# Swap Line Arbitrage Supply[*]

Pēteris Kloks[†]

JOB MARKET PAPER

March 12, 2025

**Abstract**

While Federal Reserve swap lines are now the primary policy tool for easing offshore U.S. dollar borrowing cost during times of stress, its pass-through to the FX market remains poorly understood, largely due to a lack of data on the OTC FX swap market. Using a bespoke settlement dataset, I conduct the first comprehensive empirical study of agent positioning in FX swaps around swap-line take-ups globally across jurisdictions, currencies and time, and provide two main results. First, I show novel evidence that swap lines lower U.S. dollar borrowing cost not only through a reduction in non-U.S. bank *demand* for U.S. dollar (substitution channel), as is commonly expected, but also through an increase in U.S. dollar *supply* (arbitrage channel). Second, such arbitrage lending is primarily absorbed by the interbank market rather than by non-bank customers directly and, counter-intuitively, lent even to U.S. banks, who appear to be willing to pay the cross-currency basis to receive such funding. I rationalize the latter finding with a simple conceptual framework that links limits to arbitrage capital with U.S. bank balance sheet constraints. My results offer novel policy implications.

*Keywords:* Central bank swap lines, Covered interest parity, Global funding markets, Intermediary constraints.

*JEL classification*: F31, G12, G15.

---

[*] I am especially thankful to Angelo Ranaldo (principal adviser) as well as Andrea Barbon, Can Gao, Cara Stromeyer, Carlos Cañon, Claudio Borio, Eddie Gerba, Edouard Mattille, Gerardo Ferrara, Marco Gortan, Martin Brown, Pasquale Della Corte, Patrick McGuire, Petros Katsoulis, Ricardo Reis, Robert Czech and Vladyslav Sushko for useful comments and discussions, and audiences at the GPEF PhD Day (2024) and the Young Swiss Economists Meeting (poster session, 2025). This paper is further scheduled to be presented at the IBEFA-WEAI Summer Meeting (2025), the BIS–CEPR-Gerzensee-SFI Conference on Financial Intermediation (poster session, 2025), the Annual Meeting of the Swiss Society for Financial Market Research (poster session, 2025), the Third Durham Conference for Finance Job Market Papers (2025) and at the Fourth PhD Workshop in Money and Finance organized by the Sveriges Riksbank and the Center for Monetary Policy and Financial Stability at Stockholm University (2025). I further thank Vladimir Visipkov at the Continuous Linked Settlement Group (CLS) for help in constructing the dataset. This work did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. All remaining errors are my own.

[†] Send correspondence to Peteris Kloks, University of St. Gallen / Swiss Finance Institute, Switzerland. E-mail: peteris.kloks@unisg.ch.

# 1. Introduction

Access to uninterrupted U.S. dollar funding in times of stress is crucial to prevent financial stability episodes given the outsize role that the reserve currency serves in global trade and finance. In terms of policy response, Federal Reserve swap lines have become the main tool to ease the cost of U.S. dollar borrowing in synthetic funding markets. The size of swap lines is large and growing, with the combined network of U.S. dollar liquidity lines reaching up to 20% of the world's GDP. However, policymakers still have surprisingly little empirical evidence as regards to the nature of the pass-through mechanism of an active swap line (an agreement between two central banks) to the private markets (contracts involving commercial banks and non-bank customers), largely due to a lack of globally representative and granular data on the over-the counter (OTC) FX swap market.

This paper fills the gap by drawing on a bespoke high-frequency dataset from Continous Linked Settlement (CLS) on quantities and prices in settled FX swap contracts globally, and provides two main results. First, by analyzing agent positioning in the synthetic U.S. dollar funding market across geographical jurisdictions, currencies and tenors over the past decade, I present evidence that Federal Reserve swap lines help ease offshore U.S. dollar borrowing cost not only through a reduction in non-U.S. bank *demand* for the dollar in FX swaps (substitution channel), which is the commonly known pass-through mechanism, but also through an increase in non-U.S. bank dollar *supply* (arbitrage channel). To identify the role of swap lines, I examine COVID 2020 as well as quarter-end periods, which serve as important historical market stress episodes. The intuition is that a swap line arbitrage trade is unlikely to be attractive during normal times due to a penalty rate imposed by the central bank, but may become profitable in periods of stress. Whereas prior literature has predominantly focused on the effects of foreign bank demand for the U.S. dollar, this work explores the supply side. By uncovering the role of foreign banks as willing arbitrageurs in the FX swap market, I paint a more complete picture of the various swap line pass-through mechanisms at play, thereby adding to our understanding of this critical policy tool.

The second main result of the paper relates to who receives such U.S. dollar supply by foreign banks. I demonstrate that foreign bank excess supply of U.S. dollars around COVID 2020 was not necessarily intermediated to non-bank end-customers directly, but was rather first absorbed by the interbank market, which, importantly, included lending to U.S. banks. The result is unexpected because prior literature views non-US banks either as mere borrowers of U.S. dollar for their own hedging and funding needs, or as intermediaries who borrow in the inter-dealer market on behalf of customers. In both cases, the expected direction of the flow of U.S. dollar liquidity points away from U.S. banks and towards foreign banks (and, finally, possibly to non-banks). In contrast, my results reveal that U.S. dollar liquidity flows in the other direction, too. In other words, I find evidence that foreign banks also *lend* U.S. dollars to U.S. banks, even during market stress episodes, which is consistent with the main intuition of this paper: non-US banks play a dual role acting not only as dollar borrowers, who consume liquidity and pay the basis, but also as willing arbitrageurs, who provide it and earn the basis, rather than solely the former, as is commonly assumed.

A better understanding of how a U.S. dollar liquidity line between two central banks passes through into private markets is important for several reasons. On the one hand, prior research has highlighted that frictions in non-US bank access to U.S. dollar liquidity matter for price efficiency in the FX market. This study provides new evidence of how such frictions hinder the ability of foreign banks to arbitrage deviations from the law of one price, that is, deviations from covered interest rate parity (CIP). On the other hand, this study is the first to establish a link between Federal Reserve swap lines and U.S. banks, an angle virtually ignored in the current literature despite the fact that it is U.S. banks who dominate the FX market globally according to survey data. U.S. banks play a critical role in supporting an efficient functioning of the FX market, bringing together parties that wish to trade and share risks. In this paper, I argue that the ability of U.S. banks to provide U.S. dollar liquidity to non-banks may suffer in periods when constraints to their risk-bearing capacity coincide with there being less counterparties willing to share such risks, such as when non-US bank access to the U.S. dollar is impaired.

The paper proceeds in four main steps. First, I design and obtain a novel bespoke dataset on quantities and prices in settled FX swap contracts globally across U.S. and non-U.S. actors. To do so, I manually classify 4,170 banking entities per *nationality* of the overarching banking group. The data allows me to observe both the volumes and prices charged by U.S. banks to various bank and non-bank counterparty groups. It is available at a daily frequency and across all major U.S.

dollar currency pairs and FX swap maturities offering a highly representative picture of U.S. bank FX swap market activity globally. Importantly, in my classification an FX swap traded by J.P. Morgan in London identifies the party as a U.S. global systemically important bank (G-SIB). This data is particularly novel given that other sources, such as BIS statistics, provide only a locational view, and would thereby classify J.P. Morgan's London branch as a UK entity, making it harder to identify the role of U.S. banks in global market making. Importantly, my data does not cover only U.S. banks but other bank nationality groups, too. Thus, I can sort market participants into six regions of the world: the U.S., the Eurozone, the UK, Switzerland, Japan, and a residual group combining all other nationalities (ROW). Finally, to differentiate the demand and supply effects, I classify each trade into dollar borrowing or lending. That is, trades that result in dollar cash inflows at the near leg of the contract are flagged as dollar purchases; in contract, those that result in dollar cash outflows are classified as sales. Because U.S. dollar interest rate commands a premium in the synthetic dollar funding market, evidence for higher dollar sales in times of stress can indicate the degree to which foreign banks use the FX swap market as a source of arbitrage activity. Separating dollar purchases and dollar sales allows to perform analyses distinct from merely looking at the net position, which would reflect demand and supply effects jointly.

Second, I employ the newly constructed data set to provide novel empirical evidence for a swap line arbitrage lending channel by foreign banks in times of stress. To identify the role of swap lines, I analyze agent positioning in FX swaps around important historical stress episodes such as COVID 2020 and quarter-end reporting periods. While a swap line arbitrage trade is unlikely to be attractive during normal times due to a penalty rate imposed by the central bank, it may become profitable in periods of stress if two conditions are simultaneously met: U.S. dollar borrowing costs exceed the level at which swap line arbitrage becomes profitable (in other words, exceed the swap line ceiling as defined in Bahaj and Reis (2021)), and the arbitrageur has access to Federal Reserve swap line funding. In this respect, COVID 2020 is a particularly important case-study as it marked the highest Federal Reserve swap-line take-up since the Great Financial Crisis. The episode nevertheless provides a challenge for an empirical study for several reasons. On the one hand, the peak of market stress in mid-March coincided with sudden changes in numerous other confounding factors, which, if not controlled for, make any identification difficult. On the other hand, one should expect no persistent arbitrage opportunities to emerge in the first place once

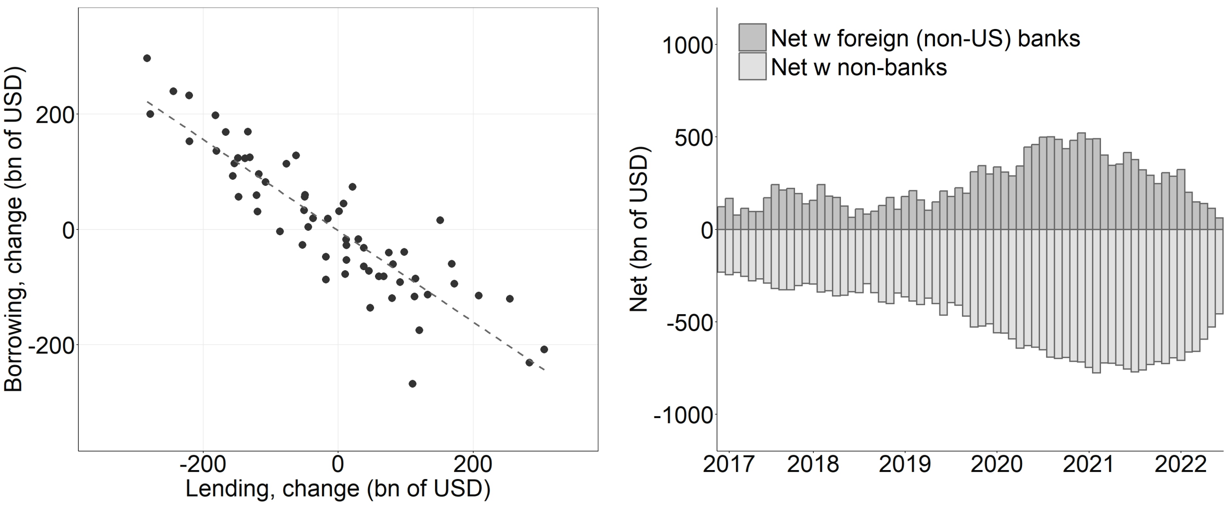
U.S. dollar borrowing costs return to pre-crisis levels. I overcome these identification challenges by examining the FX market in the weeks following the peak of the crisis, rather than focusing on the peak itself, and by exploiting a unique quasi-natural experiment. In particular, I use the observation that the U.S. dollar borrowing rate, while having returned to well within the bounds at which swap line arbitrage is no longer profitable, took several weeks longer to revert to normal levels for the dollar-yen pair, which thus serves as a treatment group. A foreign bank who acts as an arbitrageur could then borrow U.S. dollar via swap lines at the local central bank and lend it out in the FX swap market, making a profit. Using this episode in a difference-in-difference setting, I provide causal evidence for swap line arbitrage and estimate that at least 25% of Bank of Japan's swap line take-up was ultimately transmitted to the private FX market through the hands of affected foreign banks.

Third, I turn to examining who receives such foreign bank U.S. dollar supply. Before turning to empirical evidence, I develop a simple conceptual framework to explain why it is conceivable that U.S. banks might be among the list of willing borrowers of such funding — that is, why U.S. banks may be willing to pay a premium to obtain U.S. dollars in the FX swap market. This is counter-intuitive, as these banks have other natural sources of dollar liquidity, such as access to U.S. repo markets, that are cheaper than borrowing via FX swaps, which command a premium. To understand why, consider the importance of U.S. bank balance sheet constraints. U.S. banks observe client demand across a continuum of customers in the FX swap market. In case such demand is not balanced, U.S. banks face the need to fund the imbalanced FX swap position somewhere, as customer positions do not net out and the nature of an FX swap contract implies a cash outflow at the near leg of the trade. Crucially, my settlement data reveal that non-bank demand in FX swaps globally is indeed heavily imbalanced and tilted towards consuming U.S. dollar liquidity, a finding in line with prior research (Bräuer and Hau, 2022). In such a case, a U.S. bank faces a decision of how to fund its open position, and it has two options of how to do so. One method is to fund the position by borrowing U.S. dollars *outside* of the FX swap market, say via repo in U.S. money markets or via repo from the Federal Reserve. While cheap in terms of the interest rate, repo borrowing entails hidden shadow costs that significantly expand the balance sheet of a bank and thereby hurt the Basel III leverage ratio (Du, Tepper, and Verdelhan, 2018, Ranaldo, Schaffner, and Vasios, 2020). The alternative method for a U.S. bank is to attract funding *within* the FX swap market from other market participants, including from foreign banks. Because non-bank demand consumes dollar liquidity in total, a U.S. bank can do so by offering to *pay* a non-zero cross-currency basis to willing arbitrageurs, thereby attracting U.S. dollar liquidity and thus achieving a smaller net open position. In contrast to a repo, an FX swap is an off-balance sheet instrument. In periods of market stress when balance sheet constraints bind, the FX forward desk of a U.S. bank may face increasing internal risk limits on its open net FX swap exposure. This is because funding an open net exposure outside the FX market via a repo transaction would worsen its Basel III Leverage Ratio. In such a setting, it is perfectly conceivable that U.S. banks may be willing to pay a cost in the form of a cross-currency basis to avoid the Leverage Ratio impact of a balance-sheet intensive funding instruments such as repo. In other words, a constrained U.S. bank benefits from an uninterrupted availability of arbitrage capital in the FX market, including from foreign banks, because it provides it the flexibility to fund its U.S. dollar intermediation business off-balance sheet in times of stress.

Fig. (1) presents the main motivating evidence in support of the idea that U.S. banks fund part of their imbalanced customer position by borrowing within the FX swap market. In fact, settlement data on U.S. bank global positions reveal quite a stunning picture: U.S. banks operate a close-to matched-book of trading even in the absence of stress episodes, as visible in Panel (a). A simple correlation between the monthly *change* in U.S. bank borrowing and lending positions in their total FX swap *gross* books across all currencies and tenors shows that buy and sell positions typically closely match each other. Moreover, when one turns to U.S. bank *net* positions, data reveal that U.S. banks achieve a close-to zero net position by offsetting non-bank customer flows against those of non-U.S. banks. Over the last decade, non-banks have increasingly become large U.S. dollar *borrowers*, thereby having an increasingly negative net position with U.S. banks. Simultaneously, U.S. banks have run an increasingly positive net position with foreign (non-U.S.) banks, as seen in Panel (b), implying that non-U.S. banks *lend* U.S. dollar at the near leg of an FX swap contract. The correlation (over monthly changes) is extremely strong at $-0.52\%$.[1] Moreover, U.S. banks' net total position is merely 4% of their gross total. Compiled with the fact that more than two-thirds of dollar volumes run through the hands of U.S. banks, I argue that U.S. banks effectively act as the global market makers in FX swaps and can thus be negatively affected

[1] The correlation between daily changes with foreign banks vs. daily changes with non-banks amounts to −0.29%.

by the (in)ability of foreign banks to act as willing counterparties in times of stress, which Federal Reserve swap lines help to alleviate.




(a) US bank **gross** position, USD borrowing vs. lending

(b) US bank USD **net** position, per c-party

**Fig. 1:** US bank matched-book USD intermediation in the global FX swap market. Panel (a): Monthly change in U.S. bank USD borrowing vs. lending gross positions outstanding. Each dot refers to the monthly change across all tenors and U.S. dollar currency pairs. Panel (b): Monthly U.S. bank net USD position with foreign (non-U.S.) banks vs. with non-bank customers. Bars refer to net across all parties, tenors and currencies and are monthly averages. For both figures data is from 2017 until 2022.

Fourth, I show empirically that U.S. banks indeed have benefited from swap line arbitrage lending by foreign banks in times of stress. The above-mentioned conceptual framework presents testable hypotheses with respect to both quantities and prices charged by U.S. banks. My bespoke granular settlement data on U.S. banks' activity in FX swaps *per counterparty group* enables me to test these hypotheses directly using market data. For quantities, I show that parts of the excess supply by foreign banks was consumed by U.S. banks, and that such foreign bank flows negatively predict U.S. bank net position with non-U.S. banks. This holds true across various frequencies (daily, weekly, and monthly) as well as across currency pairs, even when I control for market-wide trading conditions. For prices, I estimate a linear probability model for the likelihood of CIP ceiling violations. This allows me to test whether swap line arbitrageurs offered prices closer to the no-arbitrage CIP ceiling compared to a control group during the 2020 COVID episode. Through a difference-in-differences analysis, I show causal evidence that the COVID period was characterized by a higher probability of CIP violations, as expected, but the likelihood of ceiling violations was lower when U.S. banks *borrowed* U.S. dollars from Japanese banks, which I previously identify as swap line arbitrageurs in the dollar-yen currency pair, compared to a control group of non-U.S. banks who had no access to swap lines. As an important counterfactual exercise, the result does not hold true for contracts where U.S. banks *sold* U.S. dollars at the near leg of an FX swap, which supports my mechanism since it was U.S. dollar lending– but not borrowing– that was attractive to a swap line arbitrageur.

Understanding the link between swap lines and the private FX swap market is important as it reveals the limited role of central banks in alleviating U.S. dollar funding pressures directly. In fact, I show that public dollar liquidity (central banks) requires the involvement of private banks (private dollar liquidity) for better effectiveness. The Federal Reserve delegates to other central banks the responsibility of providing dollars, given their expertise and positioning within their own jurisdictions. However, my results indicate that private banks within these jurisdictions are better positioned to distribute U.S. dollars where they are most needed (through a lending channel) and where it is most advantageous (CIP basis). Private liquidity is thus crucial to achieve the Fed's aim of easing private U.S. dollar borrowing conditions.

**Link to the prior literature.** During the past decade, a growing literature has documented CIP deviations (Du et al., 2018) and showed that banking regulation is among the factors that help explain it (Cenedese, Della Corte, and Wang, 2021). This study builds on the work of Bahaj and Reis (2021) who showed theoretically and empirically how central bank policy, namely lending programs, can put a ceiling on such CIP deviations. I add the result that violations of the CIP ceiling can be worsened or improved by market makers' desire to balance their customer flows to achieve a matched-book of trading and a close-to zero net position. Moreover, I show empirical support for such a mechanism by taking the perspective of U.S. banks and hence improve our understanding of the flow of Federal Reserve swap line funding throughout the financial system. By doing so, I build on the work of Syrstad and Viswanath-Natraj (2022) who showed the role of market makers' order flow in the price-setting of FX forward and swap contracts.

Even though the academic literature on central bank swap lines is scarce, I am by no means the only one to study them (Rose and Spiegel, 2012, Bahaj and Reis, 2020, Goldberg and Ravazzolo, 2021, Choi and Ravazzolo, 2021, Ferrara, Mueller, Viswanath-Natraj, and Wang, 2022, Kekre and Lenel, 2023). Ferrara et al. (2022) uses micro-level evidence on how swap lines affect market dynamics using Bank of England swap line drawings. My findings confirm theirs insofar as I also document a reduction in borrowing volumes in some segments of the market due to a substitution effect towards swap line funding. However, I add to their results by conducting a more global empirical study that captures trading activity beyond London, the major FX hub. I am thereby the first to quantify the extent to which swap line funds were used for arbitrage lending in FX swaps in comparison to other motivations such as precautionary hoarding of U.S. dollar liquidity.

# 2. Data and Motivating Evidence

This paper sheds light on the global U.S. dollar funding flows in response to swap line drawings. To do so, I use a bespoke data set on prices and agent positioning in the global FX swap market from Continous Linked Settlement (CLS), the largest settlement firm in the world. This section describes the data in detail.

## 2.1. FX swap data by market participant nationality

With its sheer size of around US$ 3.8 trillion of global daily turnover (Bank for International Settlements, 2022), the FX swap market is the largest market in the world. However, obtaining representative data for this markets is notoriously difficult given the fragmented, over-the-counter nature of this segment. Trading occurs bilaterally and is dispersed throughout many exchanges, and relying on data from a single source may not be representative of the global landscape. My solution is to use data from CLS, the world's largest multi-currency cash settlement system. CLS records the settlement of trades and thus allows U.S. to observe trades regardless of where or on what platform (if any) they were executed. As many if not all transactions require settlement,[2] it is global settlement data that can yield a representative picture for U.S. dollar borrowing dynamics in the global FX swap market.

The data, which runs from from January 3$^{rd}$, 2012 to June 30$^{th}$, 2022 and is available at a daily frequency, show that, on an average day, market participants have a total of US$ 12.7 trillion

[2] There are some exceptions: for instance, CLS does not perform settlement for overnight swaps, the Chinese renminbi, or the Russian ruble. Moreover, a bank will not use CLS settlement when a customer has a deposit account with it (e.g., a retail investor using the banks' wealth management services). Furthermore, institutions (e.g., hedge funds) with a prime brokerage arrangement with a dealer-bank are not settled through CLS.

worth of open FX swap contracts *outstanding*[3] across 17 U.S. dollar currency pairs and 8 tenors[4] (see summary statistics in Table 1). This is captures at least 30% of the FX market according to BIS Triennial Survey estimates (Bank for International Settlements, 2019). Further comparison (see Appendix A) shows that CLS and BIS data display very similar figures when considering relative breakdowns by maturity and currencies, confirming that the data is highly representative of the global FX market. For further analysis of the FX swap market liquidity conditions using CLS data, see Kloks, Mattille, and Ranaldo (2023a).

| | Volume (in tn $) | Trades ('000) | Volume (%) | Trades (%) |
|---|---|---|---|---|
| EURUSD | 4.75 | 77,940 | 37.4 | 30.9 |
| USDJPY | 2.54 | 31,963 | 20.0 | 12.7 |
| GBPUSD | 1.66 | 30,401 | 13.1 | 12.0 |
| USDCHF | 0.54 | 10,346 | 4.2 | 4.1 |
| Other dollar | 3.20 | 101,893 | 25.2 | 40.3 |
| Maturity <= 7 days | 0.87 | 7,413 | 6.9 | 2.9 |
| Maturity > 7 days | 11.82 | 245,129 | 93.1 | 97.1 |
| Bank to Bank | 10.15 | 155,951 | 80.0 | 61.8 |
| Bank to Non-Bank | 2.54 | 96,591 | 20.0 | 38.2 |
| Involves a G-SIB Bank | 11.83 | 230,444 | 93.2 | 91.2 |
| w/o a G-SIB Bank | 0.86 | 22,098 | 6.8 | 8.8 |
| Total | 12.69 | 252,543 | 100 | 100 |

**Table 1:** FX swap outstanding open positions: 2012-2022 daily averages.

Importantly, I order three bespoke adjustments to CLS data for the purposes of this paper. First, I break down the data on open FX swap positions per *market participant nationality*. The rationale for doing so is to isolate U.S. banks from all other banks as well as to recognize that some bank nationality groups are affected by swap lines whereas others are not. Note that the *nationality* view, which I pursue in the subsequent analysis, is fundamentally different from the *residence view*. To give an example, JP Morgan London branch would be classified as a U.S. firm under the nationality view, as its headquarters are in New York, whereas it would be a UK firm from a residence perspective, as the traders sit in London. While both perspectives offer comple-

[3]The data set allows U.S. to consider the *outstanding* amount of swaps active between certain counterparties. An FX swap is included on date $t$ if its near-leg settlement date $<= t$ and its far-leg settlement date is $> t$. The data set defines a trading as rolling over at 5 p.m. New York time, in line with FX convention.

[4]I assign swaps to a total of 8 tenor buckets designed to represent tom-next, spot-next, 1-week, 2-week, 1-month, 2-month, 3-month, and longer maturities.

mentary perspectives, it is the nationality view that recognises the importance of global financial intermediaries whose balance sheets go beyond national borders (Bank for International Settlements, 2024). As a result, I proceed to manually classify 4,170 banking entities per nationality based on the location of their headquarters. In case of ambiguity, I consulted the banks' investor reports. I are able to perform the classification because CLS is aware of the identity of the entities conducting he trades. I choose to sort banks into six region of the world: the US, the Eurozone, the UK, Switzerland, Japan, and all others combined. The choice is guided by, among other aspects, the standing swap lines that the Federal Reserve has established globally.

| | Residence | | Nationality |
|---|---|---|---|
| | BIS | CLS | CLS |
| UK | 54 | 54 | 16 |
| U.S. | 19 | 19 | 47 |
| Japan | 7 | 2 | 5 |
| Eurozone | 13 | 14 | 23 |
| Switzerland | 5 | 4 | 7 |
| Other | 3 | 6 | 2 |
| Total (%) | 100 | 100 | 100 |

**Table 2:** CLS and BIS coverage comparison. CLS data is based on a sample from 2016 and is benchmarked against the BIS Triennial Central Bank Survey of foreign exchange and OTC derivatives in 2016.

Table (2) reports the summary statistics of the nationality data set across the six regions for all the banks in the sample and in comparison to data from the BIS. For robustness check, I obtained a sample of the data set based on the residence principle, which is the principle that guides the BIS Triennial Central Bank Survey of foreign exchange and OTC derivatives. As can be seen, both CLS and BIS coverage match closely based on the residence principle, both highlighting the role of London as the global hub for FX trading. In contrast, the nationality data set reveals significant and crucial differences as to who is actually trading in the market. While CLS FX spot data has been studied before by Hasbrouck and Levich (2019), Ranaldo and Somogyi (2021), and Cespa, Gargano, Riddiough, and Sarno (2021), I am, to the best of the knowledge, the first to study it in the context of U.S. dollar swap lines.[5]

Second, I manually classify banks according to whether they are a global systemically important bank (G-SIB) or not. This allows me to isolate global U.S. banks from smaller U.S. commercial

[5] Kloks, McGuire, Ranaldo, and Sushko (2023b) study FX swap liquidity using flow data. Bräuer and Hau (2022) use CLS FX swap data on fund order flow for seven currencies against the U.S. dollar.

banks and thus analyse the role of large dealers who dominate the FX market (Somogyi, 2021). Appendix B lists the G-SIB banks in the data.[6] As seen in Table (1), the FX swap market is indeed concentrated in the hands of a small set of global G-SIB dealer-banks, with more than 90% of positions globally involving a global dealer on at least one side of the trade.

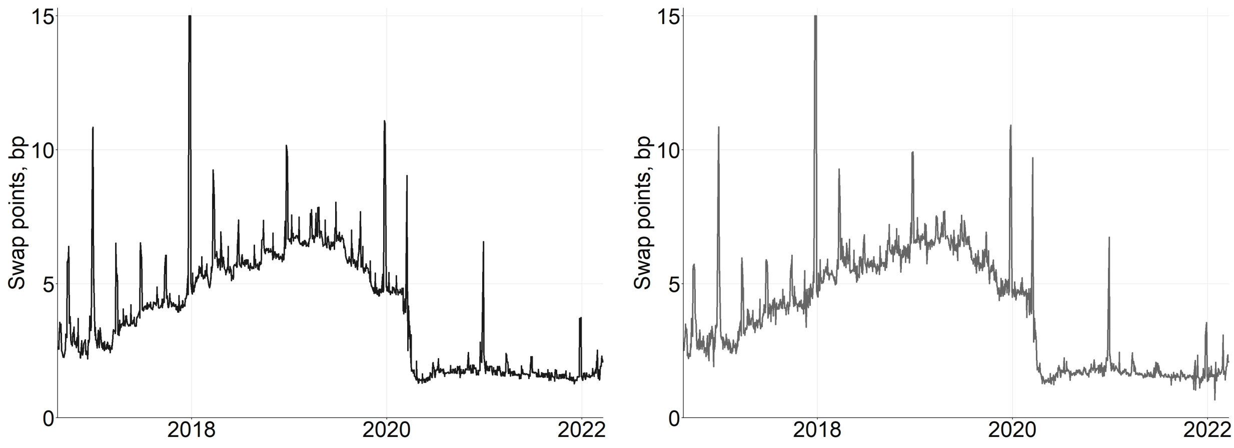
Third, I request and obtain a similar breakdown for prices. Swap points ($F - S$) are the traded price and are therefore the natural target for what consistutes a price of an FX swap. To this end, I therefore request CLS to manually match, for each contract $i$, its respective FX rates at the near ($S$) and far ($F$) legs respectively. I then request CLS to aggregate all the contracts and compute the daily volume-weighted average price for a currency $k$, tenor $j$, party $l$ and counterparty $m$. To the best of my knowledge, I am the first to study CLS FX swap prices using their settlement data.

Figure (2) depicts an example of prices charged by U.S. banks, sourced from the bespoke CLS data set and based on actual trades, in comparison to those sourced in Bloomberg, which are generally based on quote data. It shows the volume-weighted average swap points ($F - S$) for 1W EURUSD FX swaps traded on a given trading day by U.S. banks across all counterparties in comparison to the midquotes available on Bloomberg. As visible in the figure, CLS rates, albeit naturally more noisy, are generally well behaved and highly correlated with Bloomberg prices, providing confidence for their use in the subsequent analysis.

## 2.2. Federal Reserve data on liquidity swap operations

Federal Reserve swap lines have become the main policy tool to deal with U.S. dollar funding squeezes. They were first established in December 2007 and were subsequently heavily used in end of 2008, with the maximum drawdown amount peaking at $586bn$. In 2013, swap lines became a permanent policy tool and on a standing basis have been available to the Bank of England (BoE), the Bank of Japan (BoJ), the European Central Bank (ECB), the Swiss National Bank (SNB) and the Bank of China (BoC) ever since. However, swap lines were rarely tapped in the following years, reflecting a period of calmness around U.S. dollar scarcity. That changed in March 2020, which began the period of second-highest drawdowns in swap line history, reaching a maximum

[6] I classified banks as G-SIBs if they were designated as such at least 7 times during the years 2012-2021 according to the List of Global Systemically Important Banks (G-SIBs) published annually by the Financial Stability Board (FSB) in consultation with Basel Committee on Banking Supervision (BCBS) and national authorities. A welcome consequence of the classification system is that only Chinese banks are included in the ROW G-SIB bucket.




(a) Quoted swap points (Bloomberg)

(b) US bank traded swap points (CLS)

**Fig. 2:** EURUSD 1W swap points based on *quoted* swap points (Bloomberg, lhs) vs. volume-weighted daily average *traded* swap points charged by U.S. banks (CLS, rhs). Note that the values of both series are capped at 15 basis points for better visualisation purposes. Data is daily from January 2017 until March 2022.

peak of roughly $540bn$ or only slightly less than during the end of 2008 (see Appendix G, which plots the volumes of Federal Reserve swap lines over time and across the major central banks). The broad usage and effectiveness of swap lines lead to an expansion of bilateral swap lines to a worldwide network that covers more than a hundred bilateral agreements as of today. In this paper, I focus on Federal Reserve swap lines, since these refer to the liquidity provision of U.S. dollar, and restrict myself to the post-2008 period since the FX swap market data begins in 2012. I obtain daily data on swap line draw downs from the Federal Reserve Bank of New York.[7] The data includes the following variables: amount, interest rate, trade date, settlement date, maturity, currency, counterparty central bank.

For the ease of following the subsequent discussion, I also briefly summarize the nature of the swap line contract. A Federal Reserve swap line is essentially a swap of two currencies between the Fed and a recipient-country central bank for a certain maturity and a fixed cost. In such a contract, the Fed loans out U.S. dollars and receives the foreign currency as collateral. The recipient-country central bank taps the swap line when its domestic banks apply for the U.S. dollar lending facility via an auction. Swap line funds are then transferred to a commercial bank at the next business day after the auction date (T+1 settlement), with the recipient-country central

[7]Data is accessible online at: https://www.newyorkfed.org/markets/desk-operations/central-bank-liquidity-swap-operations.

bank acting as an intermediary and receiving recipient-country cash as collateral. It thus bears no foreign exchange risk but does bear the credit risk that the domestic bank will default. Note that swap lines come at a cost for the domestic commercial bank. The cost stems from primarily two sources. First, the interest rate of borrowing the U.S. dollar comes at a penalty rate (currently at 25bp) above the overnight index swap (OIS) rate. However, since no actual borrowing happens at this reference rate, swap line funding may become attractive when the actual borrowing rates exceed the OIS rate. Second, the commercial bank also incurs a haircut on the collateral it provides to the recipient-country central bank. Ultimately, the Federal Reserve, through its bilateral swap line network, achieves its role as an international lender of last resort for U.S. dollar liquidity.

### 2.3. Additional market data and the basis

An FX swap allows market participants to borrow the U.S. dollar using a foreign currency as collateral without being exposed to exchange rate risk. This is because an FX swap contract entails an initial cash flow at the near leg of the contract while simultaneously fixing the exchange rate at the far leg of the contract. It is often referred to as 'synthetic' U.S. dollar borrowing in contrast to 'direct' borrowing in U.S. money markets. The covered interest parity (CIP) principle states that the interest rate charged to borrow U.S. dollar synthetically should be the same as the cost of borrowing U.S. dollar directly:

$$F_{t,t+1} = S_t \cdot \left( \frac{1 + i^k_{t,t+1}}{1 + i^\$_{t,t+1}} \right) \tag{1}$$

where $S_t$ represents the spot rate at time $t$, $F_{t,t+1}$ is the forward rate agreed at time $t$ for a transaction occurring at time $t + 1$, and $i^k_{t,t+1}$ and $i^\$_{t,t+1}$ represent the interest earned in the foreign and U.S. dollar currencies respectively. Then, any deviation between the cash market and FX swap market dollar rate for a given maturity and is defined as the cross-currency basis. In log terms, it is therefore expressed as:

$$\chi^{k/\$}_t = \underbrace{i^\$_t}_{\text{Cash Market Dollar Rate}} - \underbrace{i^k_t - \rho^{k/\$}_t}_{\text{FX Swap Market Dollar Rate}} \tag{2}$$

where $\rho$ is the forward premium e.g. the difference between the forward ($F$) and the spot ($S$) rates respectively:

$$\rho^{k/\$}_t = log(F^{k/\$}_t) - log(S^{k/\$}_t) \tag{3}$$

Ever since 2008, borrowing USD synthetically is more expensive than doing so directly in U.S. money markets for many of the largest currency pairs incl. EURUSD, USDCHF, USDJPY and GBPUSD. The cross-currency basis can thus be viewed as a premium on USD borrowing in the FX swap market.

I am able to compute CIP deviations from two main FX data sources. First, I rely on CLS rates data at a currency-tenor-party-counterparty level, which are available at daily frequency. This includes data on daily volume-weighted average swap points ($F - S$) as well as spot rate ($S$). Second, I obtain daily FX swap points and FX spot rate from Bloomberg. In both cases, I obtain the forward rate by adding swap points to the spot rate. For Bloomberg, values refer to midquotes when a traded price is not available whereas for CLS values are always traded prices. For a measure of risk-free interest rates rates, I obtain daily data on historical Libor rates. I also obtain data on the overnight index swap (OIS) rates as they are necessary to compute the cost of swap line borrowing, which is calculated according to the OIS closing rate of the previous days.

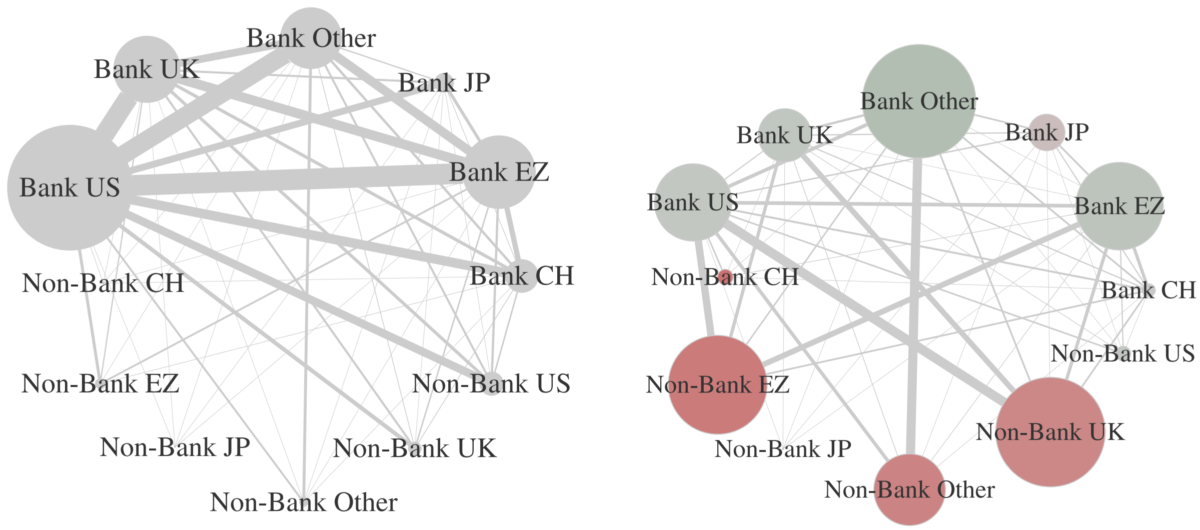
## 2.4. Motivating evidence: U.S. dealers as global market makers

Fig. (3) visualises the global market for U.S. dollar borrowing and lending in FX swaps through a network of outstanding positions using the CLS nationality data. I combine G-SIB and non-GSIB banks for simplicity.[8] For completeness, I also classify non-bank customers per geography.[9] Several messages emerge. First, the interbank market is crucial in understanding global U.S. dollar flows, as revealed by gross bank-to-bank total volumes outstanding (as proxied by the size of the circle) that are significantly larger than bank-to-nonbank volumes. Second, in terms of connectivity, the network is quite concentrated in a key number of nodes and in particular around the U.S. banks, who play an outsized role in the market.

Third, I calculate the *net* FX swap positions, i.e. I allow participants to offset buy and sell volumes of FX swap contracts at the day-currency level. Thus, for each banking group $i$, currency $j$ and tenor $k$, the daily *net* open position across all settled outstanding FX swap contracts $l$ as

[8] Note that, in total, I have 6 currency blocks and 3 institution types, thus meaning that I have 18 distinct counterparties in the data set. Given that all these counterparties trade with each other, this means that I observe 153 unique order flows.

[9] In this case, however, chose to follow the residence principle for several reasons including that many investment funds are registered in off-shore. Thus, for example, I classify an investment fund as a U.S. non-bank if its manager sits in the U.S. – even if it is legally registered in the Cayman Islands.




(a) Outstanding FX swaps, Gross

(b) Outstanding FX swaps, Net

**Fig. 3:** Global network of FX swap open *gross* and *net* positions across all tenors and for 17 U.S. dollar currency pairs combined. Gross positions (lhs) refer to buy plus sell volume, and circle sizes represents each party's (scaled) overall gross position in the global FX swap market. In comparison, net positions (rhs) refer to buy minus sell volume, with red (green) color referring to a party being a net USD borrower (lender) at the near leg and gray color indicating a neutral net overall position. Circle size represents each party's (scaled) overall net position. Data refer to daily average values from 2012 until 2022.

follows:

$$Net_{t,i,j,k} = \sum_{l=1}^{L} \mathbb{1}[\mathrm{T_t} = \mathrm{B}] \; - \; \mathbb{1}[\mathrm{T_t} = \mathrm{S}], \tag{4}$$

where $B$ and $S$ refer to trade direction and indicate whether a given trade resulted in a dollar cash inflow or outflow at the near leg of an FX swap contract (thus, indicating U.S. dollar purchases or sales respectively). The sum of net positions across all U.S. dollar currency pairs and tenors yields, for each banking group $i$, its net U.S. dollar borrowing at any given day $t$:

$$Net_{t,i} = \sum_{j=1}^{J} \sum_{k=1}^{K} Net_{t,i,j,k}. \tag{5}$$

Panel (b) of Fig. (3) examines the network after I allow agents to *net* FX swap positions.[10] The figure colors net U.S. dollar lenders (borrowers) in green (red); the color is assigned for the agents' total overall net position across all currencies, counterparties and tenors. For example, if JP Morgan and UBS agree a three-month, 100 million EURUSD FX swap on January 1$^{st}$ 2018 whereby UBS receives U.S. dollar cash flow two days after the trade date, JP Morgan is a net

[10] Note that the net position does not necessarily indicate who is the "aggressor" or who triggered a market order and thus is not the classical order flow as studied in e.g. Evans and Lyons (2002).

lender (green) and UBS is a net borrower (red). As expected, non-banks are the largest net dollar borrowers, driven by their need to hedge the currency risk of their USD investments, whereas are net U.S. dollar liquidity lenders. However, U.S. banks, which have the largest gross volumes in the world and act as a counterparty to more than two-thirds of all global trading in FX swaps, achieve a net position of just 4% on average. Appendix (H) breaks down banks' total net position observed in panel (b) of Fig. (3) per currency and confirms the intution that U.S. banks act as global dealers who aim to run a matched-book.

# 3. Conceptual Framework

This section outlines a simple conceptual framework for price setting in the global FX swap market, and thus lays the groundwork for the hypotheses tested in the subsequent sections. First, I explain why U.S. banks may become willing borrowers of U.S. dollars in the FX market in times when their balance sheets are constrained. Second, I show how Federal Reserve swap lines improve the availability of arbitrage capital when foreign bank access to U.S. dollar is impaired.

## 3.1. U.S. banks as constrained suppliers of U.S. dollar liquidity

Consider U.S. banks in a stylized model of trading of FX swaps in the spirit of Syrstad and Viswanath-Natraj (2022). U.S. banks play a critical role in supporting an efficient functioning of the FX market, providing U.S. dollar liquidity worldwide. They do so by bringing together customers, who wish to trade risks, and arbitrageurs, who are willing to share such risks. The primary contribution of the set-up outlined below is to provide intuition as to why, in times of stress, a decline in U.S. bank balance sheet capacity is associated with an increase in U.S. bank reliance on arbitrage capital in the FX market.

**Customers**. Customers, particularly non-banks, use the FX swap market to finance their foreign investment portfolio on a currency-hedged basis. Each customer's demand is represented by a function $f(\theta, \chi)$ that depends on the cross-currency basis $\chi$ quoted in the market as well as other factors $\theta_b$, which include, for instance, customer quality. Intuitively, customers are more willing to finance their foreign investment portfolio in the FX swap market when the basis is more favourable (i.e. U.S. dollar borrowing costs are lower). Moreover, counterparties with lower quality $\theta$ may be more prevalent in the FX swap market since they are less able to find alternative cheaper funding sources elsewhere. Let $x_t^D$ then define global aggregate demand for U.S. dollar liquidity at the near leg of all FX swap contracts by all customers over the interval $[0, 1]$:

$$x_t^D = \int_0^1 f(\theta, \chi) db$$

Importantly, $x_t^D$ refers to *signed* volume. In case such demand is balanced, there is an equal amount of customer orders that consume and provide U.S. dollars, and $x_t^D = 0$. In case such demand is not balanced and tilted towards net U.S. dollar purchases, $x_t^D < 0$.

**Arbitrageurs.** The FX market also contains arbitrageurs, including foreign banks, who stand ready to capture any risk-free profit opportunities. Let their utility function take the following exponential form:

$$U_t = -e^{-\rho W_t} \tag{6}$$

where $\rho$ denotes the coefficient of absolute risk aversion. The arbitrageur can decide to supply $q$ amount of dollars in the FX swap market. He earns the cross-currency basis $\chi$ by doing so but has to fund this position by borrowing U.S. dollars in the money markets at a cost $c$. Taking such a position involves at least two other costs, however. On the one hand, his counterparty may default with some probability $\theta$. Because an FX swap is effectively collateralized by the foreign currency, the arbitrageur is able to sell the collateral in case of default. His return in case of default is stochastic and based on the actual observed spot exchange rate in the next period $s_{t+1}$, where I assume that $s_{t+1} \sim N(f_t, \sigma^2)$ or, in other words, the expectation of the future spot rate is equal to today's forward rate. On the other hand, the arbitrageur takes an open position in the FX market by supplying U.S. dollars and thus has some cost of leverage. I proxy leverage by the ratio of debt to total assets $\frac{q}{W}$ and recognize that the costs to such leverage increase in the size of it (Cenedese et al., 2021). Finally, considering that the initial wealth can be invested at the risk-free interest rate $r^f$, arbitrageur's wealth in the next period can be written as:

$$W_{t+1} = \underbrace{W_t \cdot (1 + r^f)}_{\text{Return on initial wealth}} + \underbrace{q_t \cdot \chi_t}_{\text{Basis return}} + \underbrace{\theta \cdot q_t \cdot (s_{t+1} - f_t)}_{\text{Return if default}} - \underbrace{q_t \cdot c_t}_{\text{Funding cost}} - \underbrace{W_t \cdot \psi_t(\frac{q_t}{W_t})}_{\text{Cost of leverage}} \tag{7}$$

The arbitrageur supplies liquidity in the market so as to maximize his expected utility with respect to the supply of U.S. dollars $q$:

$$\max_{q_t^*} \mathbb{E}[U_{t+1}] = \max_{q_t^*} \mathbb{E}\left[-e^{-\rho W_{t+1}}\right] \tag{8}$$

Using the properties of the exponential utility function, maximizing the log of the expected utility translates to mean-variance preferences over wealth:

$$\max_{q_t^*} \rho \cdot \left( W_t \cdot (1 + r^f) + q_t \cdot (\chi_t - c_t) - \frac{1}{2} \cdot \rho \cdot \theta^2 \cdot q_t^2 \cdot \sigma^2 - W_t \cdot \psi_t(\frac{q_t}{W_t}) \right) \tag{9}$$

Taking the first order condition of the maximization problem above, arbitrageur's optimal supply of U.S. dollars in the FX swap market $q^*$ is then equal to (full derivation presented in the Internet Appendix):

$$q_t^* = \frac{\chi_t - c_t - \psi_t(\frac{q_t}{W_t})}{\rho \cdot \theta^2 \cdot \sigma^2} \tag{10}$$

**U.S. banks.** U.S. banks act as market makers in FX swaps and provide liquidity to price takers globally. Given that such customer demand is imbalanced and consumes dollar liquidity, the total amount of U.S. dollars provided by $N$ U.S. banks, after all customer trades are aggregated, does not net out and is equal to total customer net demand:

$$\sum_{j=1}^{N} D_{t,1}^j = x_t^D$$

Assuming zero inventory at the beginning of the trading day, any open FX swap position at the end of the day needs to be funded in one way or the other: unlike in say an FX forward, the contract of an FX swap implies a cash outflow at the near leg of the trade, that is, two days after the trade date. Because the cost of borrowing U.S. dollars in synthetic funding markets commands a premium relative to doing so in wholesale funding markets, the U.S. bank would generally prefer to fund any open FX swap position *outside* of the FX market, for instance, by borrowing in the U.S. repo market. However, it is also conceivable that traders at the FX forward desks of U.S. banks face constraints on the size of their net open FX swap position, that is, constraints on their leverage. How so? An important factor that needs to be taken into account when comparing the cost of U.S. dollar borrowing via repo vis-a-vis via FX swaps is hidden shadow costs, including balance sheet costs (Kloks, Mattille, and Ranaldo, 2024). In particular, funding an open position via repo expands the balance sheet and thereby worsens the Basel III leverage ratio whereas doing so via FX swaps does not (Ranaldo et al., 2020). In case that the balance sheet of a U.S. bank is constrained and not able to accommodate an infinitely large repo borrowing position, the FX forward desk of a large U.S. banks is likely to face an internal limit $\delta$ on its net open FX swap position, which I formalize below.

**Market clearing.** The market clears when the U.S. bank fully funds its net open customer position, thereby returning to an inventory of zero at the end of the trading day:

$$\left(x_t^D - min(x_t^D, \delta_t)\right) - q_t^* = 0$$

where $\delta_t$ is the limit on an open FX swap position that, in principle, can be as large as infinity (if the trader faces no limit whatsoever) or as small as zero (if a bank's balance sheet is fully constrained). It is now possible to express the degree to which U.S. banks require to attract arbitrage capital $q$. In case U.S. bank's balance sheet capacity is ample, its daily limit on its open FX swap exposure is not binding: $\delta_t > x_t^D$, $min(x_t^D, \delta_t) = x_t^D$ and hence $q_t^* = 0$. However, if U.S. bank's balance sheet capacity is scarce, the limit can become binding ($\delta_t < x_t^D$).

**Proposition 1 (U.S. bank inventory position).**

*For U.S. banks, a positive (negative) shock to non-bank customer flows is associated with a more negative (positive) imbalance with non-U.S. banks over a given trading period t if $\delta_t < x_t^D$.*

Given the market clearing condition of above, it is now also possible to derive the equilibrium level of the cross-currency basis that U.S. banks are willing to pay to (non-U.S. bank) arbitrageurs, which solves for:

$$\chi_t = \rho\theta^2\sigma^2(x_t^D - \delta_t) + c_t + \psi_t(\frac{q_t}{W_t}) \tag{11}$$

The simple conceptual framework provides an important intuitive insight: the cross-currency basis that U.S. banks may need to pay to attract the opposite flow and thereby return closer to a matched-book of trading is an increasing function of (1) (the inverse of) its balance sheet capacity $\delta$ and (2) arbitrageur's costs $c$ and $\psi$. Importantly, all of the parameters are pro-cyclical in nature: in times of market stress, balance sheet capacity of the large U.S. dealers tends to worsen at the same time as the costs to (non-U.S. bank) arbitrage capital increase.

### 3.2. Arbitrageur with and without access to Federal Reserve swap lines

An arbitrageur does not generally have access to central bank funding facilities. This does not necessarily prevent him from supplying arbitrage capital in the FX swap market ($q > 0$) as long as the basis return from doing so $\chi$ exceeds his costs *ex ante*, as noticeable in eq. (10):

$$\chi_t - c_t - \psi_t(\frac{q_t}{W_t}) > 0 \tag{12}$$

Let us now examine more carefully the mechanics of an arbitrage trade and the respective trade funding cost $c$. To arbitrage the basis in any U.S. dollar currency pair $k/\$$, the arbitrageur borrows U.S. dollar in the U.S. money market that it must pay back with interest rate $i_t^{\$}$ at the end of the fixed term. The arbitrageur then supplies the dollar in the FX market and, by definition, simultaneously borrows the non-dollar currency $k$ at the near leg at a spot rate $s_t$, signs a forward contract to exchange back $k$ for $\$$ at the far leg, and deposits the non-dollar currency $k$ at the foreign central bank's deposit facility (either directly or via a correspondent bank), earning an interest on reserves $i_t^{v*}$. As reserves are typically overnight, while the FX swap contract entails a fixed term, the arbitrageur buys an OIS contract that allows him to fix the interest on reserves to a fixed rate rather than a floating rate. The OIS trade results in a return of $i_t^* - i^{p*}$ where $i_t^*$ is the fixed part of the OIS rate and $i^{p*}$ is the reference rate. In summary, the cost of funding an arbitrage trade $c$ involves not only the cost of borrowing the dollar in U.S. money market $i^{\$}$ but also the costs , which is in line with the intuition provided in Bahaj and Reis (2021). Eq. (12) can thus be re-written as:

$$\chi_t - i_t^{\$} + i_t - i_t^{v*} + i^{p*} - \psi_t(\frac{q_t}{W_t}) > 0 \tag{13}$$

In other words, an arbitrageur will step in the FX swap market if the basis $\chi$ is larger than the difference between his marginal U.S. dollar borrowing cost $i_t^{\$}$ and the reference U.S. dollar interest rate (say, the Libor rate), minus the difference between non-U.S. central bank's policy and deposit rates, minus his cost of leverage.

Add now the possibility for some arbitrageurs to access Federal Reserve swap line via access to their local central bank U.S. dollar operations. An arbitrageur with access can borrow U.S. dollar at the rate that is the lower value of the swap line rate $i_{SL}$ and the private U.S. money market rate $i_M$:

$$i_t^{\$} = min(i_t^M, i_t^{SL})$$

where the cost of borrowing via swap lines is the OIS interest rate plus a penalty term i.e. $i_t^{SL} = i_t^{OIS} + \omega$, and $\omega = 25$ bp. By analogy, $c_t = min(c_t^M, c_t^{SL})$. Because funding via swap lines comes at a penalty term, such borrowing is only attractive when the borrowing cost soars in the private markets such as during March 2020. We can now express the quantity $q$ of dollar liquidity supply by an arbitrageur as a function of the cross-currency basis, marginal funding costs, and access to the central bank swap line:

$$q_t := \begin{cases} \frac{\chi_t - c_t - \psi_t(\frac{q_t}{W_t})}{\rho\theta^2\sigma^2}, & \text{if } \chi_t \geqslant c_t^M + \psi_t(\frac{q_t}{W_t}) \\ \mathbb{1}_{D_{access}} \cdot \frac{\chi_t - c_t - \psi_t(\frac{q_t}{W_t})}{\rho\theta^2\sigma^2}, & \text{if } c_t^{SL} + \psi_t(\frac{q_t}{W_t}) \leqslant \chi_t < c_t^M + \psi_t(\frac{q_t}{W_t}), \\ 0, & \text{if } \chi_t < c_t^M + \psi_t(\frac{q_t}{W_t}) < c_t^{SL} + \psi_t(\frac{q_t}{W_t}). \end{cases}$$

where $D_{access}$ is a swap line access dummy variable:

$$\mathbb{1}_{D_{access}} := \begin{cases} 1 & \text{for arbitrageurs with access to recipient-country swap line,} \\ 0 & \text{for all other arbitrageurs.} \end{cases}$$

To give an example, consider an arbitrageur who observes some non-zero basis $\chi_t$. He is only able to enter into the CIP arbitrage trade if his U.S. dollar borrowing cost is smaller than some threshold level i.e. $i_t^M < i_0^M$. If borrowing costs in the private market soar above that level, he would provide $q_t = 0$ if swap line funding is not available and $q_t > 0$ if it is accessible under the condition that $i_t^{SL} < i_0^M$, i.e. that swap lines cap arbitrageur's dollar borrowing cost. Note that it is only foreign banks (and not non-banks) that are directly able to access the U.S. dollar operations of its local central bank.

**Proposition 2 (Share in U.S. dollar lending).**

*Foreign banks with access to central bank swap lines increase their share of U.S. dollar lending relative to the no-access banks when* $\chi_t > c_t^{SL}$ *and* $\chi_t > c_t$.

It also immediately follows that, when the cross-currency basis is large enough such that the swap line arbitrage trade becomes profitable, swap line arbitrageurs enter the market and offer rates closer to the no-arbitrage condition than the no-access arbitrageurs.

**Proposition 3 (U.S. bank inventory funding cost).**

*Swap line arbitrageurs offer prices closer to the CIP ceiling in comparison to the no-access arbitrageurs when* $\chi_t > c_t$ *and* $i_t^{SL} < i_t^M$.

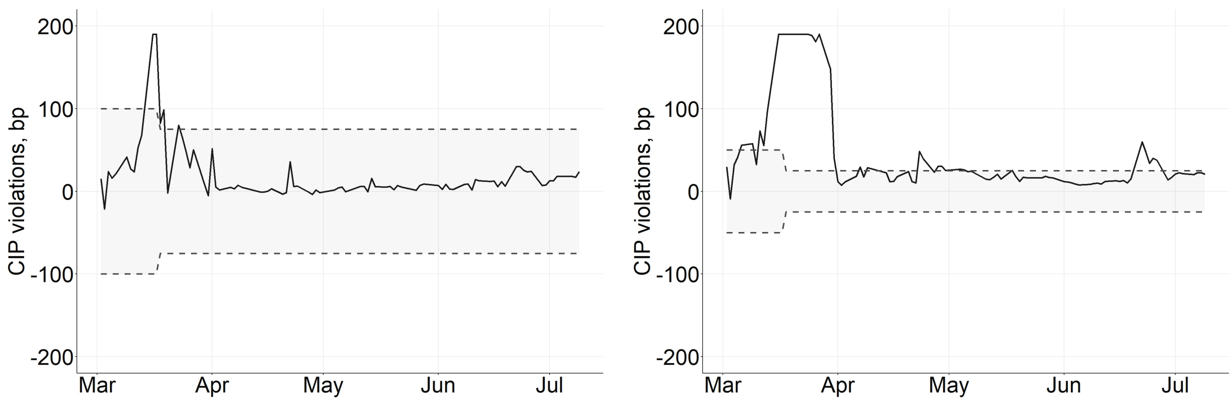
# 4. Swap Line Arbitrage: Empirical Evidence

Proposition 2 shows that violations of the CIP ceiling should result in swap line arbitrage. This section tests the proposition empirically. To do so, I rely on a carefully designed identification strategy. It rests on two pillars: first, swap line arbitrage flows should be zero (non-zero) if the CIP ceiling does not bind (binds or is violated). Second, the operational details of swap lines (maturity requirements, settlement cycles) enable us to augment our identification by recognizing that a swap line arbitrageur can directly arbitrage in some segments of the FX swap market but only indirectly in others. After describing the identification strategy in detail, the section then turns to presenting our main empirical results, which quantify the degree of swap line arbitrage in the global FX swap market around the 2020 COVID crisis.

## 4.1. Identification strategy 1: ceiling violations

A key challenge in studying the link between central bank swap lines and the private FX swap market is that a swap line arbitrage trade is only available when the CIP ceiling is violated but such violations are rare in practice. They are rare because it would offer an opportunity to arbitrageours to make a sure profit by borrowing from the central bank and lending in the FX swap market and thus compete the price of U.S. dollar down back to the level implied by the ceiling. After all, in an efficient market no arbitrage opportunities should exist even when central bank swap lines are available. The researcher studying the FX swap market is therefore faced with a problem insofar as that what he wishes to observe – a high enough CIP violation that it induces swap line arbitrage flows – is never observed if the ceiling is not violated, and thus cannot be measured empirically.

I overcome this identification challenge by exploiting a unique empirical finding first established in Bahaj and Reis (2021) that the CIP ceiling, while having bound for almost all currencies post-March 2020 as expected, was nevertheless persistently violated in some parts of the market, most notably in the dollar-yen currency pair. This can be visualised in Figure (4), which plots the 1W CIP basis from March 1 until June 30, 2020 around the no-arbitrage symmetric swap line ceiling bounds $[(i_t - i_t^S) + (i_t^{v*} - i_t^{p*}); (i_t^S - i_t) + (i_t^{p*} - i_t^{v*})]$. I plot the basis for USDJPY against that of EURUSD for comparison, and perform the same exercise in Appendix (I) for the other major currency pairs affected by the swap lines. As seen in the figures, CIP ceiling violations reduced sharply following the reduction of the swap line penalty rate from 50bp to 25bp on March 18, 2020 and stabilized well into the bounds of the ceiling – except for the dollar-yen.




(a) EURUSD

(b) USDJPY

**Fig. 4:** 1W CIP basis (Bloomberg) vs. no-arbitrage-implied CIP ceiling bounds (author's calculations). Dashed red lines refer to the upper and lower bound of the swap line-implied ceiling; shaded ribbon thus refers to the area of CIP violations $\chi_t$ that do not violate the price ceiling: $(i_t - i_t^S) + (i_t^{v*} - i_t^{p*}) \leqslant \chi_t \leqslant (i_t^S - i_t) + (i_t^{p*} - i_t^{v*})$. Data is daily from March 1 until June 30, 2020.

A situation where the ceiling binds is consistent with a mechanism whereby a swap line arbitrageur has competed down the price up to the point of no-profit. In contrast, a situation where the price is persistently well within the ceiling bounds is unlikely to have offered any such opportunities to an arbitrageur. Thus, USDJPY serves as a key element of our identification strategy: it is the only currency affected by the U.S. dollar swap lines where the CIP ceiling binds - or indeed was even persistently violated - after March 18 and is thus where I expect to be best positioned to observe, if any, evidence for swap line arbitrage.

## 4.2. Identification strategy 2: exploiting swap line operational details

I augment our identification strategy by considering the operational details of the use of U.S. dollar swap lines. I do so by considering two dimensions where differences are most pronounced: swap line take-up is segmented across (a) maturities and (b) banks.

**Maturity-level identification.** The Federal Reserve offers U.S. dollar swap lines in only two terms: 7 and 84 days, which correspond to 1W and 3M tenor points. In contrast, the FX swap market is liquid in maturities all the way up to 365 days (1 year tenor point). I conjecture that a swap line arbitrageour is therefore able to easily arbitrage mispricing in tenors up to the 3M tenor point but not thereafter. The reason is that arbitraging mispricing say in the 6M or 1Y tenor would imply rolling-over swap line funding at a cost that is not known ex-ante, as it depends on the OIS rate of the preceding day.

**Bank-level identification.** Our data unfortunately does not allow U.S. to separate banks which took up swap lines from those that did not (such information is only available to the central banks and is not publicly available to academic researchers). However, I am still in the position to cleverly exploit our cross-section of banking groups by capturing such bank-level effects indirectly. Consider the fact that swap line arbitrage in a given currency pair involves providing the receipient-country currency as collateral in the central bank swap line operation. Since the collateral has a non-negligible haircut, only banks with access to recipient-country currency, say via a stable deposit base, are best able to exploit swap line arbitrage. I therefore conjecture that swap line arbitrage is operationally easier to conduct for banks who are operational in the recipient country. For example, for the yen-dollar pair, this naturally includes all domestic Japanese banks as well as Japanese branches of foreign banks – but exclude the domestic banks of third-countries since they would face an additional cost of sourcing the recipient-country currency. Since non-Japanese banks include both banks active in Japan and not, I conjecture that our results, if any, should be statistically stronger for Japanese banks in comparison to all other banks.

A second source of bank-level variation I can exploit is the fact that some banks never accessed swap lines in the first place such as Australian and Canadian banks. I know that such banks did not access the FED's swap lines because their local central banks never requested to access them in the first place. I have grouped these banks into 'non-access' banks, which therefore constitute another control group.

## 4.3. Results

### 4.3.1. Non-U.S. bank net positions around the 2020 COVID period

Before providing causal evidence for swap line arbitrage, I first provide prima facie evidence for it. To do so, I take a naive approach and ask if any abnormal increase in net U.S. dollar *lending* is observable during the active period of U.S. dollar swap line take-up - namely, from March 23 to June 30, 2020 - by any non-U.S. bank nationality group in the currency where CIP ceiling violations were persistently violated? Such evidence would be consistent with a higher market share by a swap line arbitrageur as hypothesized in Proposition 1 of section 3. I therefore run the following ordinary-least squares panel regression:

$$Net_{t,i} = \beta_1 \cdot SwapLines + \beta_2 \cdot USDJPY + \beta_3 \cdot SwapLines \cdot USDJPY + \alpha_i + \gamma_t + \epsilon_t. \quad (14)$$

where $Net_{t,i}$ refers to the net (buy minus sell) dollar borrowing for currency pair $i$, $SwapLines$ is a dummy that equals 1 from March 23 until June 30, 2020 and 0 otherwise, USDJPY is a dummy that equals 1 for the dollar-yen currency pair and 0 for other pairs, and $\alpha_i$ and $\gamma_t$ are counterparty- and time-fixed effects respectively. I run a regression for all non-U.S. bank nationality groups individually (columns (1) to (5)) as well as their total (6). I expect a negative and significant result on $\beta_3$, our coefficient of interest, if arbitrageurs accessed the BoJ swap line and lent out the dollars at the spot leg of the FX swap contract in USDJPY, where the ceiling was persistently violated. In contrast, I do not expect a significant result on $\beta_1$ since for the rest of the currency pairs the cross-currency basis was well within the ceiling bounds, offering no arbitrage opportunities.

Results are shown in Table (3) and are in line with our expectations. In particular, I find no evidence for excess U.S. dollar lending during the swap line period above and beyond what one would expect to see in any other time period in our sample. This is expected, since the cross-currency bases behaved well within the bounds of the ceiling for most currency pairs post-March 18, 2020 when the augmented swap line framework became operational. At the same time, and perhaps more importantly, I find clear empirical evidence that points to more U.S. dollar lending in the FX swap market by Japanese banks - banks who took up swap lines with BoJ - and more so than all the other non-U.S. banks such as Eurozone banks, who also exhibit some levels of excess lending.

| | Dep: Net dollar sales in the interbank market, bn of USD | | | | | |
|---|---|---|---|---|---|---|
| | JP banks | EZ banks | UK banks | CH banks | Other banks | Total |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| SwapLines | 0.69 | −1.32 | −0.14 | −0.62* | 1.18 | −0.04 |
| | (0.66) | (1.14) | (0.38) | (0.33) | (0.83) | (0.33) |
| SwapLines:USDJPY | −15.08*** | −1.86* | 3.40*** | 1.92*** | 0.21 | −2.28 |
| | (0.09) | (1.03) | (0.21) | (0.57) | (0.60) | (2.99) |
| Constant | No | No | No | No | No | No |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Entity FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Clustered s.e. | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs (in ’000) | 112.1 | 112.1 | 112.1 | 112.1 | 112.1 | 563.3 |
| Adjusted $R^2$ | 0.48 | 0.07 | 0.04 | 0.03 | 0.22 | 0.02 |
| *Note:* | | | | *p<0.1; **p<0.05; ***p<0.01 | | |

**Table 3:** Panel regressions of net dollar sales during the swap line period. For simplicity, only the coefficients that involve *SwapLines* are reported. Panel regressions report the within $R^2$. The superscripts $***$, $**$ and $*$ indicate significance at the 1%, 5%, and 10% significance levels respectively.

I confirm the significant result of an increase in U.S. dollar lending in dollar-yen pair by Japanese banks by running the following regression:

$$Net_{t,i} = \alpha + \sum_{n=2}^{35} \beta_n \cdot D_n + \epsilon_t. \tag{15}$$

where $D_n$ equals 1 for the $n^{th}$ week of the year of 2020 and 0 otherwise. In comparison to the result in Table (3), I am able to quantify the total increase in lending across all counterparties. I report the $\beta_n$ estimates in Figure (4). The figure indicates that Japanese banks increased their provision of U.S. dollar liquidity exactly at the peak of the March 2020 but did so more after the lowering of the swap line penalty rate on March 18. At its peak, Japanese bank excess lending exceeded 70bn USD. This compares with the peak of the BoJ swap line allotments which stood at 225bn of USD. A simple back-of-the-envelope calculation estimates that as much as 25% - 30% of the BoJ swap line take-up ended up in the private FX swap market in the form of arbitrage lending.

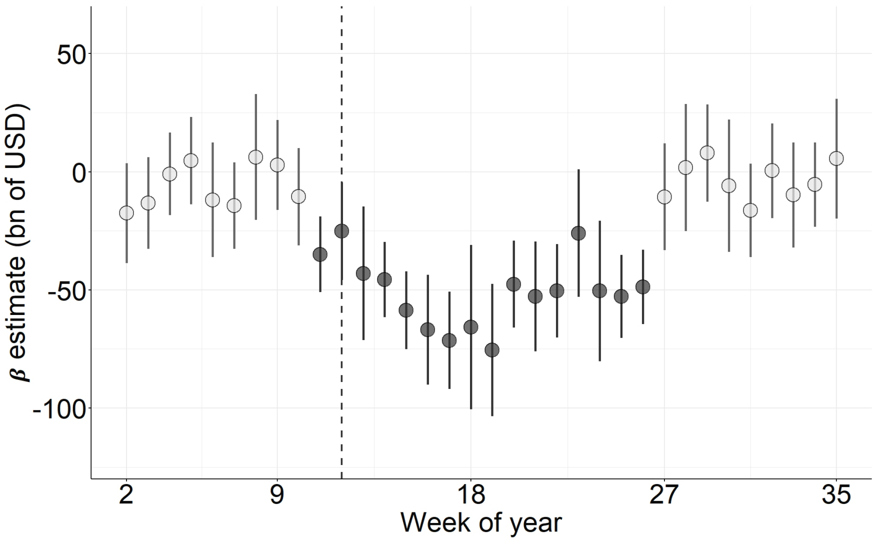



**Fig. 5:** Excess U.S. dollar lending by JP banks in 2020. The figure displays the coefficient on the net change in net U.S. dollar borrowing in a given week of the year, $\beta_n$, from the following ordinary least squares (OLS) regression: $Net_t = \alpha + \sum_{n=2}^{35} \beta_n \cdot D_n + \epsilon_t$ where $D_n$ equals 1 for the $n^{th}$ week of the year of 2020 and 0 otherwise. $Net_t$ refers to the net (buy minus sell) dollar borrowing for USDJPY and is measured in bn of USD. Dark (light) coloring indicates a statistically significant (insignificant) $\beta_n$ coefficient at the 1% significance level. The dots refer to the point estimates of the $\beta_n$; line bars add and subtract three times its standard deviation. Dashed line is Week 12 and refers to the start of the augmented swap line allotment on March 18. Data is daily for a sample from 2019 to 2022.

### 4.3.2. Difference-in-differences

I further test the evidence through a difference-in-differences strategy whereby I combine the special role of the dollar-yen with insights from the operational details of the swap lines.

First, I design a difference-in-differences regression that tests whether the above-reported result for Japanese banks (1) is driven by an increase in U.S. dollar sales rather than a drop in purchases, (2) is more pronounced for the affected FX swap maturities (at and below the 3-month tenor point) in comparison to the unaffected maturities (above 3-months and up to the 1 year tenor point) and (3) is evident in dollar-yen but not in the yen currency pairs that do not involve the dollar, namely, CHFJPY, EURJPY and AUDJPY. The latter allows U.S. to identify the change in positions as a dollar-driven phenomenon rather than a need for yen liquidity. I thus estimate the regression model (3) for the buy and sell volume and for the two tenor groups separately. Columns (7) to (10) of Table (4) report our results. For conciseness, only the difference-in-difference estimator is reported in the paper and the full regression table is delegated to the Appendix. Our results give clear evidence that the change in net position of Japanese banks is driven by an increase in sales ($\beta_{DD} = 0.57$) in the currency pair that involved the dollar (USDJPY). In contrast, dollar purchases in maturities at or below the 3M remain unaffected. Column (9) further indicates that such an increase in sales is not visible in long-term tenors whose maturity exceeded that of the swap line, and where swap line arbitrage trade was thus not available.

Second, I augment the approach with difference-in-difference-in-differences (DDD) set-up. I run the following regression, which, in the case of (U.S. dollar) sell volume, looks as follows:

$$Sell_{t,i} = \beta_1 \cdot SwapLines + \beta_2 \cdot USDJPY + \beta_3 \cdot isJPBank + \\ + \beta_{DDD} \cdot SwapLines \cdot USDJPY \cdot isJPBank + \theta \cdot \mathrm{X}_{i,t} + \gamma_t + \epsilon_t. \quad (16)$$

where $\beta_{DDD}$ measures whether JP banks do more U.S. dollar sales than the control group in USDJPY during the active swap line take-up period from March 18 until June 30, 2020. I repeat the regression for sell, buy and net volume. I further consider two control groups for the Japanese banks: banks whose local central bank did not tap the FED swap line ('Non-Access Banks') i.e. Australian and Canadian banks, as well as a group of non-U.S. banks who accessed swap lines but are not Japanese banks ('Non-JP Access Banks'). Results are reported in columns (1) to (6) of Table (4) and confirm our main result: Japanese banks increased their sales volume more than the control group of banks during this period for the dollar-yen currency pair in such a way that had a meaningful impact on their *net* U.S. dollar liquidity position, as seen in columns (3) and (6).

### 4.3.3. U.S. dollar lending and ceiling violations

As a final step, I ask whether the excess U.S. dollar lending by Japanese banks stopped when the dollar-yen cross-currency basis dropped to levels that are *inside* the ceiling bounds. Evident to the naked eye in Figure (4), the dollar-yen basis was at or above the ceiling until mid-May after which it stabilized inside the bound until the second part of June, when it tested the bound again due to the approaching quarter-end period during which the price of FX swaps typically trade higher. Thus, the period between mid-May and mid-June offers a few weeks of a window to test our hypothesis. If the Japanese trading behavior is driven by swap line arbitrage considerations, I would expect a lower degree of dollar lending during the period when ceiling bounds were not violated. Results are reported in Appendix (K) and confirm our intuition.

| | Difference-in-difference estimates | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Affected vs. Unaffected Banks* | | | | | | *Dollar vs. Non-Dollar Pairs* | | | |
| | vs. Non-Access Banks | | | vs. Non-JP Access Banks | | | Up to 3M | | Above 3M | |
| | (1) Buy, log | (2) Sell, log | (3) Net, tn | (4) Buy, log | (5) Sell, log | (6) Net, tn | (7) Sell, log | (8) Buy, log | (9) Sell, log | (10) Buy, log |
| $\beta_{DDD}$ | -0.11*** | 0.28*** | -0.005*** | -0.19*** | 0.22*** | -0.01*** | | | | |
| | (0.05) | (0.04) | (0.001) | (0.04) | (0.02) | (0.001) | | | | |
| $\beta_{DD}$ | | | | | | | 0.57*** | −0.06 | 0.18 | −0.34*** |
| | | | | | | | (0.11) | (0.14) | (0.17) | (0.13) |
| Constant | No | No | No | No | No | No | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Currencies | 17 | 17 | 17 | 17 | 17 | 17 | 4 | 4 | 4 | 4 |
| Tenors | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 1 | 1 |
| Obs. | 26,012 | 26,012 | 26,012 | 26,046 | 26,046 | 26,046 | 4,397 | 4,256 | 4,072 | 3,758 |
| Adj. $R^2$ | 0.87 | 0.89 | 0.47 | 0.91 | 0.93 | 0.43 | 0.77 | 0.59 | 0.61 | 0.69 |

**Table 4:** Difference in difference regression estimates. Columns (1) to (6) report the results of a difference-in-difference-in-differences (DDD) estimation whereby $\beta_{DDD}$ is the coefficient of interest $SwapLines : isUSDJPY : isJP$ and shows whether more affected banks borrow or lend more during the swap line period in a currency pair where the price ceiling is violated (USDJPY). Columns (7) to (10) report the results of a difference-in-difference (DD) estimation whereby $\beta_{DD}$ is the coefficient of interest $SwapLines : isUSD$ and shows whether borrowing or lending occured more in dollar than non-dollar pairs that involve the yen, effectively comparing EURJPY, CHFJPY, GBPJPY and USDJPY vis-a-vis each other. Data is daily. Standard errors are clustered by time. The superscripts $***$, $**$ and $*$ indicate significance at 1%, 5% and 10% significance level respectively.

# 5. Federal Reserve Swap Lines and U.S. Banks

Section 3 hypothesizes that U.S. banks, the global market makers in FX swaps, can benefit from swap line arbitrage lending via the inventory funding channel. It offers a number of testable hypotheses with respect to (a) quantities and (b) prices. This section tests these hypotheses empirically by leveraging the granular bespoke settlement data that offers a detailed view of U.S. bank activity in the FX swap market globally across various counterparty groups.

## 5.1. Quantities

According to Proposition 3 of section 3, U.S. bank net position with foreign banks should be generally well predicted by the non-bank customer demand that they observe. This is because U.S. banks aim to run a matched-book and thus set the price in a way as to attract arbitrage flow to offset non-bank demand. I test this relationship with the following ordinary-least squares panel regression:

$$\Delta Net_{NonUS\ Banks,i,t} = \beta \cdot \Delta Net_{NonBanks,i,t} + \gamma \cdot \mathrm{X}_{i,t} + \alpha_i + \gamma_t + \epsilon_t. \tag{17}$$

where $Net_t$ refers to the net (buy minus sell) U.S. dollar borrowing volume for currency pair $i$, $\alpha_i$ and $\gamma_t$ are counterparty- and time-fixed effects respectively, and $\mathrm{X}_{i,t}$ is a vector of control variables. A positive (negative) net position refers to net borrowing (lending) at the near leg of an FX swap contract. The control variables include proxies market-wide conditions such as volatility ($VXY$), liquidity ($BAS$). Time-fixed effects include week-of-day or month-of-year dummies as well as a holiday dummy. Above all, I expect a negative and significant result on $\beta$, our coefficient of interest, if U.S. banks aim to run a matched-book and therefore borrow more from non-U.S. banks when they lend more to customers.

Results are shown in Table (5), which runs the regression on a panel of G7 currencies at various frequencies (columns (1) to (3)) as well as on the largest currencies individually (columns (4) to (7)). The main take-away that stems out is that the correlation between U.S. bank net position with non-banks and foreign banks is highly significant and negative across all specifications. The correlation (over monthly changes) is extremely strong at $-0.52\%$. This is in line with the propositions in section 3.

| | Dep: $\Delta$ Net$_{NonUS\ Banks}$, U.S. bank net position with foreign banks | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Panel of G7 currencies* | | | *Per Currency* | | | |
| | Daily | Weekly | Monthly | EUR | GBP | CHF | JPY |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| $\Delta$ Net$_{NonBanks}$ | $-0.12^{***}$ | $-0.32^{***}$ | $-0.31^{***}$ | $-0.33^{***}$ | $-0.23^{***}$ | $-0.26^{***}$ | $-0.31^{***}$ |
| | (0.01) | (0.03) | (0.05) | (0.04) | (0.05) | (0.07) | (0.07) |
| Constant | | | | $0.32^{**}$ | 0.02 | $0.16^{***}$ | $0.41^{***}$ |
| | | | | (0.14) | (0.09) | (0.05) | (0.12) |
| Constant | No | No | No | Yes | Yes | Yes | Yes |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Currency FE | Yes | Yes | Yes | No | No | No | No |
| Observations | 11,127 | 2,784 | 540 | 557 | 557 | 557 | 556 |
| Adjusted $R^2$ | 0.03 | 0.09 | 0.11 | 0.12 | 0.07 | 0.04 | 0.07 |

**Table 5:** Determinants of U.S. bank net position with foreign (non-U.S.) banks. Columns (1) to (3) report the results of a panel regression across G7 currency pairs whereas columns (4) to (7) conduct the same regression on the four largest currencies individually (EURUSD, GBPUSD, USDCHF, USDJPY). All variables are considered in changes. Standard errors are clustered by time for the panel regressions and report Newey-West standard errors for the remaining regressions. The superscripts $***$, $**$ and $*$ indicate significance at 1%, 5% and 10% significance level respectively.

The above regression set-up considered the general relationship between foreign bank and non-bank net positions vis-a-vis U.S. banks across the whole data sample. It is therefore a general result that holds true outside periods when swap line take-up is significant. As a second step, I look at periods when swap lines are activated. Section 3 proposes that swap line arbitrage lending can end up in the hands of U.S. banks, the global market makers. I test this hypothesis by asking *who* received the excess U.S. dollar lending documented in the previous section. To do so, I run equation (14) for each counterparty nationality group separately. Appendix (L) depicts the $\beta_3$ coefficient estimates for U.S. banks and all other counterparties. Results indicate that almost half of the excess lending during the March-June period of 2020 was met by U.S. banks, in line with model predictions. Appendix (M) shows further that U.S. banks were borrowing more in the dollar-yen currency pair exactly when they faced an increase in borrowing from non-bank customers.

## 5.2. Prices

I now conduct a more formal test of Proposition 2 through a regression. I use the CLS swap rates *per party-counterparty* group to compute counterparty-specific daily CIP deviations charged by U.S. banks. The aim is to estimate whether the likelihood of a violation in the CIP ceiling is lower in cases where U.S. banks traded with a treated group of banks (swap line arbitrageurs) in comparison to a control group. If so, this would provide empirical support to the hypothesis that swap line arbitrage helped lower U.S. bank inventory funding costs during the 2020 COVID crisis.

I thereby estimate a linear probability model for each tenor $k$ and counterparty $j$ on a trading day $t$:

$$\mathbb{1}(viol)_{k,j,t} = \beta_1 \cdot SwapLines + \beta_2 \cdot isJPBank + \beta_3 \cdot AffectedTenor + \\ + \beta_4 \cdot SwapLines \cdot isJPBank \cdot AffectedTenor + +\theta \cdot \mathrm{X}_{k,t} + \gamma_t + \epsilon_t. \quad (18)$$

where $\mathbb{1}(viol)_{t,k,j}$ is an indicator function referring to whether, on a trading day $t$, the volume-weighted average price faced by U.S. banks with a counterparty $j$ was high enough to violate the CIP ceiling:

$$\mathbb{1}(viol)_{t,k,j} := \begin{cases} 1 & \text{if } \chi_t - (i_t^{\$} + i_t - i_t^{v*} + i^{p*}) > 0, \\ 0 & \text{otherwise.} \end{cases}$$

In addition, *SwapLines* refer to the active period of Federal Reserve's liquidity operations take-up (March 23 to June 30, 2020), *isJPBank* is our proxy for the treated banks taking value of 1 for Japanese banks and 0 for those banks who never accessed U.S. dollar swap lines, and *AffectedTenor* compares the effect for short-term tenors vs. long-term ones. For the baseline regression, I consider 1W tenor in comparison to the 1Y maturity since 1-week FX swaps exhibit the necessary conditions of having a non-negligible number of days when the CIP ceiling was violated and where JP banks exhibit excess U.S. dollar lending, and 1-year FX swaps have a maturity long enough to be considered unaffected by swap line lending operations, designed for maturities up to and below three months.

Moreover, I compare the prices for contracts that lead to U.S. banks facing U.S. dollar cash inflows at the near leg of an FX swap ("purchases") vs. those that lead to outflows respectively ("sales"). I compare purchases vs. sales because swap line arbitrage was attractive for selling the dollar but not vice-verca.

Table (6) depicts the results of the Probit model for U.S. bank U.S. dollar purchases - columns (1) to (4) - in comparison to their U.S. dollar sales - (5) to (6) respectively - in the dollar-yen currency pair from 2018 until 2022. Results show that the 2020 COVID period was characterized by a higher probability of CIP ceiling violations, as expected. However, the likelihood that U.S. dollar borrowing costs exceeded the price ceiling was lower when U.S. banks borrowed from Japanese banks than a the control group ($\beta_{DD}$). This is consistent with the proposition of my model. In other words, a U.S. bank is able to turn to the swap line arbitrageur – and thereby keep its inventory funding costs lower – when U.S. borrowing costs spike. Note that a similar observation cannot be made for U.S. bank U.S. dollar sales with Japanese banks, which constitute an important control since swap line arbitrage was not attractive for these contracts. Note that these results hold for the dollar-yen as this is the currency where CIP violations were persistent even after March 23, 2020; the set-up does not allow to analyze other currencies as their bases behaved well-within the ceiling bounds.

| | Dep: Probability of CIP ceiling violations $\mathbb{1}(viol)_{t,k,j}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | *US Bank USD purchases* | | | | *US Bank USD sales* | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| SwapLines | 0.60* | 1.01*** | 0.83** | −0.87 | 0.42 | 1.22*** | 0.90*** |
| | (0.34) | (0.33) | (0.34) | (0.75) | (0.27) | (0.30) | (0.33) |
| isJP | 0.12* | 0.13 | 0.13 | −0.20 | −0.09* | −0.09 | −0.09 |
| | (0.07) | (0.08) | (0.08) | (0.13) | (0.05) | (0.06) | (0.06) |
| isJP:SwapLines ($\beta_{DD}$) | −0.30** | −0.36** | −0.41** | 0.20 | 0.001 | −0.01 | −0.02 |
| | (0.15) | (0.15) | (0.20) | (0.13) | (0.14) | (0.15) | (0.17) |
| SwapLines:IsAffected | | | | 1.51** | | | |
| | | | | (0.72) | | | |
| isJP:SwapLines:IsAffected ($\beta_{DDD}$) | | | | −0.59*** | | | |
| | | | | (0.21) | | | |
| Constant | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls | No | No | Yes | Yes | No | No | Yes |
| Time FE | No | Yes | Yes | Yes | No | Yes | Yes |
| Observations | 1,208 | 1,208 | 1,208 | 1,350 | 1,711 | 1,711 | 1,711 |

**Table 6:** Probit model of the effects of swap line arbitrage on the CIP deviations faced by U.S. banks. Columns (1) to (3) report the results of a difference-in-difference (DD) regression whereas column (4) extends it to a difference-in-difference-in-difference (DDD) set-up by considering the tenor as an additional treatment. The regression considers the dollar-yen currency pair only as this is where CIP ceiling violations were persistent. Newey-West standard errors are reported. Note that the DDD regression was not possible to estimate for U.S. bank U.S. dollar sales (hypothetical column (8)) due to lack of observations during March 23 - June 30, 2020. The superscripts $***$, $**$ and $*$ indicate significance at 1%, 5% and 10% significance level respectively.

# 6. Conclusion

Although the size of the Federal Reserve swap line network represents a stunning 20% of the world's GDP, policymakers still have very little empirical evidence as to how such central bank funding transmits to offshore U.S. dollar borrowing rates. My research sheds new light on this mechanism. First, I document that settlement data offers an alternative source of data to map agent positioning in the FX swap market, complementing existing studies that use more granular but less globally representative data such as central bank trade repository data. Second, I uncovered novel evidence that foreign banks use swap line funding not only to reduce dollar demand in FX swaps (substitution channel), but also to increase dollar supply. I interpret the second as arbitrage lending, which is consistent with the idea that non-US banks play a dual role in global synthetic dollar funding markets, acting at times to both demand and supply dollar liquidity, not just the former, as is commonly assumed. Third, I studied who receives such foreign bank dollar supply during market stress episodes such as during COVID 2020 and concluded that it has primarily been absorbed by the interbank market, including by U.S. banks. This is counter-intuitive, since one would expect the direction of the flow of U.S. dollar liquidity to always point away from U.S. banks and towards foreign banks whereas I reveal it flows in the other direction, too. I rationalize this finding with a simple conceptual framework arguing that U.S. banks need to fund an imbalanced customer demand and may choose to do so off-balance sheet via FX swaps when their balance sheets are constrained.

The findings of this study have important policy implications. When U.S. dealers are constrained, repo markets and, by analogy, even standard Federal Reserve facilities may be unviable sources of funding an imbalanced customer demand in FX swaps because it expands the balance sheet. Swap lines are effective because the Federal Reserve can indirectly rely on foreign banks as vehicles for transmitting U.S. dollar liquidity off-balance sheet to the private markets. In such a case, public dollar liquidity (central banks) requires the involvement of private banks (private dollar liquidity) for better effectiveness.

# References

Bahaj, S., Reis, R., 2020. Central bank swap lines during the covid-19 pandemic. Covid Economics 2, 326–40.

Bahaj, S., Reis, R., 2021. Central bank swap lines: Evidence on the effects of the lender of last resort. The Review of Economic Studies 89, 1654–1693.

Bank for International Settlements, 2019. Triennial central bank survey of foreign exchange and derivatives market activity in 2019. Available at: https://www.bis.org/statistics/rpfx19.htm.

Bank for International Settlements, 2022. Triennial central bank survey of foreign exchange and derivatives market activity in 2022. Available at: https://www.bis.org/statistics/rpfx22.htm. Accessed: 30 January 2024.

Bank for International Settlements, 2024. International finance through the lens of bis statistics: residence vs nationality. BIS Quarterly Review, March 2024 .

Bräuer, L., Hau, H., 2022. Can time-varying currency risk hedging explain exchange rates? Swiss Finance Institute Research Paper No. 22-77 .

Cenedese, G., Della Corte, P., Wang, T., 2021. Currency mispricing and dealer balance sheets. Journal of Finance 76(6), 2763–2803.

Cespa, G., Gargano, A., Riddiough, S., Sarno, L., 2021. Foreign exchange volume. Review of Financial Studies (forthcoming) .

Choi, M., G. L. L. R. I., Ravazzolo, F., 2021. The fed's central bank swap lines and fima repo facility, staff Technical Report.

Du, W., Tepper, A., Verdelhan, A., 2018. Deviations from covered interest rate parity. Journal of Finance 73(3), 915–957.

Evans, M. D., Lyons, R. K., 2002. Order flow and exchange rate dynamics. Journal of Political Economy 110(1), 170–180.

Ferrara, G., Mueller, P., Viswanath-Natraj, G., Wang, J., 2022. Central bank swap lines: Micro-level evidence, bank of England Working Paper No. 977.

Goldberg, L., Ravazzolo, F., 2021. The fed's international dollar liquidity facilities: New evidence on effects, fRB of New York Staff Report No. 977.

Hasbrouck, J., Levich, R. M., 2019. FX market metrics: New findings based on CLS bank settlement data, NBER Working paper No. 23206.

Kekre, R., Lenel, M., 2023. The high frequency effects of dollar swap lines. National Bureau of Economic Research Working Paper, No. 31901 .

Kloks, P., Mattille, E., Ranaldo, A., 2023a. Foreign exchange swap liquidity. Swiss Finance Institute Research Paper No. 23-22 .

Kloks, P., Mattille, E., Ranaldo, A., 2024. Hunting for Dollars. Swiss Finance Institute Research Paper No. 24-52.

Kloks, P., McGuire, P., Ranaldo, A., Sushko, V., 2023b. Bank positions in FX swaps: Insights from CLS. BIS Quarterly Review (September), 17–31.

Ranaldo, A., Schaffner, P., Vasios, M., 2020. Regulatory effects on short-term interest rates. Journal of Financial Economics, forthcoming .

Ranaldo, A., Somogyi, F., 2021. Asymmetric information risk in FX markets. Journal of Financial Economics 140, 391–411.

Rose, A. K., Spiegel, M. M., 2012. Dollar illiquidity and central bank swap arrangements during the global financial crisis. Journal of International Economics 88 (2), 326–40.

Somogyi, F., 2021. Dollar dominance in fx trading. University of St. Gallen, School of Finance Research Paper No. 2021/15.

Syrstad, O., Viswanath-Natraj, G., 2022. Price-setting in the foreign exchange swap market: Evidence from order flow. Journal of Financial Economics 146(1), 119–142.

# Appendix A

The BIS Triennial Survey (Bank for International Settlements, 2019) represents the most recognized documentation of the FX market; the following tables show that our FX swap data is highly representative. Table (A1) compares our daily turnover figures for those months which the BIS surveys (i.e. April of each survey year). Table (A2) compares the maturity breakdown of swaps in CLS versus swaps in the Triennial survey. Tables (A3) and (A4) do the same with currencies and counterparties, respectively. Note that while the numbers in Table (A1) denote that CLS covers only about a third of volumes in the BIS survey, both Hasbrouck and Levich (2019) and Cespa et al. (2021) demonstrate that CLS coverage in spot is underestimated compared to the BIS survey, since a large fraction of the volume reported by the BIS is related to interbank trading across desks and double-counts prime-brokered "give-up trades."

**Table A1:** Daily Turnover (B), CLS and BIS Triennial Survey

| | CLS | BIS | CLS as % of BIS |
|---|---|---|---|
| April '13 | 740.8 | 2'240 | 33.1% |
| April '16 | 805.6 | 2'378 | 33.9% |
| April '19 | 986.9 | 3'198 | 30.9% |

**Table A2:** Maturity breakdown comparison with BIS Triennial Survey

| | Maturity | CLS Share | BIS Share |
|---|---|---|---|
| | <= 7 days | 69.3% | 70.2% |
| April '13 | > 7 days, <= 1 year | 30% | 25.9% |
| | > 1 year | 0.7% | 3.9% |
| | <= 7 days | 64.2% | 68.7% |
| April '16 | > 7 days, <= 1 year | 35.2% | 30% |
| | > 1 year | 0.6% | 1.3% |
| | <= 7 days | 61.0% | 64.4% |
| April '19 | > 7 days, <= 6 months | 36.8% | 33.1% |
| | > 6 months | 2.2% | 2.5% |

**Table A3:** Currency breakdown comparison with 2016 BIS Triennial Survey

| | CLS Share | BIS Share | BIS Share adj. |
|---|---|---|---|
| USD | 95.8% | 90.8% | 96.6% |
| EUR | 34.7% | 33.9% | 36.1% |
| JPY | 22.0% | 19.3% | 20.5% |
| GBP | 13.2% | 12.8% | 13.6% |
| CHF | 7.8% | 6.3% | 6.7% |
| AUD | 7.2% | 5.8% | 6.2% |
| CAD | 3.5% | 4.3% | 4.6% |
| Other | ≈15.8% | ≈ 26.8% | ≈ 15.6% |

*Note*: "BIS share adj." is an approximation of what BIS currency shares would be if the BIS only considered CLS currencies.

**Table A4:** Counterparty breakdown comparison with BIS Triennial Survey

| | Counterparty | CLS Share | BIS Share |
|---|---|---|---|
| April '13 | Dealers | 57.9% | 48.6% |
| | Other financial | 41.9% | 44.7% |
| | Non-financial | 0.2% | 6.7% |
| April '16 | Dealers | 51.3% | 50.7% |
| | Other financial | 48.6% | 43.1% |
| | Non-financial | 0.1% | 6.2% |
| April '19 | Dealers | 50.3% | 46.8% |
| | Other financial | 49.6% | 48.0% |
| | Non-financial | 0.1% | 5.2% |

*Note*: This counterparty breakdown leverages a separate CLS dataset which classifies parties into sell-side and buy-side banks (based on their network and frequency of trading) as well as non-bank financial institutions, funds, and corporates. We label sell-side banks as dealers, corporates as non-financial firms, and all other parties as "Other financial" to match the BIS survey nomenclature.

# Appendix B

| Region | G-SIB |
|---|---|
| United States | Bank of America |
| | Bank of New York Mellon |
| | Citigroup |
| | Goldman Sachs |
| | JP Morgan Chase |
| | Morgan Stanley |
| | State Street |
| | Wells Fargo |
| Eurozone | BNP Paribas |
| | BPCE Groupe |
| | Crédit Agricole |
| | Deutsche Bank |
| | ING Bank |
| | Santander |
| | Société Générale |
| | UniCredit |
| United Kingdom | Barclays |
| | HSBC |
| | Standard Chartered |
| Japan | Mitsubishi UFJ FG |
| | Mizuho FG |
| | Sumitomo Mitsui FG |
| Switzerland | Credit Suisse Groupe |
| | UBS |
| ROW (China) | Agricultural Bank of China |
| | Bank of China |
| | China Construction Bank |
| | Industrial and Commercial Bank of China |

**Table B1:** List of G-SIBs in our dataset, by region. Banks were classified as G-SIBs if they were designated such at least 7 times during the years 2012-2021 according to the List of Global Systemically Important Banks published annually by the Financial Stability Board.

# Appendix C

| | | TN | SN | 1W | 2W−1M | 1M | 1M−3M | 3M | 3M+ | ∑ |
|---|---|---|---|---|---|---|---|---|---|---|
| G-SIBs | US | 519 | 120 | 195 | 328 | 1435 | 1,233 | 1,883 | 3,567 | 9,280 |
| | EZ | 246 | 54 | 97 | 163 | 619 | 487 | 794 | 1,827 | 4,287 |
| | UK | 217 | 41 | 73 | 132 | 580 | 469 | 742 | 1,376 | 3,630 |
| | CH | 120 | 23 | 42 | 83 | 348 | 309 | 448 | 685 | 2,058 |
| | JP | 52 | 8 | 14 | 28 | 110 | 91 | 179 | 423 | 905 |
| | Other | 47 | 11 | 16 | 40 | 209 | 147 | 244 | 439 | 1,151 |
| | ∑ | 1,200 | 256 | 437 | 774 | 3,301 | 2,736 | 4,289 | 8,317 | 21,310 |
| Small banks | US | 4 | 1 | 1 | 6 | 55 | 17 | 23 | 47 | 154 |
| | EZ | 90 | 16 | 33 | 46 | 127 | 130 | 268 | 506 | 1,217 |
| | UK | 41 | 8 | 21 | 51 | 127 | 145 | 205 | 456 | 1,053 |
| | CH | 30 | 4 | 10 | 17 | 47 | 40 | 57 | 104 | 308 |
| | JP | 47 | 8 | 10 | 21 | 75 | 59 | 109 | 253 | 583 |
| | Other | 248 | 39 | 77 | 119 | 455 | 450 | 827 | 1,418 | 3,632 |
| | ∑ | 461 | 76 | 152 | 259 | 885 | 841 | 1,489 | 2,785 | 6,947 |
| Non-Banks | US | 3 | 1 | 6 | 27 | 410 | 241 | 195 | 385 | 1,268 |
| | EZ | 11 | 3 | 6 | 10 | 149 | 63 | 216 | 87 | 546 |
| | UK | 5 | 2 | 4 | 11 | 179 | 135 | 179 | 182 | 698 |
| | CH | 0 | 1 | 7 | 6 | 28 | 14 | 15 | 50 | 120 |
| | JP | 0 | 0 | 0 | 0 | 3 | 1 | 1 | 6 | 11 |
| | Other | 4 | 2 | 5 | 10 | 61 | 74 | 123 | 218 | 498 |
| | ∑ | 24 | 9 | 28 | 64 | 829 | 529 | 730 | 929 | 3,141 |

**Table C1:** FX swap open (outstanding) **total** volumes (dollar purchases **plus** sales), 2012-22 daily average, in bn of USD.

# Appendix D

| | | TN | SN | 1W | 2W−1M | 1M | 1M−3M | 3M | 3M+ | ∑ |
|---|---|---|---|---|---|---|---|---|---|---|
| G-SIBs | US | 0.10 | 0.02 | 0.02 | 0.02 | -0.08 | -0.06 | -0.16 | -0.16 | -0.30 |
| | EZ | -0.01 | 0.00 | 0.00 | -0.01 | -0.07 | -0.03 | -0.12 | 0.02 | -0.22 |
| | UK | -0.02 | -0.01 | 0.00 | 0.00 | -0.01 | -0.01 | -0.02 | -0.06 | -0.13 |
| | CH | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 | 0.01 | 0.00 | -0.03 | 0.02 |
| | JP | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.04 |
| | Other | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | -0.01 | -0.04 |
| | ∑ | 0.07 | 0.01 | 0.02 | 0.02 | -0.13 | -0.09 | -0.30 | -0.23 | -0.64 |
| Small banks | US | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 | 0.00 | 0.01 | 0.05 |
| | EZ | -0.03 | 0.00 | -0.01 | -0.01 | -0.02 | -0.01 | -0.01 | -0.02 | -0.11 |
| | UK | -0.01 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | -0.02 | -0.01 | -0.06 |
| | CH | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 |
| | JP | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 |
| | Other | -0.02 | 0.00 | -0.01 | -0.01 | -0.06 | -0.03 | -0.07 | -0.09 | -0.29 |
| | ∑ | 0.46 | 0.08 | 0.15 | 0.27 | 0.89 | 0.84 | 1.49 | 2.79 | -0.37 |
| Non-Banks | US | 0.00 | 0.00 | 0.00 | 0.00 | -0.03 | 0.01 | 0.00 | -0.04 | -0.06 |
| | EZ | -0.01 | 0.00 | 0.00 | 0.00 | 0.07 | 0.04 | 0.17 | 0.06 | 0.33 |
| | UK | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.05 | 0.12 | 0.12 | 0.39 |
| | CH | 0.00 | 0.00 | 0.01 | 0.00 | 0.02 | 0.01 | 0.01 | 0.03 | 0.08 |
| | JP | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.2 | 0.04 | 0.07 | 0.14 | 0.27 |
| | ∑ | -0.01 | 0.00 | 0.01 | 0.00 | 0.18 | 0.15 | 0.37 | 0.31 | 1.01 |

**Table D1:** FX swap open (outstanding) **net** volume (dollar purchases **minus** sales), 2012-22 daily average, in tn of USD. A positive number indicates US dollar net borrowing in the FX swap market at the near leg.

# Appendix E

| | | EUR | JPY | GBP | CHF | AUD/NZD/CAD | SEK/NOK/DKK | Other dollar | ∑ |
|---|---|---|---|---|---|---|---|---|---|
| G-SIBs | US | 3,039 | 2,056 | 1,316 | 434 | 741 | 396 | 1,296 | 9,280 |
| | EZ | 1,782 | 817 | 485 | 193 | 265 | 136 | 609 | 4,287 |
| | UK | 1,158 | 701 | 606 | 174 | 241 | 119 | 631 | 3,630 |
| | CH | 639 | 356 | 239 | 315 | 177 | 91 | 240 | 2,058 |
| | JP | 172 | 533 | 44 | 9 | 31 | 5 | 111 | 905 |
| | Other | 258 | 221 | 244 | 48 | 84 | 27 | 269 | 1,151 |
| | ∑ | 7,048 | 4,685 | 2,935 | 1,173 | 1,539 | 775 | 3,155 | 21,310 |
| Small banks | US | 36 | 24 | 40 | 5 | 30 | 4 | 14 | 154 |
| | EZ | 773 | 90 | 82 | 82 | 28 | 20 | 141 | 1,217 |
| | UK | 380 | 147 | 257 | 58 | 74 | 40 | 98 | 1,053 |
| | CH | 79 | 18 | 18 | 171 | 6 | 4 | 12 | 308 |
| | JP | 125 | 285 | 42 | 12 | 29 | 4 | 85 | 583 |
| | Other | 872 | 410 | 318 | 72 | 542 | 557 | 861 | 3,632 |
| | ∑ | 2,265 | 974 | 758 | 400 | 710 | 629 | 1,210 | 6,947 |
| Non-Banks | US | 433 | 319 | 192 | 30 | 101 | 29 | 164 | 1,268 |
| | EZ | 448 | 18 | 41 | 10 | 10 | 4 | 15 | 546 |
| | UK | 251 | 56 | 275 | 35 | 36 | 9 | 36 | 698 |
| | CH | 38 | 3 | 2 | 72 | 2 | 0 | 4 | 120 |
| | JP | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 11 |
| | Other | 98 | 33 | 21 | 7 | 99 | 132 | 108 | 498 |
| | ∑ | 1,267 | 440 | 532 | 153 | 248 | 175 | 326 | 3,141 |

**Table E1:** FX swap open (outstanding) **total** volume (buy **plus** sell), 2012-22 daily average, in bn of USD.

# Appendix F

| | | EUR | JPY | GBP | CHF | AUD/NZD/CAD | SEK/NOK/DKK | Other dollar | ∑ |
|---|---|---|---|---|---|---|---|---|---|
| G-SIBs | US | -0.18 | 0.06 | -0.04 | -0.02 | -0.04 | -0.01 | -0.06 | -0.30 |
| | EZ | 0.07 | -0.13 | -0.03 | -0.04 | -0.03 | -0.01 | -0.01 | -0.22 |
| | UK | -0.02 | -0.04 | -0.02 | -0.03 | -0.02 | 0.00 | 0.00 | -0.13 |
| | CH | -0.01 | -0.02 | -0.01 | 0.05 | 0.01 | 0.00 | -0.01 | 0.02 |
| | JP | -0.06 | 0.14 | -0.01 | 0.00 | -0.01 | 0.00 | -0.02 | 0.04 |
| | Other | -0.02 | -0.04 | -0.02 | 0.00 | -0.01 | -0.01 | 0.04 | -0.04 |
| | ∑ | -0.22 | -0.03 | -0.13 | -0.04 | -0.10 | -0.03 | -0.08 | -0.64 |
| Small banks | US | -0.01 | 0.01 | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 | 0.05 |
| | EZ | -0.04 | -0.02 | -0.01 | -0.03 | 0.00 | 0.00 | 0.00 | -0.11 |
| | UK | 0.00 | -0.01 | -0.02 | -0.01 | -0.01 | 0.00 | -0.01 | -0.06 |
| | CH | 0.02 | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | JP | -0.02 | 0.09 | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 |
| | Other | -0.07 | -0.11 | -0.06 | -0.01 | 0.01 | -0.07 | 0.01 | -0.29 |
| | ∑ | -0.12 | -0.05 | -0.08 | -0.05 | 0.02 | -0.07 | 0.00 | -0.37 |
| Non-Banks | US | -0.15 | 0.07 | -0.01 | 0.01 | 0.01 | -0.01 | 0.03 | -0.06 |
| | EZ | 0.31 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.33 |
| | UK | 0.13 | 0.02 | 0.21 | 0.02 | 0.01 | 0.00 | 0.00 | 0.39 |
| | CH | 0.01 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.08 |
| | JP | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Other | 0.03 | 0.00 | 0.00 | 0.00 | 0.07 | 0.11 | 0.06 | 0.27 |
| | ∑ | 0.33 | 0.10 | 0.22 | 0.10 | 0.09 | 0.10 | 0.09 | 1.01 |

**Table F1:** FX swap open (outstanding) **net** volume (purchases **minus** sales), 2012-22 daily average, in tn of USD. A positive number indicates US dollar net borrowing in the FX swap market at the near leg.

# Appendix G

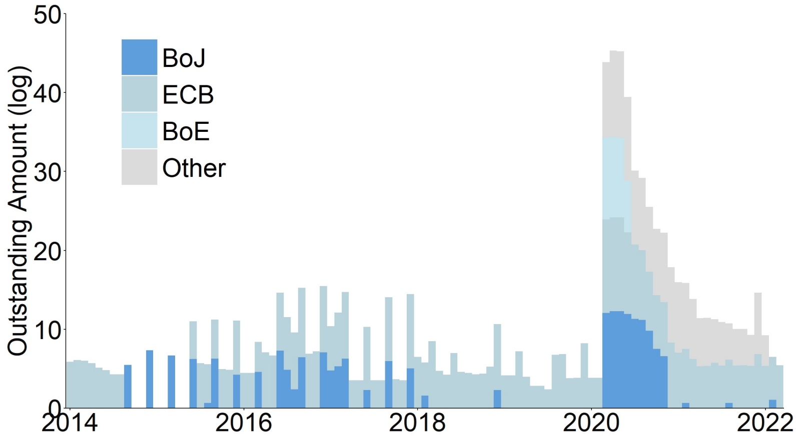



**Fig. G1:** Federal Reserve U.S. dollar liquidity swap amounts oustanding, in logs. Each bar represents monthly average values and is measured in USD. Data created by the author using data from the New York Fed.

# Appendix H

| | | Net open position (in tn of USD) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | EUR | JPY | GBP | CHF | Other | Net | Net, % |
| Banks | US | -0.18 | 0.07 | -0.02 | -0.02 | -0.08 | -0.25 | 4.0 % |
| | EZ | 0.03 | -0.15 | -0.04 | -0.08 | -0.09 | -0.33 | 11.8 % |
| | UK | -0.02 | -0.05 | -0.04 | -0.03 | -0.05 | -0.19 | 7.2 % |
| | CH | 0.01 | -0.03 | -0.01 | 0.06 | -0.00 | 0.03 | 7.0 % |
| | JP | -0.08 | 0.23 | -0.02 | -0.00 | -0.03 | 0.09 | 29.8 % |
| | Other | -0.09 | -0.15 | -0.08 | -0.01 | -0.02 | -0.36 | 12.4 % |
| | Total | -0.33 | -0.09 | -0.21 | -0.09 | -0.28 | -1.01 | 5.3 % |

**Table H1:** FX swap open (outstanding) *net* volume (buy minus sell), 2012-22 daily average, in tn of USD. A positive (negative) number indicates US dollar net borrowing (net lending) in the FX swap market at the near leg. Percentages refer to the average net position relative to total gross position, averaged across time and all USD currency pairs.

# Appendix I

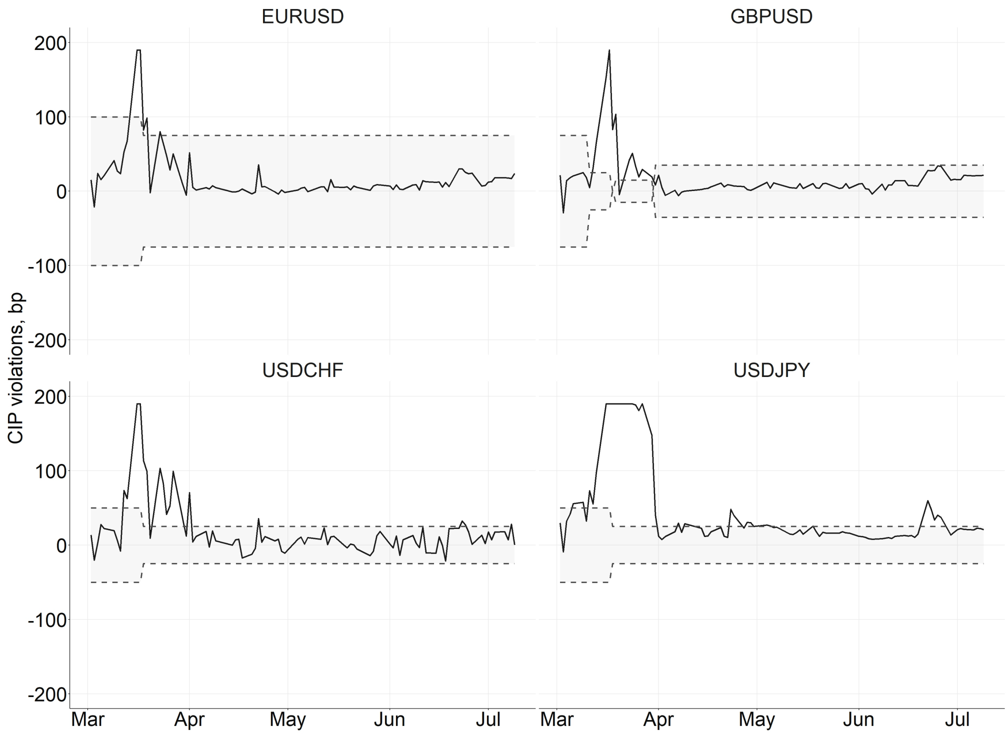



**Fig. I1:** 1W CIP basis (Bloomberg) vs. no-arbitrage-implied CIP ceiling bounds (author's calculations). Dashed red lines refer to the upper and lower bound of the swap line-implied ceiling; shaded ribbon thus refers to the area of CIP violations $\chi_t$ that do not violate the price ceiling: $(i_t - i_t^S) + (i_t^{v*} - i_t^{p*}) \leqslant \chi_t \leqslant (i_t^S - i_t) + (i_t^{p*} - i_t^{v*})$. Data is daily from March 1 until June 30, 2020.

# Appendix J

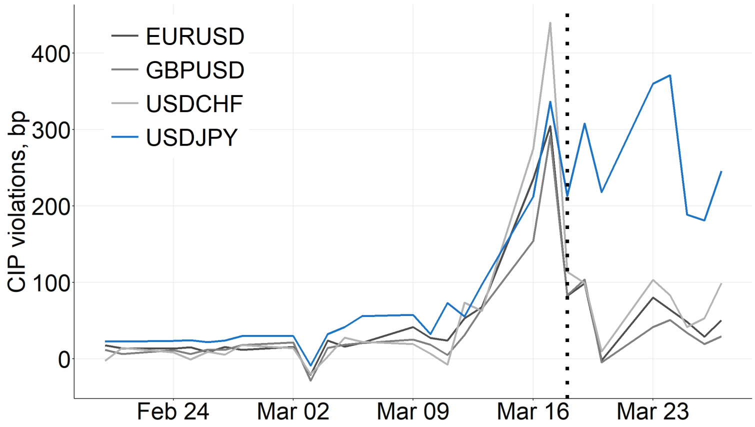



**Fig. J1:** CIP violations around March 2020 across the largest currency pairs for the 1W tenor. Interest rates are LIBOR. FX rates are frrom Refinitiv. CIP deviations refer to annualized values. Dashed line is refers to the start of the augmented swap line allotment on March 18. AUDUSD and USDCAD are excluded as these currencies were not affected by U.S. dollar swap lines. Data is daily.

# Appendix K

| | Dep: Dollar sales, 1W | | |
|---|---|---|---|
| | JP | Non-JP | All |
| Pre-Implementation | 0.03 | 1.68*** | 1.37** |
| | (0.97) | (0.58) | (0.59) |
| Implementation | 3.03*** | 1.22 | 0.78 |
| | (1.03) | (1.05) | (0.91) |
| $D_1 : \rho - c > 0$ | 6.73*** | 0.27 | 1.44*** |
| | (1.05) | (0.28) | (0.35) |
| $D_2 : \rho - c <\approx 0$ | −0.45 | −1.67*** | −1.50*** |
| | (0.53) | (0.26) | (0.23) |
| $D_3 : \rho - c > 0$ | 1.85*** | 0.69 | 0.70** |
| | (0.70) | (0.46) | (0.42) |
| Constant | Yes | Yes | Yes |
| Controls | Yes | Yes | Yes |
| Obs | 174 | 696 | 870 |
| Adjusted $R^2$ | 0.41 | 0.50 | 0.44 |
| *Note:* | *p<0.1; **p<0.05; ***p<0.01 | | |

# Appendix L

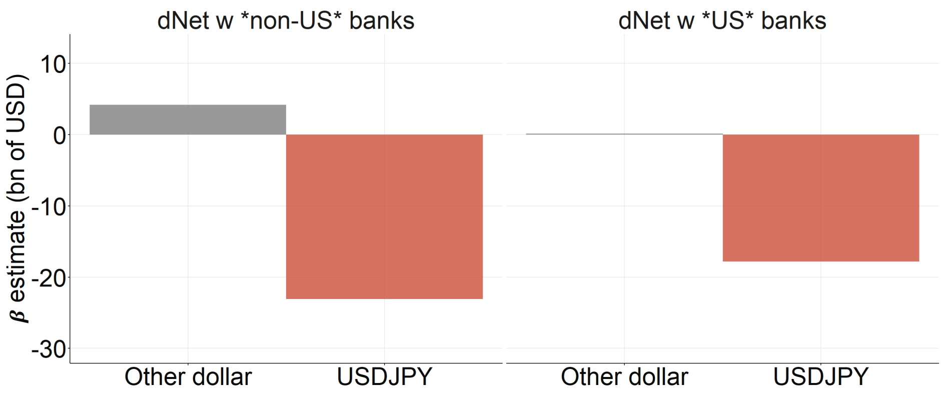



**Fig. L1:** Excess U.S. dollar lending by JP banks in 2020 per counterparty group. The figure displays the coefficient on the net change in net US dollar lending, $\beta$, from the following ordinary least squares (OLS) regression: $Net_{i,t} = \alpha + \beta \cdot SwapLines + \epsilon_{i,t}$ where $SwapLines$ equals 1 for March 18 to June 30 of 2020 and 0 otherwise. $Net_{i,t}$ refers to the net (buy minus sell) dollar borrowing for currency $i$ and is measured in bn of USD. Red (green) coloring indicates a statistically significant increase in net lending (borrowing) wheras gray shading indicates no significant change at the 1% significance level. Data is daily for a sample from 2019 to 2022.

# Appendix M

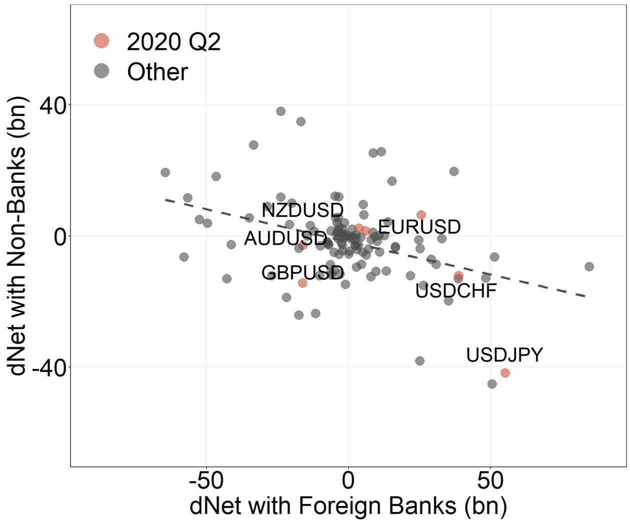



**Fig. M1:** US dealer net position in the interbank market vs. with non-bank customers. Each dot represents the quarterly change in US bank *net* position in a currency-counterparty group. Counterparties refer to foreign (non-US banks) vs. non-bank customers and are grouped together. Currencies refer to the G7 currencies. Data is 2018 to 2022.