodes with a large drop in dollar funding, wholesale dollar liabilities fall by 15.8%. In Section 4.3.3 we describe how we arrive at this exact number. We therefore consider a shock that tightens the wholesale dollar borrowing constraint by 15.8%. Table 4 shows the impact of the shock, both for the case where the euro borrowing constraint is binding and where it is non-binding. When it is binding we have $B_1^{€,w} \leq \bar{B}^{€} = B_0^{€,w}$. When it is non-binding we assume that $\bar{B}^{€}$ is sufficiently large that the constraint never binds.

Table 4 reports pre-shock and post-shock values of variables as well as changes from pre-shock to post-shock levels. Percentage changes are denoted with the percentage sign. The dollar swap market position is shown as a fraction of all bank assets. The CIP deviation and probability of default are in basis points.

Table 4: Impact of Dollar Liquidity Shock

	€ borrowing constraint binding			€ borrowing constraint not binding		
	pre-shock	post-shock	change	pre-shock	post-shock	change
euro lending	39.5	38.8	-1.9%	39.5	39.5	0%
dollar lending	8	7.25	-9.3%	8	7.97	-0.4%
wholesale euro borrowing	11.6	11.6	0%	11.6	12.83	10.6%
wholesale dollar borrowing	8	6.74	-15.8%	8	6.74	-15.8%
net worth	2.6	2.38	-8.5%	2.6	2.6	0%
$ swap position (% assets)	0	1.09	1.09	0	2.6	2.6
CIP deviation (bps)	0	13	13	0	31	31
probability default (bps)	50	66	16	50	50	0
percent discount euro loans	0	14.8	14.8	0	0	0
percent discount dollar loans	0	14.9	14.9	0	0.62	0.62
interest rate € borrowing (%)	2.51	2.68	0.17	2.51	2.52	0.01
interest rate $ borrowing (%)	2.51	2.68	0.17	2.51	2.52	0.01

Notes: The results are based on the benchmark parameters shown in Table 3. The dollar liquidity shock involves a 15.8 percent tightening of the dollar borrowing constraint relative to the pre-shock equilibrium, where banks can borrow up to the level of period 0 dollar borrowing.

4.3.1 Binding euro borrowing constraint

As discussed in Section 3.1, in response to a drop in dollar borrowing, banks need to reduce dollar lending or increase their swap market position, or a combination. Increasing the swap market position implies reduced euro lending when banks are unable to borrow more euros. This means that the cost of asset liquidation related to ν raises both the cost of reducing dollar lending and the cost of increasing the swap market position. With ν much larger than η as in our benchmark parameterization, the additional cost of dollar swaps related to η does not play an important role. In this case banks will therefore reduce dollar lending and increase dollar swaps (and therefore reduce euro lending) by an equal amount.

Since euro lending is considerably larger than dollar lending, percentage-wise dollar lending drops much more than euro lending (9.3% versus 1.9%). The swap market position rises to just over one percent of bank assets. The increased demand for dollar swaps by banks raises the CIP deviation by 13 basis points.

The net worth of banks drops by 8.5% due to the asset liquidation. This causes the probability of bank default to increase from 50 to 66 basis points. It also raises the euro and dollar wholesale funding interest rates by 17 basis points.

4.3.2 Euro borrowing constraint not binding

When the euro borrowing constraint does not bind, the tradeoff between reducing dollar lending and increasing dollar swaps changes considerably. Banks can then increase their swap market position by increasing euro borrowing. While the cost of reducing dollar lending still depends on ν, the cost of a dollar swap position now depends on η. Since ν is much larger than η, in this case banks mostly buy dollar swaps. Table 4 shows that dollar lending drops only 0.4%. Euro lending does not change at all. The increase in the swap market position is almost as large as the drop in dollar borrowing, rising by 2.6% of assets. This causes a 31 bps increase in the swap rate or CIP deviation. Since banks sell very few loans, they experience virtually no losses from loan liquidation. The period 1 net worth of banks is therefore unaffected and neither is the probability of bank default.

4.3.3 Comparison to the Data

Table 5 compares the model results just discussed to the data. The data moments are based on the 22 episodes with a decline in wholesale dollar funding of at least 10% discussed in the introduction. Figure 2 shows the average of balance sheet variables, the CIP deviation and EDF (probability of default) during the quarters prior to and after the start of these episodes. In Table 5 we convert this to a single measure of change for each of these variables.

We make a distinction between balance sheet variables and price-based variables. Balance sheet variables change slowly. We see in Figure 2 that the decline in wholesale dollar funding takes place over 4 quarters. With $T = 0$ being the start of the events, we compute the change in balance sheet variables as the percentage change from the average level over $[T-4, T-1]$ to the average level over $[T+4, T+7]$. For the swap market position we report the change in the position as a percentage of all bank assets.

The CIP deviation and EDF are different variables as they are price-based and therefore respond more quickly. For these variables, we report the change from the average level over $[T-4, T-1]$ to the average level over the subsequent 4-quarter period $[T, T+3]$.

We have also cross-checked in the data the increase in the probability of default against the increase in the Libor-OIS spread. The probability of default rises by 30% from 50 to 66 basis points. The average Libor-OIS spread during our 22 dollar liquidity events rises from 35 basis points to 46 basis points, which is a similar 30% increase. This increase is also computed from $[T-4, T-1]$ to $[T, T+3]$.

Table 5 shows that the model fits the data well with a euro borrowing constraint. Three of these variables are targeted: the 15.8% drop in wholesale dollar borrowing as well as the changes in the CIP deviation and probability of default. But the other variables are also broadly consistent with the data. This is not the case for the model without a binding

Table 5: Dollar Liquidity Shock: Data versus Model

	Data	Model	
		no euro slack	euro slack
euro lending	-1.7%	-1.9%	0%
dollar lending	-8.4%	-9.3%	-0.4%
wholesale euro borrowing	2.1%	0%	10.6%
wholesale dollar borrowing	-15.8%	-15.8%	-15.8%
net worth	-4.7%	-8.5%	0%
$ swap position (% assets)	0.75	1.09	2.6
CIP deviation (bps)	12.8	13	31
probability default (bps)	16.3	16	0

Notes: The data column refers to the average across 22 episodes where wholesale dollar liabilities between T+1 and T+4 are at least 10% lower than between T-3 and T. For all balance sheet variables the table reports the percentage change of the average over quarters [T-4,T-1] to the average over quarters [T+4,T+7]. For the CIP and probability of default (EDF), the data column reports the change of the average over quarters [T-4,T-1] to the average over quarters [T,T+3]. Model results are based on the benchmark parameters shown in Table 3 and a tightening of the wholesale dollar borrowing constraint by 15.8% relative to the pre-shock equilibrium. Euro slackness refers to the absence of a wholesale euro borrowing constraint (or one that is sufficiently slack so that it does not bind).

euro borrowing constraint. The 10.6% increase in euro borrowing is much larger than in the data. Dollar lending is virtually unchanged, but drops 8.4% in the data. Net worth and the probability of default are unchanged, while the increase in the swap market position and CIP deviation are much too large.

We set η and ν to target the change in the CIP deviation and probability of default with a binding euro borrowing constraint. We will discuss sensitivity analysis with respect to these parameters further below. But in the context of Table 5, we can never match the rise in the probability of default by changing ν and η for the case where the euro borrowing constraint does not bind. The change is always close to zero.

It is also possible to consider an intermediate case where there is some slack in euro borrowing. Rather than removing the borrowing constraint altogether, we could relax the euro borrowing constraint by a small 2%. This may be the result of the central bank providing some euro liquidity. The model can then by construction explain the small 2% increase in wholesale euro borrowing that we see in the data. But this is a small change in the euro borrowing constraint. As a result, the model results otherwise remain very close to the case we report where the euro borrowing constraint remains unchanged.[23]

[23]In that case we need to slightly adjust ν and η to make sure that we continue to match the observed change in the CIP deviation and probability of default.

4.3.4 Parameters η and ν

The key parameters of the model are the parameter ν that captures the cost of bank loan liquidation and the parameter η that captures frictions in the FX swap market. We have set them at respectively 0.2 and 0.0025. In the Online Appendix we report the effect of dollar liquidity shocks when we vary ν from 0 to 0.3 and η from 0 to 0.01.

Unless we set ν very close to zero (below 0.01), we find that with dollar liquidity shocks ν only affects the probability of default and only when the euro borrowing constraint is binding. This is because it increases the cost of asset liquidation. It has little effect on dollar and euro borrowing and lending, the swap market position and CIP deviation, independently of whether the euro borrowing constraint is binding.

But when assets become perfectly liquid (ν is very close to zero), results change more substantively. As discussed in Section 3.1, in this case banks mostly sell dollar loans and buy few dollar swaps, leading also to a smaller CIP deviation. This is the case both with and without a binding euro borrowing constraint. But this is inconsistent with the empirical findings in the introduction that dollar lending drops less than dollar borrowing and the swap market position rises.

As expected, a higher value of η implies a larger increase in the CIP deviation in response to a dollar liquidity shock. But other variables are virtually unaffected, assuming we keep $\nu = 0.2$. Since ν is much larger than η, varying η has little effect on the relative costs of selling dollar loans versus buying dollar swaps discussed in Section 3.1.[24]

4.3.5 Comparison to Bahaj and Reis (2022)

Bahaj and Reis (2022), from henceforth BR, consider a model that has several features similar to ours. They also consider a three-period partial equilibrium model of foreign banks that face a binding dollar borrowing constraint. Like we do, they consider the impact of a tightening of this dollar borrowing constraint. Their banks also do not take on any net dollar exposure, so that a decline in dollar borrowing is offset by a combination of a drop in dollar lending and a rise in the dollar swap position. Financial frictions lead to a limited supply of FX swaps by US banks, with the supply increasing in the CIP deviation. They assume that there is no binding borrowing constraint in local currency, corresponding to the euro borrowing constraint being slack in our model.

However, BR deviate in one respect. While banks hold two-period assets, these cannot be liquidated in period 1. Instead, they introduce new one-period assets in period 1. Banks

[24] We find that η only matters for extreme values. For example, if we set $\eta = 0.2$, the CIP deviation rises by an implausibly large 533 basis points. In that case, dollar lending drops a bit more, by 12.4% instead of 9.3% in the benchmark. The default probability then rises by 24 basis points instead of 16 basis points in the benchmark.

lend to firms that have a concave production function in capital. A drop in loans then raises the interest rate as the marginal product of capital increases. Instead of the cost of reducing lending operating through a liquidation cost ν as in our model, in BR it operates through an opportunity cost in the form of a higher interest rate on loans.

The foreign banks in BR then face a cost associated with both reducing dollar lending and increasing dollar FX swaps (through a higher CIP deviation). There will therefore be a combination of both a drop in dollar lending, which reduces investment by firms in their model, and an increase in FX swaps. The latter also implies an increase in the CIP deviation. All of this is consistent with the evidence related to dollar funding contractions that we document.

Nonetheless, the BR model has some implications that differ from ours. First, the bank increases local currency borrowing equal to the rise in FX swaps. In the data we find very little change in local currency borrowing. Second, while they do not consider the bank default probability, the absence of an asset liquidation cost combined with a higher interest rate on loans will likely reduce the probability of default. In our model the asset liquidation cost lowers bank net worth and raises the bank probability of default, in line with the evidence.

4.4 External Dollar Shortage Shock

Table 6 reports results when there is an external dollar shortage shock that leads to an increase in demand for synthetic dollar funding and dollar swaps by $\epsilon^u = 2$. The size of the shock is not connected to any data. The results are reported both for the case of a binding and a non-binding dollar borrowing constraint. A binding dollar borrowing constraint implies that $B_1^{\$,w} \leq \bar{B}^{\$} = B_0^{\$,w}$. A sufficiently large $\bar{B}^{\$}$ implies that the dollar borrowing constraint will never bind. While a dollar liquidity shock directly affects the balance sheet of a bank, forcing it to make adjustments, this shock is external to banks and only affects them through a rise in the swap rate or CIP deviation.

4.4.1 Binding dollar borrowing constraint

When the dollar borrowing constraint binds, the CIP deviation increases by 49 basis points. The higher swap rate incentivizes banks to sell dollar swaps, so that they are long in dollars off the balance sheet. They need to take an offsetting short dollar position on the balance sheet. But since banks cannot borrow dollars, they can only do so by selling dollar loans. However, selling loans is costly. As a result, even though the CIP deviation increases by a considerable 49 basis points, banks only sell dollar swaps equal to 0.05% of bank assets and reduce dollar lending by only 0.3%.

The impact on banks is therefore very small. Net worth and the probability of default are unchanged. The shock mainly hurts borrowers of synthetic dollars external to banks, who need to pay a substantially higher interest rate.

Table 6: Impact of External Dollar Shortage Shock

	$ borrowing constraint binding			$ borrowing constraint not binding		
	pre-shock	post-shock	change	pre-shock	post-shock	change
euro lending	39.5	39.5	0%	39.5	39.5	0%
dollar lending	8	7.98	-0.3%	8	8	0%
wholesale euro borrowing	11.6	11.58	-0.2%	11.6	10.6	-8.6%
wholesale dollar borrowing	8	8	0%	8	9	12.5%
net worth	2.6	2.6	0%	2.6	2.6	0%
$ swap position (% assets)	0	-0.05	-0.05	0	-2.1	-2.1
CIP deviation (bps)	0	49	49	0	25	25
probability default (bps)	50	50	0	50	50	0
percent discount euro loans	0	0	0	0	0	0
percent discount dollar loans	0	0.49	0.49	0	0	0
interest rate € borrowing (%)	2.51	2.51	0	2.51	2.51	0
interest rate $ borrowing (%)	2.51	2.51	0	2.51	2.51	0

Notes: The results are based on the benchmark parameters shown in Table 3. The external dollar shortage shock is $\epsilon^u = 2$.

4.4.2 Dollar borrowing constraint not binding

When the dollar borrowing constraint is not binding, banks can sell dollar swaps and offset the resulting long dollar position by borrowing dollars wholesale. Without any dollar borrowing constraint, banks increase dollar borrowing by 12.5% and sell dollar swaps equal to 2.1% of assets. There is a decrease in euro borrowing that is equal to the increase in dollar borrowing. Banks essentially replace synthetic dollar borrowing with wholesale dollar borrowing.

The impact on non-US banks is again small. There is no change in either dollar or euro lending. Bank net worth and the probability of default are again unaffected. Since non-US banks now sell a lot more dollar swaps than with a binding dollar borrowing constraint, the CIP deviation rises less, by 25 basis points.

4.4.3 Parameters η and ν

The parameter ν does not affect the results when the dollar borrowing constraint is not binding. This is because no asset liquidation is needed. When the dollar borrowing constraint is binding, we find that there is still very limited asset liquidation for our benchmark value of $\nu = 0.2$. But when we reduce ν to levels much closer to 0, the bank significantly reduces dollar lending. It keeps wholesale dollar borrowing unchanged, but it increases synthetic dollar lending, while reducing on-balance sheet dollar lending.

The parameter η has very little effect on the results other than increasing the CIP deviation as η rises. If we set $\eta = 0.025$ (ten times that in the benchmark), under a binding dollar borrowing constraint, the shock increases the CIP deviation by a massive 450 basis points. But even that only lowers dollar lending by 0.3%. It leaves bank net worth and the probability of bank default virtually unchanged.

4.4.4 Connection to Barajas et al. (2020)

Barajas et al. (2020) find that an increase in the CIP deviation reduces cross-border dollar lending by non-US banks and increases their probability of default. An exogenous increase in the CIP deviation that they have in mind fits well with the exogenous external dollar shortage shock considered here. Nonetheless, we find that an increase in the CIP deviation leaves dollar lending virtually unchanged, unless ν is very close to 0 and there is a binding euro borrowing constraint. However, independent of ν and η, the probability of default is unaffected, which is inconsistent with the findings by Barajas et al. (2020).

A possible explanation may be that the CIP deviation is not entirely exogenous. We have seen that a dollar liquidity shock simultaneously raises the probability of default, lowers bank dollar lending and raises the CIP deviation. So these variables are more likely to be closely connected as a result of a dollar liquidity shock that directly affects banks.

4.5 Policy Implications

We now address the role of central bank policy, both dollar liquidity (e.g., through central bank dollar swap lines) and domestic currency liquidity. Providing dollar liquidity when faced with a dollar liquidity shock in essence reverses the shock. This means for example that central bank dollar swap lines can significantly raise dollar lending by banks, reduce the CIP deviation and reduce the probability of bank default. Bahaj and Reis (2022) provide evidence of increased corporate dollar bond purchases by foreign banks.

The alternative of providing liquidity in the local currency also limits the negative impacts of a dollar liquidity shock. We can see that in Table 4 by considering the case where the euro borrowing constraint is not binding. Dollar lending by banks then drops very little, while euro lending does not drop at all. However, it leads banks to increase their dollar swap position much more, which raises the CIP deviation. This is detrimental for firms and financial institutions that rely on synthetic dollar funding.

The impact of dollar liquidity shocks on financial stability, as measured by net worth and the probability of default, is not large when calibrated to our 22 dollar contraction episodes. Nonetheless, really bad outcomes are possible with larger shocks, bank-run equilibria and high-frequency liquidity events that we have abstracted from.

We have seen that for larger dollar liquidity shocks, the effect of the shock on the endogenous probability of default is highly non-linear. A feedback loop develops where the increase in the bank's probability of default, due to losses associated with assets sales, raises the cost of borrowing, which further raises the probability of default. Providing even a limited amount of dollar liquidity can avoid this feedback loop and avoid a really bad outcome. Even for a more modestly sized dollar liquidity shock, there may be a concern that a further decline in wholesale dollar funding will push banks into this bad feedback loop. Taking up dollar swap lines may be a precautionary measure to avoid getting there, or worse, getting to the region where only a self-fulfilling bank-run exists, as illustrated in panel A of Figure 3.

Self-fulfilling bank-runs are possible even in the absence of any dollar liquidity shock. It is well known that liquidity provision by the central bank can help avoid such bank-run equilibria. In our case, both dollar and domestic currency liquidity can avoid such outcomes. Even if we rule out a run on domestic currency wholesale deposits by assuming that the central bank will ultimately bail out these lenders (as we will consider in sensitivity analysis), there could still be self-fulfilling bank-runs based on dollar wholesale liabilities. The very existence of a dollar swap line can avoid such equilibria, even without ever using the swap line.

Our model has abstracted from high-frequency events that lead to acute short-run dollar liquidity needs by global banks. In our theory, the bank makes balance sheet adjustments to respond to dollar liquidity shocks. In practice, such adjustments can take some time, which banks may not have when faced with an immediate dollar liquidity shortage. In that case, a quick inflow of dollars through the central bank and central bank swap lines may be critical. Closely related, there can also be a very short duration freeze of the FX swap market. This has happened for very brief periods of time during both the global financial crisis and the Covid crisis. In such cases central bank dollar funding may again be critical.

External dollar shortage shocks mainly have the effect of raising the CIP deviation. While we have seen that this has very limited effects on the bank balance sheet, net worth and probability of default, a higher CIP deviation is detrimental for institutions that rely on synthetic dollar funding. The recent literature has shown that central bank dollar swap lines can significantly lower the cost of synthetic dollar funding. At the same time, our model implies that providing dollar liquidity directly to non-banks is a more efficient response to external dollar shortage shocks. We see in Table 6 that providing unlimited dollar liquidity to banks only reduces the increase in the CIP deviation by half, while banks do not increase their dollar lending. This is the result of the cost that banks face in taking swap market positions.

The alternative of providing liquidity in the local currency when faced with a higher CIP deviation due to an external dollar shortage shock is of no help. We have seen that banks wish to reduce their local currency borrowing with these shocks.

4.6 Sensitivity Analysis and Extensions

We have already discussed sensitivity analysis with respect to ν and η. In the Online Appendix we also show how the response to dollar liquidity shocks depends on other parameters and extensions. Here we only briefly summarize these results. Further discussion is provided in the Online Appendix.

We consider how results are affected when we allow the cost of liquidating euro and dollar loans to differ. We vary $\nu_d - \nu_e$, while keeping their average value equal to 0.2. In one extreme $\nu_d = 0$ and $\nu_e = 0.4$, so that there is no cost to liquidating dollar loans, but a high cost to liquidating euro loans. Banks then naturally sell dollar loans when faced with a dollar liquidity shock. Dollar assets and liabilities drop equally and the swap market position remains zero. The CIP deviation is unaffected by the shock. At the other extreme, where $\nu_d = 0.4$ and $\nu_e = 0$, the cost of selling dollar loans is so high that banks will not sell any dollar loans. When the euro borrowing constraint binds, they will instead sell euro loans, which they can do without any cost. But this creates a larger net long dollar position on the balance sheet. This leads to a larger demand for dollar swaps and a larger increase in the CIP deviation.[25]

Next we consider some extensions. In the first extension we allow the pre-shock synthetic dollar position to vary between -5% and +5% of bank assets. This corresponds to the 5th and 95th percentiles for the various countries in the sample. We next consider an extension that allows wholesale euro and dollar lenders to be risk-averse, with risk aversion rates varying between 0 and 2. After that we introduce extensions where a fraction $bail_e$ and $bail_d$ of obligations to respectively euro and dollar wholesale lenders is bailed out by the government in case of bank default, with both varying from 0 to 1. We also consider an extension where the dollar borrowing constraint is strictly binding in the pre-shock equilibrium by raising the

[25] The probability of bank default rises most in the intermediate case where $\nu_e = \nu_d = 0.2$. This is because in the two extreme cases, banks avoid losses associated with selling loans. They only sell loans for which they do not incur any liquidation cost.

interest rate $i_0^{\$,l}$ on dollar loans (see also Appendix B). It turns out that the impact of a dollar liquidity shock on balance sheet variables, the synthetic dollar position, the probability of default and the CIP deviation are all virtually unaffected by these extensions.

We finally consider an extension that combines the 15.8% dollar liquidity shock with an external dollar shortage shock, with ϵ^u varying from 0 to 2. We have seen that external dollar shortage shocks mainly affect the CIP deviation. It is therefore not surprising that when the two shocks are combined, the only variable that is affected is the CIP deviation. The larger the external dollar shortage shock that we mix with a given dollar liquidity shock, the larger the rise in the CIP deviation.

5 Conclusions

Non-US global banks play a major role in lending dollars across the globe, including to the US. These dollar exposures are balanced by direct short-term dollar borrowing and synthetic dollar borrowing. This reliance on dollars represents a potential source of financial vulnerability for the global financial system in times of global dollar shortages. The model we have proposed enables us to investigate how non-US global banks react to dollar funding shocks, both dollar liquidity shocks that hit banks directly and external dollar shortage shocks. We have also investigated whether there is a role for central bank dollar swap lines or local currency liquidity to ameliorate the effects of these shocks.

We find that a dollar liquidity shock that reduces access to wholesale dollar funding is consistent with the stylized facts related to dollar funding contractions as long as banks cannot easily replace the reduced dollar funding with domestic currency funding. We find that external dollar funding shocks that give rise to a higher CIP deviation have limited effects on bank borrowing and lending, net worth, the swap market position and default probability. We find that dollar liquidity provision through swap lines offsets the negative impacts of a negative dollar liquidity shock, especially by raising dollar lending and lowering the CIP deviation. In terms of financial stability, dollar liquidity provision is most useful in extreme cases of very large dollar liquidity shocks or to stave off bank-run equilibria.

The model can be extended in several directions. One natural extension is to more fully describe the non-bank sector. For example, reduced dollar lending to the non-bank sector could lead to an increase in demand for synthetic dollar funding, which feeds back to the swap market. Another extension could consider the heterogeneous impact on individual countries and spillovers across currency zones. Finally, an extension could consider the implications for exchange rates that we have abstracted from.

Appendix

A Dollar Liquidity Crisis Events

In Figure 2 we plot the responses of bank balance sheet variables, the CIP deviation and the EDF around dollar liquidity crises. Specifically, we define the starting period T=0 of a dollar liquidity shock in country c to be a quarter where the average of USD liabilities from quarters T+1 to T+4 is at least 10% less than the average of USD liabilities from quarters T-3 to T. Period T=0 is the first period where this criterion is satisfied. After this period, we assume that there cannot be another dollar liquidity crisis in the same country for at least two years. Using this definition, Table A1 lists the 22 crisis events and the T=0 start date for our 14 countries between 2003 and 2022.

Table A1: Dollar Liquidity Crisis Events

Q3 2007	Switzerland	Q1 2011	Denmark
Q4 2007	Netherlands	Q1 2012	Switzerland
Q2 2008	Germany	Q2 2012	Netherlands
Q3 2008	Italy	Q3 2013	Denmark
Q3 2008	UK	Q2 2014	Japan
Q4 2008	France	Q3 2014	UK
Q4 2008	Denmark	Q2 2015	Singapore
Q1 2010	Spain	Q1 2016	India
Q1 2010	Netherlands	Q2 2019	India
Q4 2010	Italy	Q3 2020	Spain
Q1 2011	France	Q2 2021	Denmark

B Pre-Shock Equilibrium

In the pre-shock equilibrium all endogenous period 1 variables are equal to corresponding period 0 variables. Therefore $L_1^\$ = L_0^\$$, $L_1^€ = L_0^€$, $B_1^{\$,w} = B_0^{\$,w}$, $B_1^{€,w} = B_0^{€,w}$, $S_1 = S_0$, $W_1 = W_0$, $i_1^\$ = i_0^\$$ and $i_1^€ = i_0^€$.

This is accomplished as follows. First, we adjust σ to target a probability of default p_D of 0.005. This determines $i_1^\$ = i^s + p_D$ and $i_1^€ = i^s + (1 - bail_e)p_D$. In the main analysis we set $bail_e = 0$. We then set $i_0^\$$ and $i_0^€$ equal to these period 1 interest rates. From now on we drop the time subscript from wholesale dollar and euro funding rates as they are equal in periods 0 and 1.

It follows immediately from (12) that $W_1 = W_0$ when $L_1^{\$} = L_0^{\$}$ and $L_1^{€} = L_0^{€}$. Using $W_1 = W_0$ and setting loan levels in period 1 equal to those in period 0, it follows from (22)-(23) that

$$i_0^{€,l} = d + i^{€} + l_e + \gamma\sigma^2 L_0^{€}\frac{1}{W_0} \tag{B.1}$$

$$i_0^{\$,l} = d + i^{\$} + l_d + \gamma\sigma^2 L_0^{\$}\frac{1}{W_0} \tag{B.2}$$

Here we set $\mu_e = \mu_d = 0$. When these are the interest rates on bank loans, banks choose to keep loans unchanged, so that the constraints (16)-(17) do not bind.

Notice that $i_0^{€,l}$ and $i_0^{\$,l}$ depend on l_e and l_d. We will set $\bar{B}^{€} = B_0^{€,w}$ and $\bar{B}^{\$} = B_0^{\$,w}$. When banks without borrowing constraints ($l_e = l_d = 0$) choose to set period 1 wholesale euro and dollar funding equal to period 0 levels, the borrowing constraints are indeed not binding. We can then set $l_e = l_d = 0$ in the expressions above for $i_0^{€,l}$ and $i_0^{\$,l}$. We will show below that banks indeed choose period 1 wholesale funding levels that are equal to those in period 0.

Before we discuss the wholesale borrowing levels, first consider synthetic dollar borrowing. We assume $S_0 = \delta K$, where K is the total size of the balance sheet. We set $\delta = 0$ in most of the analysis (except for the sensitivity analysis in the Online Appendix). Since $B_0^{\$,w} + S_0 = L_0^{\$}$ and we take $B_0^{\$,w}$ as given, we set $L_0^{\$} = B_0^{\$,w} + \delta K$ and $L_0^{€} = K - L_0^{\$}$. We now need to make sure that $S_1 = S_0 = \delta K$. Using (21), together with $l_d = l_e = 0$, implies $f_1 - e_1 = i^{\$} - i^{€} - \eta\delta K$. This must be equal to the equilibrium swap rate in (26). It follows that we need to set

$$u = \frac{1}{\eta}(i^{\$} - i^{€}) - 2\delta K \tag{B.3}$$

In the main analysis $\delta = 0$ and $bail_e = 0$, so that $u = 0$.

We finally need to make sure that $B_1^{\$,w} = B_0^{\$,w}$ and $B_1^{€,w} = B_0^{€,w}$. We have from (6)- (7) that

$$B_1^{\$,w} = L_1^{\$} - S_1 \tag{B.4}$$

$$B_1^{€,w} = S_1 - W_1 + L_1^{€} - B^{€} \tag{B.5}$$

The same identities apply to period 0 as well. Setting $S_1 = S_0$, $W_1 = W_0$, $L_1^{\$} = L_0^{\$}$ and $L_1^{€} = L_0^{€}$, it indeed follows that $B_1^{\$,w} = B_0^{\$,w}$ and $B_1^{€,w} = B_0^{€,w}$.

This description of the pre-shock equilibrium also applies to the sensitivity analysis in the Online Appendix. The expression for the wholesale funding rates is slightly different when we assume risk-averse lenders, as discussed in the Online Appendix, but otherwise the pre-shock equilibrium is determined in the same way. The only case in the sensitivity analysis that is different is when we vary l_d. In the description above we assume that the dollar borrowing constraint does not strictly bind in the pre-shock equilibrium, so that $l_d = 0$. In the Online Appendix we vary the endogenous Lagrange multiplier l_d by letting $i_0^{\$,l}$ vary. It follows from (B.2) that l_d will then vary one-for-one with $i_0^{\$,l}$.

Since δ and $bail_e$ are held at zero when we vary l_d, $S_1 = S_0 = 0$ and $i^{\$} = i^{€}$. Using (21) then implies $f_1 - e_1 = l_d$. Equating this to the equilibrium swap rate in (26), it follows that we must set $u = l_d/\eta$.

References

Abbassi, Puriya and Falk Bräuning. 2020. "Demand Effects in the FX Forward Market: Micro Evidence from Banks' Dollar Hedging". *The Review of Financial Studies 34*, 4177–4215.

Aldasoro, Iñaki and Torsten Ehlers. 2018. "The Geography of Dollar Funding of non-US Banks". *BIS Quarterly Review, December*, 15–26.

Aldasoro, Iñaki, Torsten Ehlers, Patrick McGuire, and Goetz von Peter. 2020. "Global Banks' Dollar Funding Needs and Central Bank Swap Lines". *BIS Bulletin 27*.

Anderson, Alyssa, Wenxin Du, and Bernd Schlusche. 2025. "Arbitrage Capital of Global Banks". *The Journal of Finance 80*, 2591–2638.

Bacchetta, Philippe, Scott Davis, and Eric van Wincoop. 2026. "Offshore Dollar Funding Shocks and the Dollar Exchange Rate". *Journal of International Economics* (forthcoming).

Bahaj, Saleem and Ricardo Reis. 2022. "Central Bank Swap Lines: Evidence on the Effects of the Lender of Last Resort". *The Review of Economic Studies 89*(4), 1654–1693.

Barajas, Adolfo, Andrea Deghi, Claudio Raddatz, Dulani Seneviratne, Peichu Xie, and Yizhi Xu. 2020. "Global Banks' Dollar Funding: A Source of Financial Vulnerability". *IMF Working Paper 20/113*.

Barbiero, Omar, Falk Brauning, Gustavo Joaquim, and Hillary Stein. 2024. "Dealer Risk Limits and Currency Return". *Working Paper*.

Bernanke, Ben S., Mark Gertler, and Simon Gilchrist. 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework". *Handbook of Macroeconomics 1*, 1341–1393.

Bohorquez, Diego. 2023. "The United States as the International Lender of Last Resort". *mimeo*.

Borio, Claudio, Mobeen Iqbal, Robert McCauley, Patrick McGuire, and Vladyslav Sushko. 2018. "The Failure of Covered Interest Rate Parity: FX Hedging Demand and Costly Balance Sheets". *BIS Working Paper No. 590*.

Cenedese, Gino, Pasquale Della Corte, and Tianyu Wang. 2021. "Currency Mispricing and Dealer Balance Sheets". *The Journal of Finance 76*(6), 2763–2803.

Cerutti, Eugenio M, Maurice Obstfeld, and Haonan Zhou. 2021. "Covered Interest Parity Deviations: Macrofinancial Determinants". *Journal of International Economics 130*, 103447.

Committee on the Global Financial System (CGFS). 2010. "The role of margin requirements and haircuts in procyclicality". *CGFS Papers, No. 36*.

Committee on the Global Financial System (CGFS). 2020. "US Dollar Funding: An International Perspective". *CGFS Papers, No. 65*.

Du, Wenxin, Alexander Tepper, and Adrien Verdelhan. 2018. "Deviations from Covered Interest Rate Parity". *The Journal of Finance 73*(3), 915–957.

Eguren-Martin, Fernando, Matias Ossandon Busch, and Dennis Reinhardt. 2024. "Global Banks and Synthetic Funding: The Benefits of Foreign Relatives". *Journal of Money, Credit and Banking 56*, 115–152.

Eren, Egemen, Andreas Schrimpf, and Sushko Vladyslav. 2020. "US Dollar Funding Markets during the Covid-19 Crisis - The International Dimension". *BIS Bulletin 15.*

Ferrara, Gerardo, Philippe Mueller, Ganesh Viswanath-Natraj, and Junxuan Wang. 2022. "Central Bank Swap Lines: Micro-Level Evidence". *Bank of England Staff Working Paper No. 977*.

Friedrichs, Melanie, Corey Garriott, and Robert Mann. 2026. "Sizing the us cross-border repo market". *The OFR Blog, Office of Financial Research, US Department of the Treasury*.

Gertler, Mark and Nobuhiro Kiyotaki. 2015. "Banking, Liquidity, and Bank Runs in an Infinite Horizon Economy". *American Economic Review 105*, 2011–43.

Global Financial Stability Report (GFSR). 2019. "Banks' Dollar Funding: A Source of Financial Vulnerability.". *IMF, Chapter 5*.

Goldberg, Linda S. and Fabiola Ravazzolo. 2022. "The Fed's International Dollar Liquidity Facilities: New Evidence on Effects". *NBER Working Paper No. 29982*.

Iida, Tomoyuki, Takeshi Kimura, and Nao Sudo. 2018. "Deviations from Covered Interest Rate Parity and the Dollar Funding of Global Banks". *International Journal of Central Banking*, 275–325.

Ivashina, Victoria, David S. Scharfstein, and Jeremy C. Stein. 2015. "Dollar Funding and the Lending Behavior of Global Banks". *The Quarterly Journal of Economics 130*(3), 1241–1281.

Kekre, Rohan and Moritz Lenel. 2025. "The High Frequency Effects of Dollar Swap Lines". *American Economic Review: Insights 7*, 107–23.

Keller, Lorena. 2024. "Arbitraging Covered Interest Rate Parity Deviations and Bank Lending". *American Economic Review 114*, 2633–67.

Khetan, Umang. 2024. "Synthetic Dollar Funding". *Working Paper*.

Kloks, Peteris, Edouard Mattille, and Angelo Ranaldo. 2024. "Hunting for Dollars". *Swiss Finance Institute Research Paper 24-52*.

Kloks, Peteris, Patrick McGuire, Angelo Ranaldo, and Vladyslav Sushko. 2023. "Bank Positions in FX Swaps: Insights from CLS". *BIS Quarterly Review, September*, 17–31.

Lengwyler, Yvan and Beatrice Weder di Mauro. 2023. "Global Lessons from the Demise of Credit Suisse". *VoxEU.org, September*.

McCauley, Robert and Patrick McGuire. 2009. "Dollar Appreciation in 2008: Safe Haven, Carry Trades, Dollar Shortage and Overhedging". *BIS Quarterly Review, December*, 85–93.

McGuire, Patrick and Goetz von Peter. 2009. "The US Dollar Shortage in Global Banking". *BIS Quarterly Review, March*, 47–63.

McGuire, Patrick and Goetz von Peter. 2012. "The Dollar Shortage in Global Banking and the International Policy Response". *International Finance 15*, 155–178.

Moskowitz, Tobias J., Chase P. Ross, Sharon Y. Ross, and Kaushik Vasudevan. 2026. "Risk and Specialization in Covered-Interest Arbitrage". *Journal of Finance* (forthcoming).

Rime, Dagfinn, Andreas Schrimpf, and Olav Syrstad. 2022. "Covered Interest Parity Arbitrage". *The Review of Financial Studies 35*(11), 5185–5227.