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# Covered Interest Parity Arbitrage

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To understand deviations from covered interest parity (CIP), it is crucial to account for heterogeneity in funding costs across both banks and currency areas. For most market participants, the no-arbitrage relation holds fairly well when implemented using marginal funding costs and risk-free investment instruments. However, a few high-rated banks do enjoy CIP-arbitrage opportunities. Dealers avert inventory imbalances stemming from lower-rated banks' usage of FX swaps to obtain dollar funding by inducing opposite (arbitrage) flows from high-rated banks. Arbitrage trades are difficult to scale, however, because funding costs increase as soon as arbitrageurs increase positions. (*JEL* E43, F31, G15)

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The persistent deviations from covered interest parity (CIP) have been one of the most puzzling phenomena in international financial markets in the aftermath

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of the global financial crisis (GFC) in 2008.[1] The concept of CIP builds on the principle of "no-arbitrage," the most fundamental condition in financial markets. It postulates that one should not earn risk-free profit by borrowing in one currency and lending in another, while fully covering the foreign exchange (FX) risk. The study of how a fundamental relation, such as CIP, breaks down can offer valuable insights into the functioning of some of the world's largest and systemically important financial markets and the constraints faced by the key players operating in them.[2]

In arbitrage, the devil is in the details. Testing the validity of a no-arbitrage condition, such as CIP, requires carefully accounting for the key costs, inherent risks, and any other frictions affecting the arbitrage trade. Obviously, accounting for transaction costs is important. However, as we stress in this paper, it is even more important to account for the *marginal funding cost* the arbitrageur faces, and to make sure the trade is indeed *risk-free* from the arbitrageur's perspective. The main angle of our paper is that we analyze empirically how the incentives of the main players in international money and FX swap markets are crucially shaped by their funding costs.

Taking these considerations seriously in our empirical tests, we find that the no-arbitrage condition implied by CIP does in fact hold quite well for a large share of market participants, even though commonly used aggregate measures may indicate material arbitrage profits in recent years. However, we also show a limited set of CIP arbitrageurs in a position to reap economically attractive arbitrage profits, namely, high-rated globally active banks that can access USD money markets at low funding costs.

Our paper consists of three main parts. The first part focuses on the main determinants of CIP arbitrageurs' decision of whether it is economically attractive to enter the trade. We focus on short-term (1-week to 3-month) arbitrage opportunities for *global banks*, which are the main arbitrageurs in FX swap and money markets that matter at the margin. These banks operate in funding markets in multiple currencies, have broad access to short-term risk-free assets (including central bank facilities around the world), face constant funding needs, and can flexibly choose the cost-optimal funding option.[3]



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[1] See BIS (2015), Barclays (2015), Pinnington and Shamloo (2016), Du, Tepper, and Verdelhan (2018), Shin (2016), BIS (2016), Borio et al. (2016), Avdjiev et al. (2019), Arai et al. (2016), Duffie (2017), and Debelle (2017), among others.

[2] The key subject of study in this paper is the market for FX swaps, that is, derivative contracts simultaneously combining a spot transaction and an opposite forward. FX swaps are traded over-the-counter (OTC), and market participants widely use them to facilitate cross-border borrowing and investment and to manage their exposure to FX risk. Banks use FX swaps for liquidity management in different currencies and for managing currency risk. By any standard, the FX swap market is huge, with a daily trading volume exceeding US$3.2 trillion (BIS 2019).

[3] To be clear, while we consider nonbank financial institutions to also respond to CIP deviations, they are not the major players that matter at the margin. Hedge funds, for instance, depend on leverage provided to them by their prime brokers to arbitrage price dislocations. Banks generally avoid charging their own customers below their own funding cost and hence would be reluctant to provide hedge funds with the leverage to profitably exploit any

With its focus on arbitrage from the perspective of global banks, our approach is distinct from approaches in the extant CIP literature in two key ways. First, we argue that it is important to rely on money market rates that adequately capture fluctuations and heterogeneity in banks' marginal funding costs in the funding leg of the arbitrage. Despite several funding alternatives for an arbitrage trade (including repo or drawing down central bank reserve balances), we argue that unsecured funding, such as commercial paper (CP) or certificates of deposit (CD), are the only sources of funding that fully represent the cost for the arbitrageur *at the margin* for trades of the maturities covered in this paper. For instance, an arbitrage trade funded with repo borrowing requires unencumbered collateral. Unencumbered collateral, however, can be immediately liquidated and hence has a shadow cost equal to the unsecured funding spread. Second, we argue that it is important to treat the funding and investment legs of CIP arbitrage trades differently. For the funding leg, as argued above, the most appropriate choice is the unsecured rate at which a bank can raise wholesale money market funding from nonbank investors because such rates are best suited to capture the cost of balance-sheet expansion at the margin. By contrast, the investment vehicles in the investment leg must be safe instruments for the trade to be entirely risk-free for the arbitrageur. Consistent with this requirement, we consider central bank deposit facilities and short-term government securities (Treasury bills) as instruments in the investment leg of the arbitrage.

Based on this setup, we find that economically meaningful *risk-free* CIP arbitrage opportunities exist during our postcrisis sample period but are limited to a narrow group of market participants. The vast majority of banks face prohibitively high marginal funding costs in USD, but economically viable arbitrage opportunities are available to those high-rated banks that have access to direct USD funding at attractive terms and can invest at the deposit facilities of foreign central banks. Such arbitrage opportunities are less attractive if short-term government securities are the only risk-free investment asset available (given that their interest rates tend to lie below the rate of remuneration on central bank deposit facilities).

The second part of our analysis lays out a simple framework to guide our subsequent empirical tests. The framework is not intended to replace a full-blown equilibrium model but primarily serves as conceptual tool, building on the real-world frictions that we emphasize as being relevant. The crucial question we address is how a constellation with arbitrage profits for high-rated banks can persist over prolonged periods. To do so, we take the perspective of an FX swap dealer facing the challenge to balance flows in an environment where funding costs in different currency areas diverge. This situation has been a main

CIP deviations. Real money asset managers (e.g., pension funds, central bank reserve managers, or sovereign wealth funds) can be considered to be long-only investors and hence typically would not enter into leveraged arbitrage trades. That said, their search for attractive cross-border investments will also respond to pricing in the FX swap market, yet such investments cannot be regarded as arbitrage in the strict sense, because they do not involve a full (self-financed) round trip.

feature of money markets in recent years due to the excess liquidity created by the balance-sheet policies of major central banks outside of the United States (notably the Bank of Japan [BoJ], the European Central Bank [ECB], and the Swiss National Bank [SNB]). While the unsecured wholesale funding markets in USD have remained costly and highly fragmented, funding spreads have significantly decreased on the back of central banks' balance-sheet policies in other major currency areas.

Such divergence in funding costs is a crucial driver of the demand pressure for USD in the FX swap market. Non-U.S. banks domiciled in currency areas with large excess liquidity can always resort to their domestic deposit base, but typically do not have this option in USD.[4] In particular, low-credit quality non-U.S. banks struggling to obtain USD directly in U.S. money markets are pressured to turn to the FX swap market to raise USD funding in order to overcome the dollar shortage. Within our framework, it therefore falls on a narrow set of high-rated global banks with ample access to USD funding to step in on the other side, supplying USD to the FX swap market. To do so, these banks must be enticed by the arbitrage profits the trade offers. Broader funding constraints in U.S. money markets will hence coincide with larger CIP deviations because high-rated banks will require a higher profit to meet the demand for USD through the FX swap market.

Our framework posits that the supply curve of U.S. dollars is upward sloping, making it difficult to scale the arbitrage to fully eliminate CIP deviations. Indeed, various balance-sheet constraints make it difficult for top-tier banks to provide the necessary supply of USD through the FX swap market. This difficulty is exacerbated by the limited number of banks in a position to take advantage of the arbitrage. As shown in Du et al. (2018), regulatory constraints, such as the leverage ratio, are a particular limitation at quarter ends, when most global banks report snapshots of their balance sheets. But, in line with our main perspective on funding in this paper, banks also face constraints when they seek to obtain funding at the margin from investors, such as money market funds (MMFs). The latter typically have tight concentration limits, giving rise to an upward-sloping supply curve in the U.S. funding market. Such constraints tend to tighten as aggregate USD funding conditions deteriorate, hampering the main arbitrageurs' ability to correct FX-swap-market dislocations.

In the third part of our analysis, we investigate the main predictions of our framework empirically and shed light on the key mechanisms. Specifically, we dig deeper into three aspects.

First, in a cross-currency setting, we show that larger excess liquidity (proxied by the size of the central bank balance sheet relative to gross domestic product [GDP]) coincides with an easing of funding conditions in the respective currency and an incentive to raise USD through the FX swap market. Our

[4] The demand-side pressure has been exacerbated by the enduring demand by non-U.S. banks for USD funding, given the special status of the USD in the international financial system.

hypothesis is that low-rated banks respond to the relative ease in funding conditions outside of the USD and predominantly rely on domestic sources in combination with an FX swap to fund USD assets. Indeed, using banks' balance sheet data, we show that after the GFC low-rated non-U.S. banks have increasingly relied on borrowing from their headquarter to fund their USD assets, thereby exerting pressure for U.S. dollars in FX swap markets. In contrast, high-rated banks obtain more USD funding directly than needed to fund their own balance sheets, leading to net positive claims on their headquarters. This pattern suggests that high-rated banks do indeed raise USD funding to conduct the CIP arbitrage.

Second, we study the impact of imbalances in the demand for and supply of U.S. dollars in the FX swap market—as captured via swap order flow—to better understand the price determination in the FX-swap-market and the breakdown of CIP in this market environment. According to our framework, relatively easier funding conditions outside of the United States create strong incentives for lower-tier banks to obtain USD funding via the FX swap market as opposed to raising such funding directly in U.S. money markets. To entice high-rated banks to step in as arbitrageurs, FX swap dealers respond to such imbalances by adjusting the FX swap rate, thereby helping the FX swap market to clear. Consistent with this mechanism, we find that the price impact of swap order flow is particularly elevated in situations where the deviations from CIP are severe.

Third, we explore how the pricing distortions and arbitrage opportunities can persist for some time, by studying the main limits faced by arbitrageurs to scale up their positions. To this end, we rely on issuance-level data for short-term certificates of deposit (CD) in USD funding markets. Our regression results indicate that reasonably large increases in issuance volumes will increase USD funding costs when the arbitrage opportunities are high, thereby eroding a good part of the CIP-arbitrage profit. In addition, we find evidence that issuers' funding costs increase when MMFs' average exposure to the respective issuer is elevated. Interestingly, this effect increases when arbitrage opportunities are higher. This in turn suggests that constraints arising from investors becoming too exposed toward the issuer become more binding, because the arbitrageurs attempt to increase borrowing in a period when funding conditions are already strained. Overall, these findings support our proposition that funding constraints in U.S. money markets are important factors besides regulatory constraints in explaining why CIP-arbitrage profits for a limited set of market participants can persist.

The GFC has revitalized research interest in the validity of CIP. A first wave of papers (e.g., Baba, Packer, and Nagano 2008; Baba and Packer 2009) focused on the USD funding shortages of global banks as a key driver of the relationship's breakdown.[5] Based on this research, and more recently



[5] Other important contributions with a focus on dislocations during the crisis include Coffey et al. (2009), Gârleanu and Pedersen (2011), Goldberg, Kennedy, and Miu (2011), Griffoli and Ranaldo (2010), McGuire and von Peter

Bahaj and Reis (Forthcoming), a consensus emerged that providing USD liquidity via major central banks' swap lines with the Federal Reserve was instrumental in alleviating the USD shortage and helped to significantly ease the CIP dislocation.

Our paper is mostly related to the second wave of research that seeks to explain why deviations have been so persistent post-GFC, even in the absence of any obvious market stress. Du et al. (2018) carefully document the price dislocations, stressing in particular the importance of bank regulations, and suggest a causal link between regulation and CIP deviations. Sushko et al. (2016) highlight the role of FX hedging demand. Cenedese, Della Corte, and Wang (2021) use trade-repository-volume data to study limits to arbitrage and to study imbalances in the dealer-to-customer segment of the FX swap market. Iida, Kimura, and Sudo (2018), Wong and Zhang (2017), and Wong, Leung, and Ng (2016) stress the importance of counterparty risk. Andersen, Duffie, and Song (2019) show that in the presence of debt overhang, deviations in the law of one price between two similar risky assets need to be equal to the arbitrageurs' credit spread for the trade to be beneficial for the bank's shareholders.

Furthermore, our paper relates more broadly to work emphasizing the role of intermediation frictions and the role of limits to arbitrage. Gabaix and Maggiori (2015) provide an equilibrium model where intermediation frictions and segmentation effects can lead to the failure of both uncovered and covered interest parity. The results in our paper are also linked to theoretical work emphasizing the constraints faced by arbitrageurs in segmented markets (e.g., Gromb and Vayanos 2002), frictions in funding markets (e.g., Brunnermeier and Pedersen 2009; Gârleanu and Pedersen 2011), and slow-moving capital (e.g., Mitchell et al. 2007; Duffie 2010).

Finally, although our approach differs from those of other current papers, our focus on funding liquidity differences across currency areas and heterogeneity across banks in terms of funding costs has antecedents in some of the earliest work on CIP. Tsiang (1959), for instance, emphasizes that being liquid in crucial currencies like the USD is valued differently than being liquid in others. Both Tsiang (1959) and Branson (1969) stress the importance of heterogeneity across the banks that are the key arbitrageurs. Following this tradition, we point to banks' marginal unsecured funding costs as the main source of heterogeneity and of their ability to arbitrage the CIP condition.

## 1. CIP Arbitrage and the Choice of Interest Rates

In this section, we define some key terms and show that the choice of interest rates is a crucial input for studying CIP violations.

(2012), Bottazzi et al. (2012), and Syrstad (2014). The literature on the topic has received a recent boost following the work by Du et al. (2018). See the overview of the literature by Du and Schreger (2021) and the references therein.

### 1.1 CIP versus LOOP

We distinguish between two key concepts: the no-arbitrage condition known as covered interest parity (CIP) and the law of one price (LOOP). Our focus is on CIP, but to understand dynamics in the FX swap market, it will be necessary to refer to LOOP as well.

**Covered interest parity.** CIP is based on the basic proposition that a *self-financed, risk-free* arbitrage trade—borrowing in, for example, U.S. dollar (USD), investing in a risk-free asset in, for example, euro (EUR), and using an FX swap to ensure riskless conversion of the proceeds—should not yield any profits.[6] In this example the following steps apply:

1. Borrow USD for, say, 30 days, at rate $r_{t;\$}$ directly in U.S. money markets.
2. Sell USD against EUR spot to obtain $1/S_t$ EUR.
3. Invest the EUR at the currently available 30-day EUR rate $r_{t;\star}$ in EUR money markets, and simultaneously enter a forward $F_t$, reversing the currency exchange at a predetermined price in 30 days (effectively entering a FX swap contract).
4. At maturity, collect the USD from the FX swap and repay the USD debt, $\left(1+r_{t;\$}\right)$.

In the example above, the arbitrageur will borrow at ask rates, lend at bid rates, buy spot at ask (EUR is the base currency in the EURUSD exchange rate), and sell forward at the bid. No-arbitrage then holds if the USD borrowing rate is equal to or higher than the synthetic (implied) investment rate, that is, the investment rate in foreign currency after hedging the FX risk:

$$\left(1+r_{\$}^{a}\right) \geqslant \frac{F^{b}}{S^{a}}\left(1+r_{\star}^{b}\right), \tag{1}$$

where the superscripts $a$ and $b$ symbolize ask and bid rates, respectively, and $r^a > r^b$.[7]

A proper implementation of CIP arbitrage requires all transactions (borrowing, spot, forward, and lending) to be made simultaneously such that the profits are known ex ante (we therefore drop the time subscript). The forward contract removes the FX risk, and, if the interest rates in the investment leg are risk-free, this trade will amount to a risk-free and self-financed arbitrage trade. Arbitrageurs typically implement the spot-forward combination via an FX swap since the swap market is more liquid than the outright forward market (e.g., BIS 2019).



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6 Throughout the paper, we take the perspective of borrowing in USD because this is the most relevant case.

7 For further details regarding the measurement of all market conventions, see Internet Appendix 2.

Additional transaction costs may apply for certain trading strategies. For instance, it is possible to arbitrage cross-currency deviations in risk-free Treasury-bill rates by short selling the Treasury bill that is relatively expensive, hedging the FX risk in the FX swap market, and investing in the relatively cheap Treasury bill denominated in another currency. In this case, additional shorting costs apply.

**Law of one price violations.** The basic law of one price in international money markets implies that the interest rate on similar funding instruments should be equal across currencies after accounting for the FX hedging cost. To assess LOOP deviations, we compare the *direct* borrowing costs in the money market of one currency with the *implied* borrowing costs (based on the FX swap markets). The latter rates are given by the costs of raising funds in the money market of another currency (say in EUR), arrived at by converting the funds into the target currency (here, USD) while simultaneously hedging the currency risk.[8] In contrast to CIP, where the borrowing happens at the ask rate and the investment at the bid rate, comparing borrowing or investment rates across currencies means that the interest rate legs in both currencies are either at the ask (borrowing) or at the bid (investment).

A simplified version of LOOP is quite commonly referred to as *cross-currency basis*, defined as

$$Basis = \underbrace{\frac{F}{S}(1+r_\star)}_{\text{Synthetic \$-rate}} - \underbrace{(1+r_\$)}_{\text{Direct \$-rate}}, \tag{2}$$

that is, the discrepancy between the synthetic interest rate implied by the FX swap, $\frac{F}{S}(1+r_\star)$, and the direct interest rate, $(1+r_\$)$. A higher basis, as defined here, indicates that the USD trades at a premium in the swap market compared to raising funds directly in U.S. money markets.[9]

There are some important differences between testing for LOOP versus CIP violations. First, the investment leg of CIP must be risk-free, while the requirement for LOOP is that the rates in the two currencies represent the same risk. Second, exploiting deviations from CIP leads to an *expansion of the arbitrageur's balance sheet* because the trade's investment leads to a rise in the asset side and the required funding raises the liability side of the balance sheet. By contrast, LOOP deviations represent an opportunity for borrowers to fund a *given* position in an asset more cheaply by raising funds in another currency and

[8] In this paper we mainly focus on a funding perspective of LOOP. However, one could take an investment perspective by comparing the return on a direct investment in an asset in the target currency (say, a U.S. Treasury bill) with that on a synthetic asset (i.e., the implied investment return based on a similar asset in another currency hedged back into the target currency).

[9] We define the basis this way, given the straightforward link to arbitrage strategies that involve borrowing in U.S. money markets. Note that others sometimes define the basis the other way around (e.g., Du et al. 2018).

hedging the FX risk via the FX swap market. Responding to LOOP deviations thus does not require an expansion of the balance sheet, but boils down to a recomposition of the funding (or investment) mix.[10]

## 1.2 The choice of money market rates

The formula (2) above provides little guidance on the choice of interest rates when analyzing the validity of the CIP condition. Standard textbook treatments of CIP arbitrage, for example, Hull (2017), typically consider risk-free rates in both legs of the transaction. The reasoning behind this approach is that the appropriate discount rate for a risk-free investment should be the risk-free rate. In much of the older, pre-GFC literature (e.g., Akram, Rime, and Sarno 2008), the preferred measure was interbank rates, such as LIBOR, a market that has seen a massive drop in activity postcrisis. An advantage of using LIBOR in past CIP work was that the rates are harmonized across currencies and, at least in the pre-GFC environment, were deemed to reasonably represent banks' short-term funding costs. At the time, the credit risk inherent in these rates was regarded as fairly minor, as also evinced by the almost negligible spread pre-GFC between LIBOR and the risk-free rate as proxied by the rate on overnight indexed swaps (OIS).[11]

The cross-currency basis with LIBOR rates, here in logs and suppressing the time and bid-ask subscript, can be expressed as

$$Basis^{LIBOR} = f - s + l_{\star} - l_{\$}, \tag{3}$$

where $l_{\star}$ represents LIBOR in the foreign currency, while $l_{\$}$ stands for USD LIBOR. Using LIBOR rates may have been sensible pre-GFC, but evidence over the past few years shows that for many currencies there have been sizeable deviations of the LIBOR basis post-GFC. The fact that LIBOR contains credit risk and may also not be representative of banks' funding costs calls for a different perspective.

A key point of our paper is that in the postcrisis environment of highly fragmented money markets, it is crucial to carefully choose interest rates that adequately capture the marginal funding cost in the funding leg (as LIBOR was originally supposed to), and simultaneously to ensure that the investment rates be truly risk-free as required in an arbitrage trade. Moreover, because of heterogeneity across banks and segmentation in USD funding markets in

10 While this approach is sometimes termed "borrower's arbitrage" in the literature, we deem it more appropriate to characterize such behavior as exploiting "relative value" opportunities.

11 Overnight indexed swaps (OIS) contracts are derivatives that involve exchanging a fixed rate against a predefined floating overnight rate. The instruments are used for hedging purposes, but not for raising funds. Since the overnight rate usually contains a negligible credit risk premium (because of the very short term) and a majority of central banks target the overnight rate, this rate is usually close to the key policy rate. It is therefore often regarded as a proxy for the risk-free rate. An OIS contract does not involve any exchange of the principal (because it is a derivative), only the net difference between the realized overnight rate during the term of the contract and the agreed fixed rate.

particular, actual arbitrage profits will be quite different depending on particular banks' funding costs and market access. Profits will hence differ greatly across banks and can be represented as[12]

$$\begin{aligned} Arb\text{-}Profit_j &= f - s + r_{j;\star} - r_{j;\$} \\ &= Basis^{LIBOR} + (r_{j;\star} - l_\star) - (r_{j;\$} - l_\$). \end{aligned} \quad (4)$$

LIBOR rates hide a large degree of heterogeneity in funding costs (especially in USD money markets), with a few players able to borrow unsecured at lower rates than LIBOR, but a significant set of players for which $r_{j;\$} > l_\$$. In addition, when lending at LIBOR in foreign currency, the arbitrageur will face counterparty credit risk. For realistic risk-free investment options (see below), $r_{j;\star} < l_\star$. These effects mean that actual arbitrage profits will be lower than what headline cross-currency basis measures may indicate.[13] In the empirical analysis below, we will seek to quantify these profits that are available to arbitrageurs in different currencies and that will, most importantly, vary because of their specific USD funding costs.

**Data on money market instruments.** We consider three tenors of money market and FX swap rates: 1-week, 1-month, and 3-month (with special emphasis on the 3-month tenor unless there are important lessons to be learned from the shorter tenors). These tenors are the most liquid and natural choices for implementing CIP arbitrage in money markets. Our study comprises the set of most liquid currencies worldwide, that is, the euro (EUR), the Japanese yen (JPY), the British pound sterling (GBP), the Canadian dollar (CAD), the Australian dollar (AUD), and the Swiss franc (CHF), all quoted against the U.S. dollar (USD).[14]

Depending on instrument and currency, data availability starts in the precrisis period and runs until the beginning of 2021. But, unless otherwise stated, our main focus is on CIP deviations in calm market conditions (the postcrisis period from the beginning of 2013 until the end of 2019), for which explaining CIP deviations has proven particularly challenging (Du et al. 2018).

Unlike in the textbook CIP description, market participants face a plethora of money market rates, all with very different characteristics. As shown by Duffie and Krishnamurthy (2016), the dispersion across different types of rates has increased substantially postcrisis. Against the backdrop of structural changes in funding markets and a large degree of fragmentation, care must be exercised to select rates that most adequately capture the *marginal funding costs* of the

[12] For expositional reasons, we continue to suppress bid-ask spreads. However, bid-ask spreads are taken into account in all calculations of arbitrage profit in this paper.

[13] As we will discuss in Section 2, this is also the case for risk-free interest rates (though omitted here for expositional purposes).

[14] Table IA.I in the Internet Appendix provides an overview of the data sources.

critical arbitrageurs in international money markets (i.e., global banks). We hence focus on instruments, such as commercial paper (CP) or certificates of deposit (CD), which have emerged as the main marginal sources of short-term funding for banks postcrisis.[15] These instruments are typically held by nonbanks, such as MMFs or other institutional investors, and provide a flexible way for banks to attract short-term unsecured funding. We obtain these data for different credit rating buckets.

In parts of our analysis, we also consider other instruments like repo, Treasury bills, interbank deposit rates/LIBOR, and overnight indexed swaps (OIS). Moreover, we consider the rates of remuneration on foreign central bank deposit facilities (e.g., by the ECB and the Bank of Japan), at which a limited set of arbitrageurs—notably global banks—can invest funds in a risk-free manner.

**Descriptive statistics: Money market rates for funding and investment.** Table 1 reports descriptive statistics for 3-month CP spreads (for two rating categories) over OIS rates (Table IA.II in the Internet Appendix shows the same descriptive statistics for 1-week and 1-month maturities).[16] Panel A of the table shows substantial heterogeneity across banks' USD funding costs. High-rated banks (A-1/P-1 rating) on average pay significantly less for USD funding than mid-rated banks (A-2/P-2 rating) or lower-rated banks do. For 3-month USD funding, the former pay about 17 basis points (bps) on average less than the latter do.

Table 1 further shows that over the sample period, USD funding was on average significantly more expensive than funding in other major currencies (see also Section 3.1 for further analysis of the drivers behind this phenomenon). The difference is especially stark when comparing against the JPY: a high-rated bank can fund itself about 45 bps more cheaply in JPY than in USD markets, a fact that illustrates the difference in funding costs across the two currency areas. Even though interbank rates (such as IBORs) are less suitable to capture banks' marginal funding costs post-GFC, the descriptive statistics shown in panels B and C corroborate the picture of sizeable differences in funding costs across currency areas. Similarly, we observe notable differences across currencies in the costs of obtaining term repo funding, with EUR and JPY term repo spreads particularly compressed compared to those in the USD.

As for risk-free instruments in the investment leg, captured by $r_{j;\star}$ in Equation (4), we primarily consider foreign government Treasury bills and central banks' (CB) deposit facilities (see Table 2 for descriptive statistics). The

[15] Note that short-term funding instruments like CP and CD were important prior to the crisis as well, but in the precrisis period, interbank markets were significantly more active and most banks could source funding at rates close to LIBOR. Consequently, in that period, LIBOR was a reasonable representation of banks' marginal funding costs.

[16] OIS rates are referenced since they are commonly regarded as a proxy for risk-free rates and are insensitive to fluctuations in credit and liquidity premiums for short-term funding and thus cannot represent the *marginal* funding costs of the typical arbitrageurs when funding conditions change.

**Table 1**
**Comparison of money market spreads for different currencies (3-month maturity)**

| | Mean | Median | SD | Obs. |
|---|---|---|---|---|
| *A: Commercial paper (CP)/Certificate of Deposit (CD)* | | | | |
| | | Mid-rated banks (A-2/P-2) | | |
| *3 month* | | | | |
| EUR | 4.88 | 3.11 | 9.60 | 1,979 |
| GBP | 15.68 | 15.65 | 7.93 | 1,977 |
| JPY | −11.62 | −13.67 | 14.11 | 1,439 |
| USD | 36.37 | 31.53 | 20.28 | 2,059 |
| | | High-rated banks (A-1/P-1) | | |
| *3 month* | | | | |
| EUR | −2.31 | −2.50 | 7.04 | 1,996 |
| GBP | 8.74 | 8.29 | 8.31 | 1,985 |
| JPY | −25.99 | −26.45 | 20.28 | 1,950 |
| USD | 19.32 | 13.05 | 15.26 | 2,062 |
| *B: Interbank offer rate (IBOR)* | | | | |
| *3 month* | | | | |
| AUD | 22.23 | 21.54 | 13.95 | 2,087 |
| CAD | 33.15 | 30.73 | 9.94 | 2,002 |
| CHF | 3.91 | 1.29 | 9.32 | 2,020 |
| EUR | 6.68 | 5.50 | 5.40 | 2,050 |
| GBP | 10.65 | 9.92 | 7.48 | 2,029 |
| JPY | 1.93 | 1.81 | 4.05 | 2,029 |
| USD | 22.64 | 16.28 | 14.84 | 2,026 |
| *C: Repo* | | | | |
| *3 month* | | | | |
| EUR | −20.79 | −19.40 | 11.07 | 2,043 |
| GBP | 2.23 | 1.83 | 11.36 | 1,143 |
| JPY | −5.99 | −6.92 | 4.87 | 1,959 |
| USD | 2.16 | 0.69 | 4.69 | 767 |

This table presents descriptive statistics for spreads between different 3-month money market rates over OIS rates in several currencies. Panel A presents results for commercial paper (CP) for high-rated (A-1/P-1) and mid-rated (A-2/P-2) banks; panel B presents spreads for IBOR rates; and panel C shows spreads for repo rates. All rates are measured as ask rates, and the mean, median, and standard deviation of spreads are expressed in basis points. Sample: January 2013 to January 2021. See the Internet Appendix Table IA.II for 1-week and 1-month tenors. *Sources*: Bloomberg and JPM Markets.

main difference between the two vehicles is that Treasury bills are accessible by all market participants (including nonbanks), whereas CB deposit facilities are available only to the eligible counterparties of the central bank (i.e., banks). Moreover, the remuneration of CB deposits is in most cases unresponsive to the amount of reserves placed in the facility.[17] By contrast, Treasury-bill rates (and similarly the rates on reverse repos) fluctuate with changes in demand and supply conditions. Table 2 shows that over our sample, the rate on Treasury bills often lies below the OIS rate and that the CB deposit rate is therefore relatively more attractive.

## 2. Arbitraging CIP Deviations

We now turn to the first part of our analysis of CIP arbitrage. For simplicity, we consider only arbitrage trades with direct borrowing in USD and swapping

[17] In cases where the central bank has adopted tiered deposit remuneration (Bech and Malkhozov 2016), we use the lowest rate as an expression of the marginal remuneration rate. The more favorable rates apply only to a restricted amount.

**Table 2**
**Descriptive statistics: Risk-free investment vehicles in CIP arbitrage**

*A. T-bills*

| | Mean | Median | SD | Obs |
|---|---|---|---|---|
| AUD | −6.00 | 0.19 | 53.88 | 527 |
| CAD | −7.57 | −8.05 | 5.61 | 2,008 |
| CHF | −5.09 | −3.25 | 15.03 | 1,998 |
| EUR | −15.92 | −14.40 | 12.35 | 2,026 |
| GBP | −8.12 | −8.30 | 7.26 | 1,798 |
| JPY | −10.70 | −8.99 | 8.83 | 1,556 |
| USD | −5.87 | −6.58 | 7.51 | 2,087 |

*B. Central bank deposits*

| | Median | Average change | Number of changes | Jan. 2021 |
|---|---|---|---|---|
| AUD | 125 | −25 | 11 | 0 |
| CAD | 75 | −5 | 10 | 25 |
| CHF | −75 | −38 | 2 | −75 |
| EUR | −40 | −10 | 5 | −50 |
| GBP | 50 | −8 | 5 | 10 |
| JPY | −10 | −20 | 1 | −10 |
| USD | 50 | −1 | 16 | 10 |

This table presents summary statistics for risk-free investment vehicles in risk-free CIP arbitrage. Panel A presents descriptive statistics on the spread between 3-month Treasury-bill rates and OIS rates (in basis points). Panel B provides summary statistics on the remuneration on central bank deposit facilities (in basis points). All Treasury-bill rates are measured as bid rates. The German Treasury-bill rate is used for EUR. The SNB (CHF) and BoJ (JPY) have a tiering structure for their deposit rates, meaning that not all reserves are remunerated at the same rate. Sample: January 2013 to January 2021. *Source*: Bloomberg.

into foreign currency, as opposed to the other direction since the latter trading strategy has mostly been unprofitable.[18]

## 2.1 CIP arbitrage involving risk-free rates

As a starting point, and in line with typical textbook treatments (e.g., Hull 2017), we study CIP deviations for risk-free money market instruments. While our main focus in the paper is on unsecured funding, an initial look at deviations for risk-free rates is useful to provide some context and shed light on some of the constraints market participants are facing.

Figure 1 sets the stage by showing the deviations across different subsamples, pre- and post-GFC. Although our paper's main focus is the postcrisis period, it is useful to compare this period with a tranquil period prior to the GFC. Figure 1 shows that, already pre-GFC, some substantial deviations existed for risk-free money market instruments, such as repo agreements and Treasury bills. Deviations for risk-free rates are therefore not a new phenomenon. The underlying drivers thus cannot solely be attributed to factors that have changed post-GFC, such as the tightening of banking regulation.

A primary reason for deviations for risk-free rates, also precrisis, is cross-currency differences in the cost of collateral. High-quality collateral in one

[18] See, for example, Table IA.III in the Internet Appendix for results for arbitrage in both directions. Section 2.5 of the Internet Appendix discusses the special case of the Australian dollar for which there are negative CIP arbitrage profits regardless of the direction of the trade (borrowing in USD or borrowing in AUD).

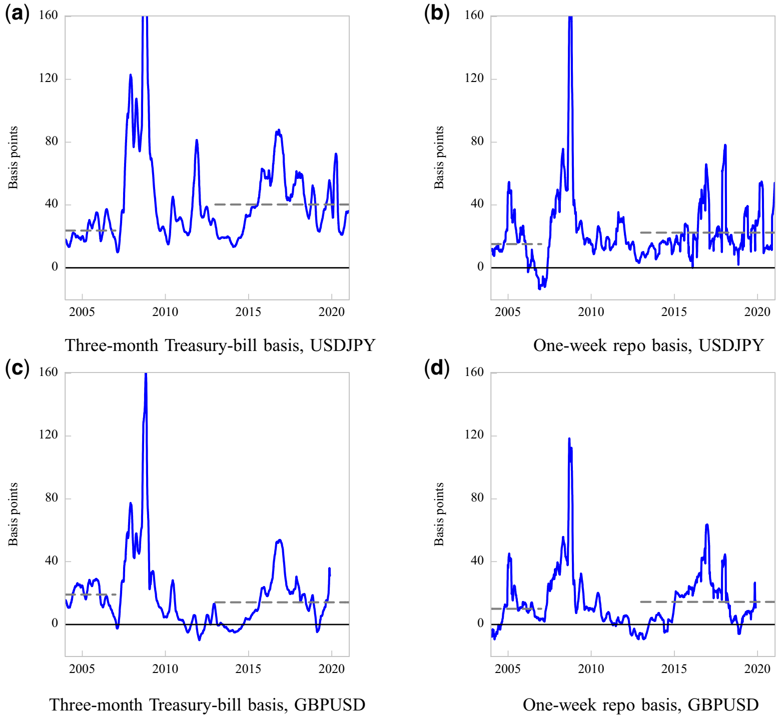



**Figure 1**
**CIP deviations based on Treasury bills and repos for JPY and GBP**
This figure shows the evolution of the 3-month Treasury-bill basis and the 1-week repo basis for Japanese yen (JPY) and Sterling (GBP) vis- à -vis the U.S. dollar (USD). The solid lines represent a smoothed series for ease of visibility (based on a 3-month moving average). The units are in basis points. Positive values indicate a higher synthetic dollar rate (implied via the FX swap market) when compared to the direct USD rate. Dashed lines represent the average basis in two subsamples, up to and after the Global Financial Crisis. The vertical axis is capped at 160 bps for visibility (maximum values are 263, 163, and 161 for panels A–C). Sample: January 2004 to January 2021. *Sources*: Bloomberg and Global Financial Data.

currency is valued by investors differently than is similar collateral denominated in another. It is commonly accepted that a special investor preference for U.S. Treasuries, because of their safety and liquidity features, gives rise to a "convenience yield" and a depressed U.S. Treasury-bill rate (Krishnamurthy and Vissing-Jorgensen 2012). And indeed, already Tsiang (1959), in one of the earliest works on CIP, pointed out that if potential arbitrageurs value assets with similar characteristics, denominated in different currencies, differently, for example, because of convenience yields, the law of one price condition in international money markets may be violated.

A similar argument can be applied to the cross-currency repo basis (panels B and D in Figure 1).[19] Raising funds through a repo encumbers high-quality

[19] Indeed, we find the Treasury bill and the repo basis to be closely connected, with correlations of approximately 70%.

collateral, such as U.S. Treasuries. Just as the Treasury-bill basis may be nonzero because of differences in convenience yield, the repo basis may be nonzero due to cross-currency differences in how investors value the collateral value of the Treasury securities.[20] Indeed, Kohler and Müller (2019) show that the repo basis is close to zero when the collateral is denominated in the same currency.

The findings and discussion above point to a shadow cost associated with holding unencumbered high-quality collateral (which also includes central bank (CB) reserves).[21] A high-quality asset is either encumbered, and then not usable for other purposes as a source of funding, or it is unencumbered and hence ultimately funded by unsecured debt. The relevant funding cost for unencumbered assets is therefore the unsecured interest rate at the respective maturity.[22] In the presence of cross-currency differences in the spread between the unsecured funding rate and the interest rate on high-quality assets for the same maturity, the shadow cost will not be equal across currencies.

What does this shadow cost mean for the cross-currency basis for risk-free rates? Arbitraging this basis involves giving up an asset in the funding currency that has a higher shadow cost than does the asset received as collateral in the investment currency (see also Section 5 in the Internet Appendix for some concrete examples). As shown in Figure 1, the cross-currency bases for repo rates and Treasury bills have indeed been substantially different from zero since early 2000s. This difference does not mean, though, that market participants are prevented from taking advantage of the cross-currency basis using repo, Treasuries, or reserves (Correa, Du, and Liao (2021) show, for example, that large U.S. banks respond to CIP deviations by drawing down their reserve balances, an activity which is constrained to short periods around quarter-ends).[23] Instead, we argue that unencumbered assets have a shadow cost equal to the difference between the unsecured rate and the rate on the respective risk-free assets. In its decisions on the economic rationale of the trade, the bank's treasury unit will hence factor in the differences between the advantage of EUR collateral and the disadvantage of giving up USD collateral (i.e., differences in the shadow cost).

[20] Internet Appendixes 4 and 5 provide detailed analyses of trading strategies involving repos, and other risk-free rates, such as Treasury bills and OIS.

[21] For assets already deployed as collateral, and hence encumbered, the collateralized interest rate reflects the cost of financing the very specific asset serving as collateral. See also Section 3.1 for additional institutional background.

[22] This is also the case for CB reserves (as they are ultimately also funded by unsecured debt). From the vantage point of the bank's treasury, the maturity profile of the funding of the reserves is crucial (see Internet Appendix 7.3.1). Thus, while the bank may have some flexibility in taking advantage of short-term opportunities, the role of funding costs increases with the maturity of the trade and will be the dominant factor for trades we focus on in this paper (1W-3M).

[23] The deposits that match the CB reserves may be quickly withdrawn (as is common with wholesale deposits). Hence, using reserves for anything but very short arbitrage trades implies taking on liquidity risk. This may be alleviated when the influx of deposits is very large and persistent such that they can be regarded as more sticky (a situation more common in Japan or the euro area). See Internet Appendix 7.3.1 for further discussion.

## 2.2 CIP arbitrage based on unsecured funding

As the previous subsection showed, deviations from CIP for risk-free instruments, such as Treasury bills and repos, are not a new phenomenon. However, neither Treasury bills nor repo rates capture banks' funding costs *at the margin*, and, as shown by the discussion above, cross-currency deviations observed for such rates do not necessarily signal a "free lunch." In the following, we therefore use interest rates capturing the arbitrageurs' marginal funding costs in the *funding leg*. LIBOR rates used to fill this role in the pre-GFC period, but do not do so anymore given the dramatic decline in interbank deposit markets post-GFC (see Figure IA.1a in the Internet Appendix). To capture realistic marginal funding costs in the postcrisis market environment, we therefore use CP and CD rates for the funding leg of the arbitrage.

As vehicles for the *risk-free investment leg* of the arbitrage trade, we consider (1) short-term government paper (Treasury bills), and (2) central bank (CB) deposit facilities. These choices ensure that our analysis is in line with the basic requirements for arbitrage, namely, that the arbitrageur not be exposed to risk and that the relevant costs be reflected.[24]

Table 3 summarizes 3-month CIP-arbitrage profits, funded via unsecured borrowing by banks of different credit ratings (see Table IA.IV in the Internet Appendix for 1-week and 1-month maturities). The left-hand-side panel shows CIP-arbitrage profits with CB deposit facilities as investment vehicles, while the right-hand-side panel shows the same for Treasury bills. The table presents results across two subsamples: we split the post-GFC period into before and after the reform of money market funds (MMF) (part I) and treat the MMF reform period separately (part II). The main reason for this split is that the MMF reform of October 2016 substantially affected short-term USD funding markets (see, e.g., Aldasoro et al. 2019 or Anderson, Du, and Schlusche 2021). The adjustment phase to the reform stretched over an extended period and is an interesting subsample that illustrates changes in USD funding costs as the marginal buyers of bank-issued CP/CD scaled back their presence in funding markets (see also Section 3.1 and Figure IA.1 in the Internet Appendix).

We start by considering CIP-arbitrage strategies where global banks borrow in U.S. CP markets, swap into foreign currency, and invest in *Treasury bills* in the respective currency (Table 3, right panel). During the time of the first subsample, which excludes the MMF reform period (part I), we detect no arbitrage profits for mid-rated banks (panel A, right panel).[25] The corresponding

[24] CB deposit facilities are clearly free of credit risk. However, since the maturity of CB deposits in the standing facility is overnight, there is a chance that the CB might reduce the deposit rate during the maturity of the trade. During our sample period, most of the relevant CBs have already reduced the interest rate to what is perceived as the lower bound. Moreover, the risk of lower deposit rates is possible to hedge by entering an OIS contract as the receiver of the fixed rate.

[25] Note that A-2/P-2-rated banks (while being rated below high-rated banks) still can be considered to be fairly creditworthy institutions, relative to many other financial institutions that do not have access to the CP market in the first place.

**Table 3**
**Risk-free CIP arbitrage funded via the CP market**

| | Investment: Central bank deposit facilities | | | | | Investment: Treasury Bills | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Deviation | | | | | Deviation | | |
| | Median | Std. | (%D) | (%M) | Obs. | Median | Std. | (%D) | (%M) | Obs. |
| I: Postcrisis to end 2019, excluding MMF reform period | | | | | | | | | | |
| *A. Mid-rated banks (A-2/P-2)* | | | | | | | | | | |
| AUD | **−62.9** | 21.7 | 0 | 0 | 1,466 | **−48.4** | 77.9 | 0 | 0 | 246 |
| CAD | **−47.2** | 10.2 | 0 | 0 | 1,480 | **−30.1** | 9.5 | 0 | 0 | 1,454 |
| CHF | **0.3** | 16.0 | 51 | 32 | 1,480 | **−11.8** | 12.4 | 21 | 7 | 1,429 |
| EUR | **−13.3** | 15.9 | 21 | 14 | 1,476 | **−18.2** | 10.4 | 3 | 0 | 1,418 |
| GBP | **−15.2** | 9.8 | 6 | 1 | 1,476 | **−30.5** | 10.5 | 0 | 0 | 1,343 |
| JPY | **5.6** | 13.7 | 67 | 47 | 1,478 | **−4.1** | 11.6 | 37 | 12 | 1,113 |
| *B. High-rated banks (A-1/P-1)* | | | | | | | | | | |
| AUD | **−47.3** | 20.6 | 0 | 0 | 1,466 | **−32.4** | 77.2 | 0 | 0 | 246 |
| CAD | **−31.5** | 9.8 | 0 | 0 | 1,481 | **−14.4** | 8.9 | 4 | 0 | 1,455 |
| CHF | **15.6** | 16.9 | 98 | 94 | 1,481 | **4.2** | 13.3 | 68 | 28 | 1,429 |
| EUR | **4.4** | 17.3 | 64 | 55 | 1,477 | **−2.8** | 10.0 | 38 | 19 | 1,419 |
| GBP | **1.1** | 9.3 | 61 | 30 | 1,477 | **−13.8** | 10.7 | 14 | 3 | 1,343 |
| JPY | **22.5** | 14.4 | 100 | 99 | 1,479 | **10.9** | 11.7 | 95 | 76 | 1,114 |

This table shows 3-month CIP deviations, measured in basis points, for an implementable strategy involving unsecured borrowing in the U.S. money market. Part I covers the postcrisis period, excluding the adjustment phase of the U.S. money market fund (MMF) reform (January 2013 to December 2019, less April 2016 to June 2017), while part II (next page) covers the MMF reform sample. Positive numbers represent arbitrage profits. The commercial paper (CP) funding rate differs according to two rating categories, either high-rated banks (A-1/P-1) or mid-rated banks (A-2/P-2). Two risk-free choices for the investment leg are considered: central bank deposit facilities (left-hand-side panel) and Treasury bills (right-hand-side panel). Columns give the median CIP arbitrage profit, the standard deviation of CIP arbitrage profits, and the proportion of days (%D) and months (%M), as 20 consecutive days, during the sample when a positive arbitrage profit is observed. *Sources*: Bloomberg and TradeWeb.

entries in the table for banks of medium credit quality are negative for all currencies. For high-rated banks (panel B, right panel), we observe some arbitrage profits for investments in CHF- and JPY-denominated Treasury bills (up to 11 bps on average in case of JPY).

We then turn to CIP-arbitrage strategies where global banks place the swapped funds in *foreign CBs' deposit facilities* (Table 3, left panel). Panel A shows that even for mid-rated banks, some arbitrage profits have been available in the CHF and the JPY. However, these are small in economic terms (up to 6 bps on average). By contrast, for high-rated global banks with good access to core U.S. funding markets (panel B, left panel), the profits have generally been larger, with economically viable arbitrage opportunities as large as 16 and 23 bps in CHF and JPY, respectively.

It is noteworthy that CIP arbitrage involving CB deposit facilities is much more profitable than arbitrage involving investing in Treasury bills. To see why, it is important to keep in mind that the rate of remuneration offered on CB deposits is insensitive to the volumes placed in the facility. Moreover, there is segmentation in the sense that only a select group of financial institutions has access to the deposit facility. The pricing of Treasury bills, by contrast, adjusts to demand and supply imbalances in the market. If a CIP-arbitrage opportunity combining an FX swap and Treasury bills emerges, one would expect both the FX swap price and the Treasury-bill rate to respond to the corresponding arbitrage-induced flow.

**Arbitrage profits amid the MMF funding shock.** We now turn to arbitrage over the subsample of the 2016 U.S. money market fund reform.[26] As part II of Table 3 shows, CIP-arbitrage profits of global banks edged up notably. During this episode of constrained USD funding conditions, even mid-rated banks faced economically interesting arbitrage opportunities. And such opportunities were even available with Treasury bills as vehicles in the investment leg, with profits reaching about 10 and 12 bps, on average, in the cases of the CHF and JPY, respectively. When the arbitraging banks used CB deposit facilities in the investment leg, profits for mid-rated banks exceeded 20 bps for CHF and JPY investments, while in the EUR, about 13 bps could be reaped. Top-tier banks faced very attractive arbitrage opportunities during the period (part II, panel B). The most attractive currency was the JPY: for a high-rated bank, raising funds in U.S. CP markets, swapping into yen, and placing the funds at the Bank of Japan, yielded about 46 bps during the period.

**Time-series behavior of arbitrage profits.** Figure 2 illustrates the time-series behavior of arbitrage profits involving either Treasury bills (panel A) or CB deposit facilities (panel B) as investment vehicles. We average over EUR, CHF, and JPY to highlight the cases with positive CIP-arbitrage profits, as evident was from Table 3, and use a two-week moving average to enhance the visibility of the key trends.[27] Arbitrage funded by issuing CP in all cases yields much smaller profits than what headline measures (e.g., the cross-currency basis for OIS rates) would suggest. For high-rated and mid-rated banks that invest in Treasury bills, only a few periods with positive and economically attractive CIP-arbitrage opportunities can be observed during our sample period. But, for the case where the arbitraging bank places funds at the foreign CB in the investment leg, we see prolonged periods with profitable CIP-arbitrage opportunities in EUR, CHF, and JPY (panel B in Figure 2). In particular, arbitrage profits pick up strongly in the run-up to the 2016 MMF reform, which was a major disruption to USD funding markets when prime MMFs receded as main marginal lenders in USD CP/CD markets. Clearly, however, a prerequisite for reaping such profits has been to maintain access to wholesale nonbank USD funding markets in this challenging period, and for the bank to be eligible to access the respective CB deposit facility.

[26] Although the MMF reform came into effect October 14, 2016, the major adjustments in short-term funding markets occurred already several months earlier as prime funds' assets under management dropped substantially (see Figures IA.1b and IA.2 in the Internet Appendix). Thus, we determine the start of the MMF reform period to be April 2016.

[27] Figure IA.3 in the Internet Appendix shows that when averaging over AUD, CAD, and GBP, CIP seems to hold, because profits are primarily negative. The increase into positive terrain for AUD and CAD during the COVID-19 crisis in 2020 is further discussed in Internet Appendix 7.

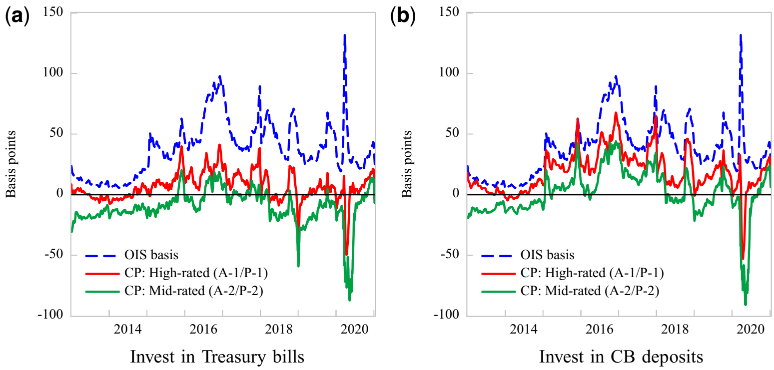



**Figure 2**
**Risk-free 3-month CIP arbitrage opportunities for global banks compared to OIS basis**
The figure shows risk-free CIP arbitrage profits—averaged over EUR, CHF, and JPY—for global banks when funded via the issuance of USD commercial paper, swapping into foreign currency and placing the funds in foreign Treasury bills (panel A) or the foreign central banks' deposit facility (panel B). Funding rates differ for mid-rated banks (A-2/P-2) and high-rated banks (A-1/P-1). In both panels, we also show the 3-month OIS basis for comparative purposes (dashed line). All series are smoothed with a 2-week moving average. Sample: January 2013 to January 2021. *Source*: TradeWeb.

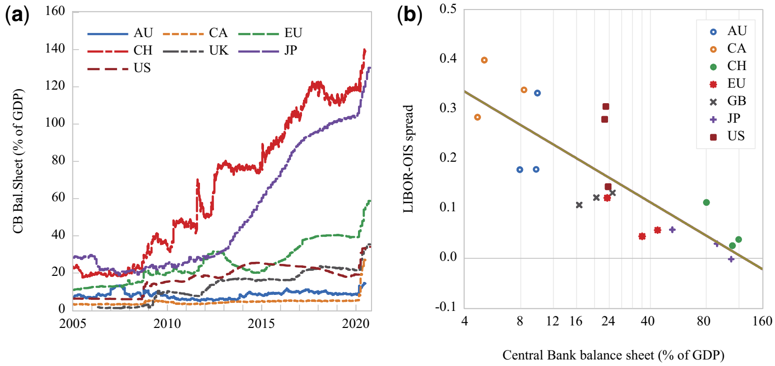
## 3. Institutional Features, Arbitrage Constraints, and Conceptual Framework

The previous analysis begs a key question: How is it possible that risk-free arbitrage profits, even if limited to a narrow set of banks, can persist over such an extended period? To tackle this question, we briefly discuss the market backdrop and the key institutional features characterizing the various market segments involved in a CIP trade and the constraints faced by the main market participants (FX swap dealers, banks, and their short-term funding-providers). Drawing on these institutional features we provide a conceptual framework to explain the FX swap and money market dislocations.

### 3.1 Market backdrop and institutional features

At a high level, three major forces have affected FX swap and money markets post-GFC: (1) the expansion of CB balance sheets and the associated injection of CB reserves; (2) greater differentiation across banks in terms of credit quality and hence funding costs; and (3) tighter constraints, imposed by both markets and regulations, making it more difficult for individual banks to scale their arbitrage.

Short-term funding markets have been heavily affected by the large-scale expansion of CB balance sheets, primarily driven by quantitative easing (QE), in the aftermath of the GFC (BIS Markets Committee 2019). Figure 3, panel A, shows that the expansions by the European Central Bank (ECB), Bank of Japan (BoJ), and the Swiss National Bank (SNB) have been substantially larger, relative to GDP, than those by the Federal Reserve and other major




Central bank balance sheet relative to GDP

LIBOR-OIS spread

**Figure 3**
**Central bank balance sheets and funding spreads**
Panel A shows the central bank balance sheet relative to GDP in Australia (AU), Canada (CA), Switzerland (CH), euro area (EU), United Kingdom (UK), Japan (JP), and the United States (US). Panel B depicts the correlation between the 3-year average of the LIBOR-OIS spreads and the central bank balance sheets relative to GDP (log scale). Each currency has three data points, namely, the average value from 2010 to 2013, 2013 to 2016, and 2016 to 2019. *Source*: Bloomberg.

CBs. Asset purchases (BoJ, ECB) and FX interventions (SNB) have led to an unprecedented commensurate increase in CB reserves as a side product. Funding conditions thus eased substantially in the JPY, EUR, and CHF money markets (notably from the beginning of 2015 and onward). In contrast, the Fed halted its balance-sheet expansion in mid-2014 and engaged in a process of balance-sheet normalization from October 2017 until September 2019, which in turn led to tighter liquidity conditions in USD markets. Panel B illustrates the correlation between the size of the CB balance sheet and funding conditions (represented by the 3-month LIBOR–OIS spread). A larger CB balance sheet tends to be accompanied by tighter money market spreads (as we also show more formally in Section 4.1).

**U.S. money markets.** Because of a number of special characteristics of U.S. money markets, which we outline next, funding conditions have remained tighter in the USD than in other major currency areas (such as the JPY or the EUR) throughout most of the post-GFC period.

Most importantly, the USD's primary status in the international financial system leads to a strong demand pressure for USD funding from non-U.S. banks, including many that do not have a proper retail deposit base in USD. These non-U.S. banks need access to USD to handle customer transactions or to fund USD assets. They typically raise money market USD funding through direct borrowing in the form of CP/CD issuance, conducting repos, or (synthetically) through the FX swap markets. This funding activity implies an enduring demand for USD money market funding from a broad set of institutions worldwide.

Another core feature of U.S. money markets is the crucial role of money market funds (MMFs) for market functioning. So-called "prime MMFs" are the marginal investors in short-term bank debt like CP and CD (about 40% of CP and about 80% of CD outstanding before the MMF reform of October 2016). Shocks originating in this sector therefore historically have had strong repercussions on USD short-term funding markets. In particular, the U.S. MMF reform of 2016 led to a significant widening of the CP/CD spreads and underscored the importance of MMFs to the functioning of USD short-term funding markets (see Figure IA.2 in the Internet Appendix).[28]

Finally, the banking sector has become generally more heterogeneous, and counterparties more discerning with regard to credit quality than pre-GFC. Postcrisis regulation of both banks (disincentivizing interbank lending) and MMFs (restricting the universe of investable assets) has contributed to this greater sensitivity. As a result, there is a strong dispersion in USD funding costs across banks, with a significant fraction of non-U.S. banks facing challenges to obtain direct USD financing.

**Foreign money markets.** Money markets in major currencies other than the USD largely service the domestic banking industry in the respective countries. They are hence much less internationalized than their U.S. counterpart. Because of large-scale CB balance-sheet expansion—particularly in the euro area, Switzerland, and Japan—domestic banks face a situation where they have "excess deposits" (and cheap funding) in domestic currency. When central banks inject large amounts of reserves through asset purchases, lending programs, or FX interventions, the extra liquidity tends to increase the domestic banks' deposit base. This leads to a broad-based easing of funding liquidity conditions, benefiting especially banks of lower credit quality that otherwise would face elevated funding costs. In the euro area, which has the most vibrant CP market outside the United States, the easing in funding costs is clearly visible in Figure 4 (see also Internet Appendix 8 on liquidity premiums). After the ECB started its public-sector asset purchase program in 2015 (marked by the shaded area), the spread between the CP funding costs of mid-rated ( A-2/P-2) banks and those of high-rated banks (A-1/P-1) tightened substantially. Such greater alignment in funding costs is the opposite of what was observed in U.S. markets during the same period. The affected domestic euro area banks thus enjoy cheap funding domestically, yet also face more challenging access to direct funding in USD markets. As we will see below, as a result, raising USD funding by swapping domestic funding into USD has become more attractive.

**FX swap intermediation: Role of dealers and banks.** The FX swap market performs the crucial role of linking the U.S. money market with its international

[28] In addition to moving from constant net asset value (NAV) to variable NAV and new rules on redemption, the 2016 reform tightened the requirement for prime MMFs regarding the maximum average maturity of their portfolios (from 90 to 60 days) and imposed further restrictions on investments in issuances from tier 2 issuers.

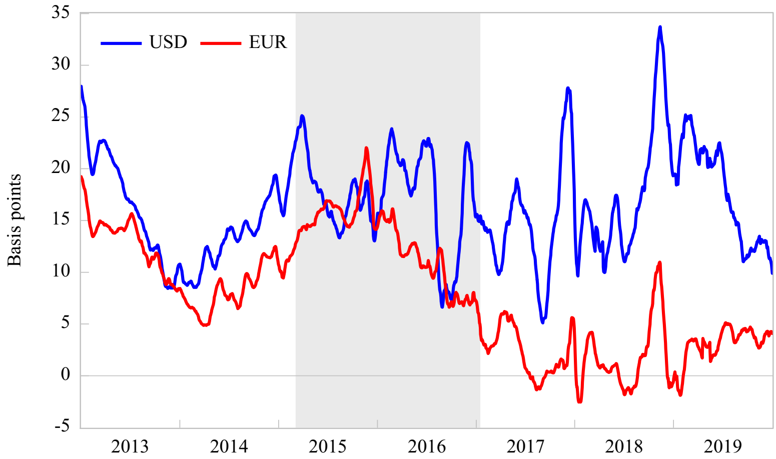



**Figure 4**
**Funding cost divergence between top-tier and lower-tier banks**
This figure shows the evolution in the difference between the funding costs of banks of different credit quality in USD and EUR, calculated as 3-month rate on commercial paper (CP) for mid-rated banks (A-2/P-2) minus that of high-rated banks (A-1/P-1). The shaded area represents the period from March 4, 2015, to January 11, 2017, the implementation of the public sector purchase program (PSPP) by ECB. Sample: January 2013 to December 2019. *Sources*: Bloomberg (USD) and TradeWeb (EUR).

counterparts. Banks without direct or too costly access to direct funding in USD can raise it synthetically using FX swaps (see Section 1.2).

The main FX swap intermediaries are dealers affiliated with large banks. Their primary objective is to earn intermediation spreads, while taking as little inventory risk as possible (Evans and Lyons 2002). When faced with imbalances, the dealer controls inventory by setting quotes so to attract opposite interest (Garman 1976; Stoll 1978).[29] A strong incentive for inventory control is further reinforced by internal overnight risk limits that effectively force the dealer to end the day "flat."

Banks set up their trading desk and internal pricing so as to align the dealer's incentives with the bank's interests. So-called "funds transfer pricing" (FTP) determines the price at which units can internally borrow or place funds with the bank's treasury unit. FTP ensures that the bank and its affiliated dealer face the same funding costs, and hence their incentives are aligned (see Internet Appendix 6 for further details regarding FTP). Consequently, we consider banks to be the key arbitrageurs, while the affiliated dealer aims to capture spreads from intermediation while keeping inventory risk contained.

Pricing of FX swaps in the interdealer market is homogeneous across counterparties. In the interdealer market, so-called "two-way credit support

[29] The dealer does have other options, such as taking on liquidity risk by waiting until opposing interest is found, or opening and funding a new position, but often has a strong preference for matched flow.

annex" (CSA) agreements are a common practice and govern the collateralization of the derivatives transactions. Both counterparties are obliged to pay a variation margin according to price movements, which effectively eliminates counterparty risks.[30]

**Arbitrage constraints.** Banks face a host of constraints in managing their balance sheets that may limit their ability to scale the arbitrage trade. These can take various forms, such as regulatory constraints, funding constraints, and internal liquidity risk management constraints. All these constraints have tightened materially since the GFC.

The importance of regulatory requirements is most clear on regulatory reporting dates (as forcefully shown by, e.g., Du et al. 2018). It is primarily the leverage ratio (LR) and the surcharge that applies to globally systemically important banks (GSIBs) that affect the cross-currency arbitrage trade. Risk-weighted capital requirements are not much affected because of the risk-free nature of the arbitrage trades we consider. In a similar vein, the trades analyzed in this paper have no implications for the overall liquidity coverage ratio (LCR), but only for the currency with which high-quality liquid assets (HQLA) are funded. However, internal-liquidity-management preferences by banks, especially in relation to USD liquidity, likely play a role too.

In most jurisdictions (with the exception of the United States and the United Kingdom), the LR is reported as a quarterly snapshot.[31] The GSIB surcharge is implemented uniformly across jurisdictions based on a year-end snapshot of various criteria and hence primarily affects the year-end turn. As a result of this regulatory reporting practice, European and Japanese banks have been known to be window-dressing their exposure to balance-sheet-intensive, that is, low-margin/high-volume, trading activity.

Several observations suggest that constraints other than banking regulation are also at play. A significant share of large global banks report end-of-quarter snapshots to regulators, for instance in the euro area, Switzerland, and Japan. For these banks, short-term CIP trades (like 1-week to 1-month trades) are typically unaffected by regulation as long as the bank refrains from rolling the trade over reporting dates and conducts only trades that do not cross quarter ends. However, since 2011, persistent CIP-arbitrage opportunities have been observed also in-between reporting dates for such short-term maturities (see, e.g., Figure 1 and Table IA.IV in the Internet Appendix). Moreover, certain types of low-margin/high-volume activities that share similarities with the CIP trade still remain on banks' balance sheets. These activities include so-called "matched-book repo," a form of repo lending to one set of counterparties



30 While interdealer pricing is homogeneous, one can observe price differentiation in the dealer-to-customer segment (see Hau et al. 2021), in particular depending on the way the trades are collateralized.

31 Japanese and European banks disclose the LR at quarter ends. LR reporting first became a full requirement in April 2019 for Japanese banks but did not enter into force before 2021 for European banks (under EU regulation).

financed by repo borrowing from another.[32] Since matched-book repo activity is flexible due to the very short maturity of the transactions, banks could easily scale down this activity and replace it with a CIP trade when such opportunities arise, without affecting the size of the balance sheet.[33]

Another important factor beyond regulation is how funding constraints—the upward-sloping supply curve of unsecured funds in USD markets—make it difficult for potential arbitrageurs to scale their arbitrage positions. Since only the top-rated banks have low enough unsecured funding costs to reap the arbitrage, as our previous analysis shows, it falls on a relatively small number of banks to eliminate the CIP deviations. Most providers of short-term funding, like MMFs or treasury units of big corporations, have strict counterparty limits on their exposure to banks.[34] Therefore, when banks are issuing large amounts in USD to fund the arbitrage trade, they must attract a larger variety of investors to fill the issuance. As a result, the interest rate on the funding increases, thereby decreasing the possible arbitrage profit.

Funding constraints may also interact with internal liquidity risk preferences. Past episodes have frequently shown that banks have a greater preference for USD liquidity than for liquidity in other currencies because USD liquidity is an insurance against financial turmoil. Such focus implies that banks are reluctant to stretch their CD/CP borrowing to the maximum because doing so could become very expensive in case of sudden liquidity needs, in particular should they coincide with a period of generalized financial market turmoil.

### 3.2 Conceptual framework

Building on the discussion of institutional features and constraints of the main players above, this subsection provides a framework to characterize the workings of FX swap and money markets postcrisis. To be clear, the suggested framework is not a full-blown equilibrium model but primarily serves as a tool that helps rationalize the observed dislocations and provides guidance for our empirical tests in Section 4.[35]

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32 This is especially visible when looking at non-U.S. banks balance sheets. See Figure IA.19 in the Internet Appendix, which suggests that foreign banks operating in the United States have significantly expanded USD matched-book repo activity in recent years (visible even in the quarterly sampled data). This evidence suggests that the LR has not acted as a binding constraint for these types of banks, outside of quarter-end periods.

33 Another observation is that even large U.S. banks that have to report the LR based on quarter-averaging typically operate with large buffers above the regulatory minima (on average 1.8 percentage points for GSIB banks and 4.8 percentage points for the remaining large banks from 2016 through 2019, see Figure IA.4 in the Internet Appendix). That said, the LR could act as a binding constraint even in the presence of significant buffers, with the point at which it starts to become truly binding from an economic point of view being difficult to determine (not least because of internal risk management considerations to maintain a buffer on top of minimum regulatory requirements).

34 MMFs are permitted to hold no more than 5% of their assets in the securities of any issuer. They may hold no more than 3% of their assets in securities of A-2/P-2 issuers altogether, and no more than 0.5% of their assets in such securities of any issuer.

35 The development of a theoretical model that accounts for the main real-world frictions highlighted in our paper is left for future research.

Figure 5 illustrates the framework. Panel A shows how, in a normal market environment (like the one pre-GFC), a single FX swap price (the $F/S$ ratio) can maintain the law of one price (LOOP) for different funding rates. The two vertical lines indicate interest rate levels in the two countries ("U.S." on the left-hand side and "Foreign" on the right-hand side). For simplicity, we look at three levels of funding rates faced by different banks in the credit spectrum (top, mid, low) as indicated on the vertical axis. The slope of the curve connecting interest rates in the two currency areas is the FX swap–implied interest-rate differential as given by the $F/S$ ratio. If the vertical distance between the different interest rates is the same, in particular when funding costs for equally risky banks are aligned in two different currency areas, LOOP will hold for all levels of funding rates with just one $F/S$ ratio. The absence of any LOOP deviations is indicated by marking the curve with zeros.

As discussed above in Section 3.1, the large supply of reserve balances post-GFC in foreign currency areas has compressed funding costs in non-U.S. money markets (see, e.g., Jondeau, Mojon, and Sahuc 2020). In Figure 5, panel B, we assume for simplicity that banks' funding costs in the currency area with the large-scale increase in reserves are driven down to as low as the rate of remuneration of the CB deposit facility. Banks of lower credit quality benefit disproportionately from the fall in funding costs. The previous bank-specific funding costs in foreign currency, now in italics, are no longer binding. In a situation of such funding cost divergence across the two currency areas, it is impossible for a dealer to quote a single FX swap rate to be consistent with LOOP (or CIP) for the key money market rates faced by all banks in the credit spectrum.

**Implications for FX swap market imbalances and dealer behavior.** In the environment described above, any dealer quote of the FX swap price will imply a profitable opportunity for at least one set of counterparties. Imagine a situation where the dealer quotes FX swap prices such that the implied rate differential equals that between the USD rate faced by high-rated banks and the foreign CB's deposit facility rate.[36] Such a quote, however, would clearly lead to an imbalance because all banks with more costly direct funding in USD could obtain USD more cheaply via the swap market. The dealer in turn would face highly one-sided demand pressure (indicated by arrows that point toward the USD for the spot leg of the swap) and would accumulate a large inventory.

To avert an imbalance and for helping the market clear, the dealer's quotes must therefore induce flows in both directions. This is accomplished by setting the swap quote so as to imply an interest rate differential such that the law of

[36] In panel B of Figure 5, this case is indicated by the red-dashed line connecting the foreign CB rate and the low U.S. rate, marked with zeros to indicate no deviation from LOOP for the high-rated banks (and hence no CIP arbitrage).

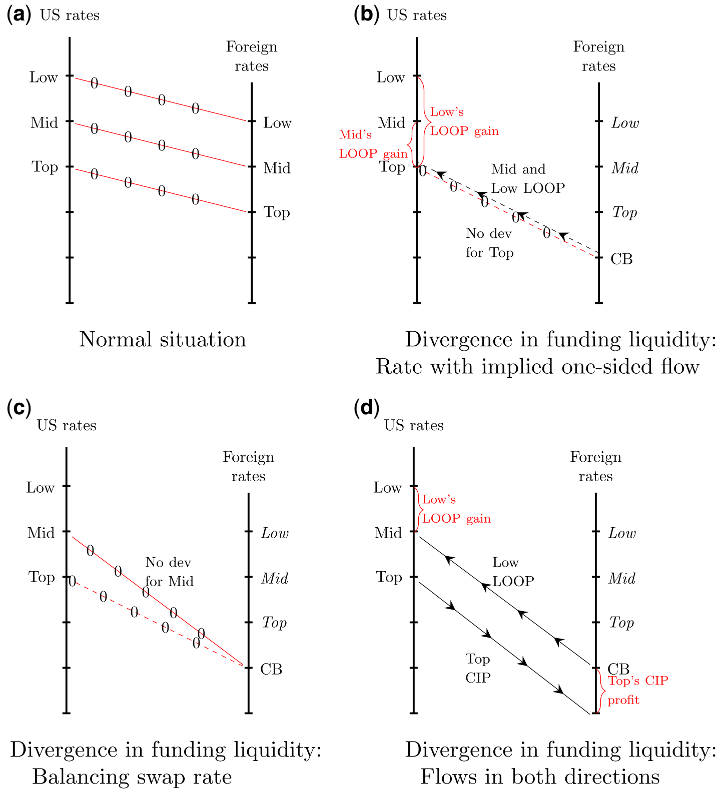


**Figure 5**
**Analytical framework for FX swap markets**
This figure characterizes FX swap market functioning, by illustrating the link between various types of interest rates, swap rates, and the direction of swap flows. The two vertical lines represent the interest rate levels in the two countries, specifically the "U.S." (left) and "Foreign" (right). We consider four different interest rate levels: unsecured rate for low-rated, mid-rated, and top-rated banks, and CB indicating the central bank's deposit rate. The slope of the curve connecting the two interest rates is the ratio of the forward to the spot, $F/S$ (in short, the "swap rate"). Since all market participants face the same swap rate, these curves are shifted vertically. A line marked with zeros implies no LOOP deviations (panel A). The solid lines represent market rates, whereas the dashed line represents a hypothetical rate. Lines with arrows represent a profitable opportunity, and the arrows show the direction of swap flows in the "spot leg" of the swap (panels B and C). In panel D, the arrows from United States represent a CIP deviation because the risk-free investment rate is higher than the implied borrowing rate. The arrow to the United States, however, represents a LOOP deviation as there are no risk-free U.S. investment opportunities available at higher rates than the swap-implied rate.

one price holds for the majority of banks.[37] Like panel B, low-quality banks facing higher USD funding costs have an incentive to obtain USD via the swap market (i.e., a response to a LOOP deviation). But in this "new normal" of

[37] The implied swap rate consistent with this interest rate differential is indicated by the solid-red line marked by zeros in panel C of Figure 5, connecting USD rates for mid-tier banks with the rate on the foreign CB's deposit facility. Note that this quote implies a slightly steeper FX swap-implied rate differential than the nonoptimal alternative (dashed line).

FX swap market functioning, the necessary flows in the opposite direction are induced by *granting an arbitrage opportunity* to those few top-credit banks that have advantages in terms of USD funding costs. Their low USD funding rates render it attractive to borrow directly in unsecured USD markets, swap the USD into foreign currencies, and place the funds (or other risk-free instruments, e.g., Treasury bills) with foreign CBs. The implied flows are shown in panel D of Figure 5 as arrows in both directions. The larger the funding cost differences across the two currencies, the steeper is the slope of the curves in panel D of Figure 5, and the larger is the arbitrage gain for the top-tier banks.

This simple framework has several implications and serves as the main guidance for our subsequent empirical tests. First, CB measures that affect the availability of reserves influence the funding spreads in the respective currency and hence the pricing in the FX swap markets. Second, the developments in international money markets outlined above will have strong implications for the funding structure of global banks. High-rated banks can cover their USD funding needs primarily in USD, while lower-tier ones must swap funding from domestic sources in the FX swap markets to cover their USD needs. Third, the interaction of these diverse sets of banks shapes the demand and supply forces in the FX swap markets so that dealers respond more strongly to order-flow imbalances when arbitrage opportunities are higher. Finally, as posited by our framework, USD funding is a limited resource: elevated arbitrage opportunities go hand in hand with a steeper supply curve and hence with higher costs of raising additional short-term USD debt.

## 4. Evidence on FX Swap Market Imbalances, Dealer Behavior, and Limits to Arbitrage

We now empirically investigate the main predictions of the framework of Section 3.2. We first turn to the relation between CB reserves and funding conditions and the implications of our framework for global banks' funding structures. We then investigate the behavior of dealers through the lens of FX swap order flow, before zooming in on the U.S. funding market and constraints for banks in scaling the arbitrage trade. Finally, we show that the exemption of CB reserves from the leverage ratio (LR) across a number of jurisdictions in the aftermath of the COVID-19 crisis led to a reduction in reporting date spikes in CIP deviations, but did not change the level and persistence of arbitrage opportunities outside reporting dates.

### 4.1 Central banks reserves and funding conditions

One key assumption in our framework is that an increase in the supply of CB reserves eases funding conditions in money markets, as suggested by Figure 3,

**Table 4**
**Central bank balance sheets: Impact on LIBOR-OIS spread and LIBOR basis**

| | LIBOR-OIS spread | | LIBOR basis | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| CB balance sheet/GDP$_{t-1}$ | −0.35*** | −0.25*** | 0.15 | 0.20*** |
| | (−5.66) | (−11.54) | (1.50) | (6.77) |
| Constant | 0.28*** | 0.25*** | 0.11** | 0.10*** |
| | (12.34) | (31.09) | (2.93) | (8.59) |
| Fixed effects: | | | | |
| Currency FE | X | | X | |
| Time FE | X | X | X | X |
| Observations | 196 | 196 | 168 | 168 |
| Adj.$R^2$ | .75 | .43 | .82 | .39 |

This table presents panel regression results for the estimation of Equation (5) to analyze the impact of expansions of the central bank balance sheet (relative to GDP, and lagged one quarter) on (a) 3-month LIBOR-OIS spreads and (b) the 3-month cross-currency basis for LIBOR rates (LIBOR basis). The panel data set includes AUD, CHF, JPY, EUR, CAD and JPY, and USD (only in regressions for LIBOR-OIS spreads in columns 1 and 2). Coefficients are expressed in percentage points. $t$-values, clustered along the time-dimension, in parentheses. Data frequency is quarterly. Sample: January 2013 to December 2019. *Source*: Bloomberg. $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

panel B.[38] Our empirical analysis below provides support for this assumption. To analyze the link between central bank balance sheet policies and funding conditions more formally, we run the following panel regression:

$$(LIBOR-OIS)^{3m}_{i,t} = \alpha + \beta \cdot CB^{bal}_{i,t-1} + d_t + d_i + \epsilon_{i,t}. \tag{5}$$

Table 4 shows the results from Equation (5). We find a strong and significantly negative relation between the CB balance sheet ratio (scaled by GDP and lagged by one quarter to avoid potential endogeneity between the CB balance sheet and the LIBOR-OIS spread) and funding spreads. The relation is strong both within currencies (column 1) and across currencies (column 2). Moreover, when we consider CIP-arbitrage opportunities as a dependent variable in columns 3 and 4, represented by the LIBOR basis, we find a positive relation between arbitrage opportunities and the CB balance sheet. The estimates suggest that a one-standard-deviation change in the CB balance sheet (relative to GDP) leads to a 7- to 11-bps lower LIBOR-OIS spread and to about a 7-bps higher LIBOR basis (positive values here mean that the USD LIBOR is lower than the FX swapped LIBOR in the foreign currency).

These results suggest that CB balance-sheet expansions and the associated additional supply of reserve balances tend to ease funding conditions, which—consistent with our framework—also has a bearing on CIP violations. Further results, including on the role of fluctuations in the Treasury General Account (TGA) at the Fed, are reported in Internet Appendix 7 to conserve space, and

[38] Note that unconventional monetary policies, such as asset purchases, go hand in hand with a rise in the availability of CB reserves. For instance, the CB uses reserves to settle asset purchases which in turn increases banks' holdings of CB reserves. Hence, because of the lack of data availability, we use the size of the CB balance sheet as a proxy for the amount of CB reserves available to banks.

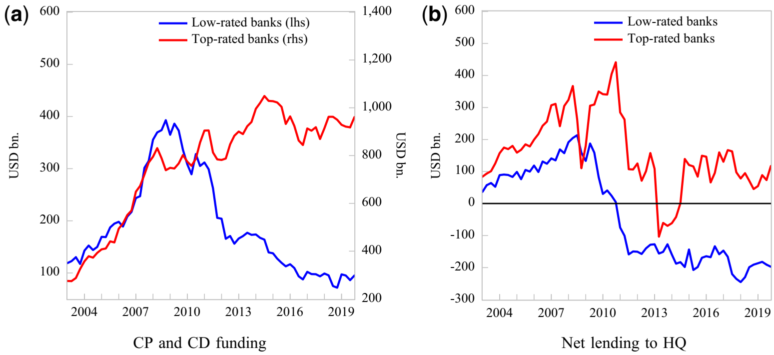


**Figure 6**
**Foreign banks' U.S. operations: Funding and connections to headquarters**
Panel A tracks the evolution of the amounts outstanding of USD, CP, CD, and time deposits by foreign banking organizations operating in the United States. Panel B shows foreign banking organizations' net lending to headquarter. Positive values mean that the U.S.-registered organization provides funding for its headquarters' assets, while negative values mean that the bank's headquarter is funding the U.S.-registered organization's USD assets. In both panels, the banks are split between high-rated (A-1/P-1) and mid-rated (A-2/P-2) banks. The rating categorization is made once for the whole sample and based on the ratings from Moody's and S&P at end of year 2019. Units are in USD billions. Sample: 2003Q1 to 2019Q4. *Source*: FFIEC 002 reports filed to the SEC.

corroborate the importance of the supply of reserve balances for funding costs in unsecured markets.

## 4.2 Implications for banks' funding structures and arbitrage

Our evidence and discussions above suggest that funding conditions are heavily affected by central bank balance sheet policies and that FX swap markets will need to absorb the pressure when funding conditions in major currencies diverge. Such divergence implies that, according to our framework, high-rated banks will primarily seek to obtain funding directly in USD, whereas banks of lower quality will turn to synthetic USD funding (i.e., domestic currency funding coupled with an FX swap).

We provide evidence of such responses in the funding structure by drawing on balance-sheet data for large global banks active in the United States. Panel A of Figure 6 shows that pre-GFC, virtually all foreign banks borrowed a significant amount of USD directly in U.S. money markets. Post-GFC, the direct USD funding has dwindled for mid-rated banks, whereas high-rated banks still retain a strong direct presence. Such funding differences have important implications for internal capital markets within the banking organization, as captured through " net due to headquarters" (see Figure 6, panel B).[39]

[39] Net due to headquarters is measured as the difference between the net due to headquarters on the asset and the liability sides of the balance sheet. A positive number therefore implies that the foreign banking organization is sending money to its headquarters, while a negative number means it is receiving funding for its USD assets from its headquarters.

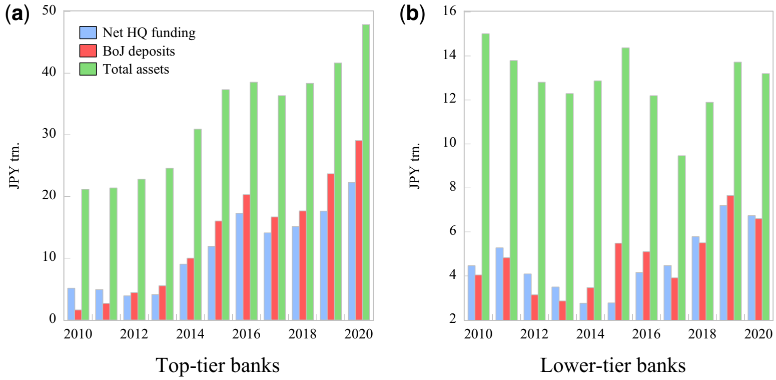


**Figure 7**
**Foreign banks' cash deposits with the Bank of Japan**
This figure shows the assets, measured in trillions of JPY, of global banks' subsidiaries in Japan, for different rating categories. The different bars represent total assets, holdings of cash (held at the Bank of Japan deposit facility), and net funding by headquarters. Top-tier banks (panel A) are rated A-1/P-1 (and include some with A-1+/P-1 rating), and panel B is for lower-tier banks (rating A-2/P-2 and lower). *Source*: KPMG Japan.

While high-rated non-U.S. banks *send* money to their headquarters, lower-tier peers *receive* the funding from their headquarters. Such intragroup net claims on headquarters can be interpreted as a reasonable proxy for FX swap activity. Low-quality banks are now increasingly reliant on non-USD funding swapped into dollars to fund USD-denominated assets. We also find evidence (shown in Figure IA.5 of the Internet Appendix) that large U.S. banks prior to the GFC received large amounts of funding from their foreign branches abroad, but are now sending money from the United States to their foreign affiliates instead. This evidence is an indication of arbitrage activity by large and high-rated U.S. banks. These bank balance-sheet data thus illustrate the incentives for flows running in both directions in line with Figure 5, panel D, of our framework.

The footprint of arbitrage activity by global banks is also visible in the usage of CB deposit facilities. Figure 7 shows JPY cash holdings by foreign banks operating in Japan (green bars), as well as the amounts placed in the deposit facility of the BoJ (red bars). Panel A shows JPY holdings by high-rated banks, while those of all other global banks active in Japan are shown in panel B. Blue bars represent the amount of net headquarter funding from abroad. High-rated banks have indeed substantially bolstered their JPY cash holdings with the BoJ in recent years. They did so primarily by channeling funds from their head offices, thereby exploiting CIP-arbitrage opportunities. The JPY holdings by high-rated foreign banks have increased, especially since the introduction of the QQE (quantitative and qualitative easing) program by the BoJ in April 2013. This evidence is consistent with the prediction of the framework in Section 3.2 that banks with access to cheap funding in USD exploit the cross-currency arbitrage trade.

### 4.3 Dealers' responses to FX swap market imbalances

As outlined in Section 3.1 above, dealers have a primary incentive to set their FX swap quotes so that they face a balanced order flow and hence can control their inventories. Imbalances can arise when lower-quality banks face constraints in raising USD directly and need to turn to the swap market to fill the gap (in line with the previous discussion on Figure 6). Such imbalances will be associated with a positive swap order flow, that is, the flow to obtain USD through the swap's spot leg. Faced with positive order flow, the swap dealer will quote a higher swap rate ($F-S$), thereby implying a steeper curve in Figure 5, to attract a matching flow of the opposite sign (Garman 1976; Stoll 1978). The matching flow will come from the less-constrained banks in the USD market (typically high-rated banks) that are in a position to supply USD to the swap market. Consequently, CIP deviations will increase in response to a positive order-flow imbalance.

To assess this mechanism, we rely on panel regressions of the form

$$\Delta CIP_{i,t}^{dev} = \alpha_i + \gamma \cdot CIP_{i,t-1}^{dev} + D_{i,t} \cdot \beta_{swapOF} OF_{i,t}^{swap} + D_{i,t} \cdot \beta_x X_{i,t} + \varepsilon_{i,t}, \quad (6)$$

where we regress the change in CIP deviations for currency $i$ on a measure of FX swap order flow, $OF_{i,t}^{swap}$, and control variables, $X_{i,t}$. Order flow is standardized, and a positive number represents a flow into USD at the spot leg and into foreign currency at the forward leg (see Internet Appendix 3 for a description of order-flow data).[40] All variables capturing the dynamics are interacted with dummies $D_{i,t}$ indicating whether or not there is an arbitrage opportunity. This interaction allows us to capture whether the variables have a different impact during periods of funding constraints in USD money markets than in normal periods. As an extra control, we use a broad spot FX USD index, as suggested by Avdjiev et al. (2019), where positive changes indicate a USD appreciation.[41]

Table 5 presents results on the impact of order flow on CIP deviations. The latter are computed as 3-month arbitrage profits based on the CP funding costs of mid-tier (A-2/P-2) and high-rated banks (A-1/P-1), with CB deposits as investment vehicles (given less scope for arbitrage using Treasury bills). The coefficient for swap order flow is positive and significant in all regressions. In orderly markets, that is, those with no deviation, only a small quote update of 0.2 bps, for a one-standard-deviation change in flow, is needed to alleviate an imbalance. During periods when A-1/P-1 banks face CIP-arbitrage opportunities, a positive flow imbalance signals to the swap dealer that funding conditions in U.S. money markets are worsening. According to our framework, such situations occur when mid-rated banks turn to the FX swap markets to

[40] The regression also includes the lagged level of CIP deviation to capture the forces pulling any deviations back to zero (akin to an error-correction mechanism).

[41] Results for alternative sets of control variables are summarized in Figure IA.6 in the Internet Appendix.

**Table 5**
**CIP arbitrage and FX swap market order flow imbalances**

| | Mid-rated (A-2/P-2) | | | High-rated (A-1/P-1) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Error correction | −0.03*** | −0.03*** | −0.04*** | −0.02*** | −0.02*** | −0.02*** |
| | (−4.57) | (−4.58) | (−6.11) | (−3.38) | (−3.39) | (−3.83) |
| Swap OF, in arb. | 1.13*** | 1.12*** | | 0.74*** | 0.73*** | |
| | (3.61) | (3.56) | | (3.66) | (3.60) | |
| Pos. Swap OF, in arb. | | | 1.48*** | | | 0.83*** |
| | | | (4.52) | | | (3.41) |
| Neg. Swap OF, in arb. | | | 0.52 | | | 0.59 |
| | | | (0.73) | | – | (1.31) |
| Swap OF, no arb. | 0.19*** | 0.19*** | 0.18*** | 0.20*** | 0.20*** | 0.20*** |
| | (4.44) | (4.43) | (4.39) | (4.89) | (4.91) | (4.91) |
| Dollar index, in arb. | | 0.01** | 0.01** | | 0.01*** | 0.01*** |
| | | (2.60) | (2.63) | | (3.55) | (3.56) |
| Dollar index, no arb. | | 0.01*** | 0.01*** | | 0.00*** | 0.00*** |
| | | (3.49) | (3.49) | | (2.96) | (2.96) |
| Lagged $\Delta CIP$ | −0.20*** | −0.20*** | −0.20*** | −0.02 | −0.02 | −0.02 |
| | (−4.90) | (−4.99) | (−4.98) | (−0.49) | (−0.54) | (−0.57) |
| Obs. | 10,453 | 10,453 | 10,453 | 10,458 | 10,458 | 10,458 |
| Adj.$R^2$ | .08 | .09 | .09 | .04 | .05 | .05 |

This table shows results from panel regressions of changes in 3-month CIP deviations on FX swap order flow, across six different currencies, following Equation (6). CIP deviations are based on an arbitrage strategy funded in the U.S. commercial paper market for either mid-rated (A-2/P-2) or high-rated (A-1/P-1) banks and measured in basis points. The constant (not reported) and error-correction term (lagged level of CIP deviation) have constant coefficients across deviation regimes, while the other explanatory variables are allowed to have different effects, depending on whether or not a profitable CIP arbitrage ("arb") exists as captured through a dummy variable. Swap order flow is standardized by its standard deviation, while the broad dollar index return is measured in basis points. Columns 3 and 6 add a dummy variable to the specification depending on whether or not order flow is positive (into USD at spot leg). Robust $t$-statistics (cross-sectional clustering) are reported in parentheses below the coefficient estimates. Sample: January 2013 to December 2019. *Sources*: Bloomberg, TradeWeb, and TR TickHistory. *$p$ <.1; **$p$ <.05; ***$p$ <.01.

raise USD rather than directly through the U.S. money market (see Section 3.2 ). To cope with an ensuing imbalance, a large adjustment in the quoted FX swap points of 0.73 bps (see columns 4 and 5 in Table 5) is necessary to attract offsetting flows from high-rated banks. By the same token, a positive flow, when also mid-tier banks benefit from deviations, signals even worse USD funding conditions. This situation requires an even greater adjustment in swap quotes by the dealer alleviate the imbalance, as indicated by the 1.1 bps price impact coefficient in columns 1 and 2.

In columns 3 and 6 of Table 5, we find notable differences in the price impact of swap order flow depending on whether it is the USD or the foreign currency that is sought. If funding constraints in USD markets are more severe than in other currencies' markets, one would expect to see a larger coefficient for flows directed into USD (demand pressure to obtain USD), but a smaller coefficient for flows directed out of USD (pressure to obtain foreign currency). The coefficients indicate a strong price impact of 1.5 and 0.8 bps when there is pressure to obtain USD. The impact is insignificant and much lower when it is foreign currency that is sought. These differing impacts corroborate our points

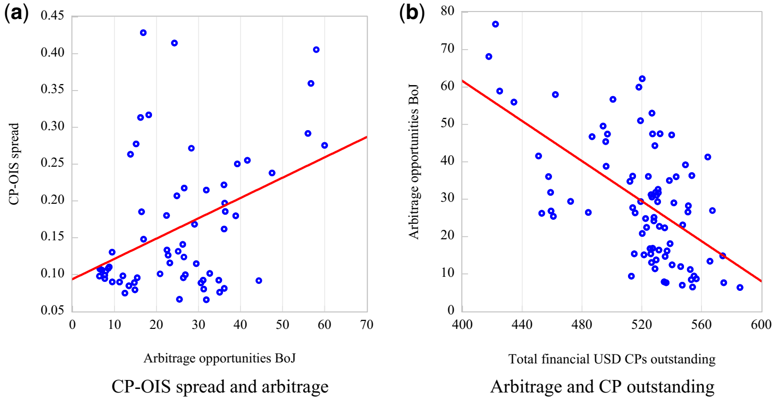


**Figure 8**
**Funding constraints and arbitrage opportunities**
Panel A illustrates the correlation between the 3-month CP-OIS spread for high-rated (A-1/P-1) banks in USD and 3-month CIP arbitrage profits (based on borrowing in the U.S. CP market and investing at the deposit facility of the BoJ). Panel B shows the correlation between 3-month CIP arbitrage profits (based on borrowing in the U.S. CP market and invest in the deposit facility of the BoJ) and total financial CP debt outstanding in USD. Sample: January 2013 to December 2019, monthly frequency. *Sources*: Bloomberg and Investment Company Institute.

in Section 3.1 about the special role of funding constraints in the USD for the pricing in the FX swap market.[42]

## 4.4 Funding constraints and limits to scalability

Our previous results in Section 2 suggest that the burden to arbitrage CIP deviations falls on a limited set of high-rated banks. Below, we will present results suggesting that USD funding constraints (i.e., an upward-sloping supply curve in U.S. money markets) are an important factor in preventing these banks from deploying more capital to the arbitrage.

Figure 8 suggests that funding constraints in USD and CIP-arbitrage opportunities for high-rated banks are indeed positively correlated. Higher CP-OIS spreads typically correlate with larger arbitrage opportunities. In addition, consistent with the funding constraint hypothesis, the outstanding volume of CPs issued by banks tends to fall, not rise, when CIP-arbitrage opportunities are high. As a result, consistent with our framework, when arbitrage opportunities are greatest, short-term funding in USD is particularly difficult to obtain.

To shed further light on the constraints banks are facing in U.S. funding markets, we now analyze individual banks' issuances of certificates of deposit (CD) in USD based on a granular data set. Descriptive statistics on CD issuance

42 Additional results on the impact of order-flow imbalances across different maturities (Figure IA.7), and that the impact increases over regulatory reporting days (Table IA.V), are reported in the Internet Appendix.

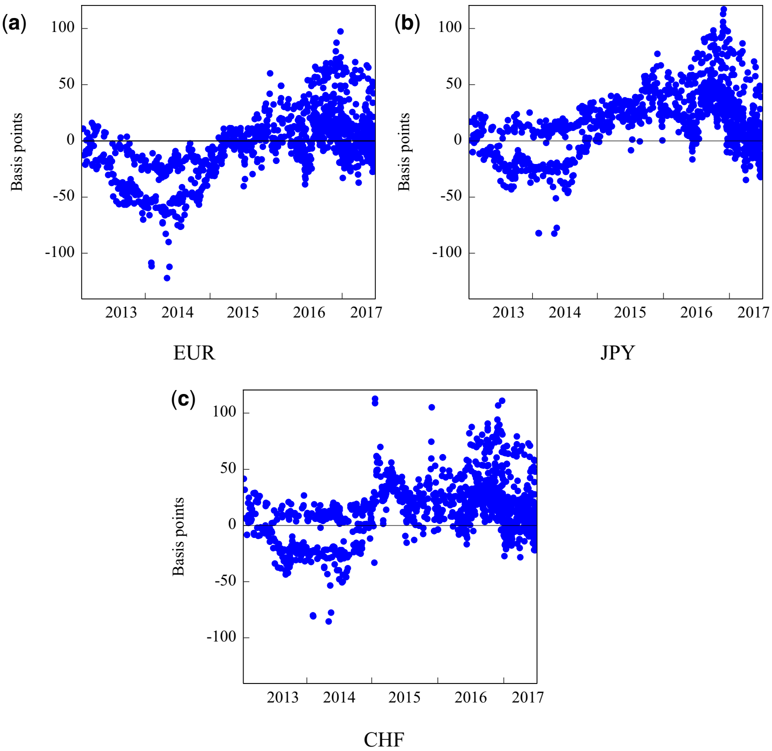


**Figure 9**
**Dispersion in CIP arbitrage opportunities (funded via CD issuance) across high-rated banks**
This figure shows the dispersion in 3-month CIP arbitrage opportunities across high-rated (A-1/P-1) banks, given their funding costs in USD CD markets. Each dot represents one CD issuance. The hypothetical profits are computed for placement at central bank deposit facilities at the investment leg. Positive numbers indicate positive arbitrage profits. Panels A–C show CIP arbitrage opportunities when swapping to EUR, JPY, and CHF, respectively. Sample: January 2013 to June 2017. *Source*: Bloomberg.

volumes are presented in Table IA.VI in the Internet Appendix, and further data-specific details are given in the Internet Appendix 3.

Drawing on the CD transactions of individual banks with access to this funding market, Figure 9 depicts the corresponding profits from CIP-arbitrage trades. An important initial takeaway is the large heterogeneity across banks: even within the set of high-rated (A-1/P-1) banks that does have access to USD CD markets, many do not enjoy economically attractive arbitrage opportunities because of their elevated funding costs.[43]

To better understand the scalability of CIP arbitrage by global banks, we analyze next whether the USD funding spread (CD rate minus the OIS rate)

[43] Also note that CIP-arbitrage profits appear slightly lower when we use volume-weighted averages of CD rates compared with baseline results using CP rates (see Figure IA.8 in the Internet Appendix).

increases as individual banks seek to place higher CD issuance volumes. Further, we assess how MMFs' exposure to the issuer, and more generally the outstanding level of short-term CD debt, affect funding spreads and how these effects vary with the level of arbitrage opportunities. We rely on panel regressions of the following form:

$$r^{CD}_{i,t,m} - r^{OIS}_{t,m} = \beta_1 \cdot CDIssued_{i,t,m} + \beta_2 \cdot CDIssued_{i,t,m} \cdot d^{Arb}_t + \gamma_1 \cdot X_{i,t,m} + \gamma_2 \cdot X_{i,t,m} \cdot d^{Arb}_t + FE_{i,t,m} + \varepsilon_{i,t,m}, \quad (7)$$

where $r^{CD}_{i,t,m} - r^{OIS}_{t,m}$ is the CD-OIS spread for bank $i$ at time $t$ with maturity $m$, $CDIssued_{i,t,m}$ is the issued amount, and $FE_{i,t,m}$ captures alternative fixed-effect specifications. The standard errors are clustered at the bank and time levels.[44] Other specifications differ by the inclusion of various control variables $X_{i,t,m}$, in particular CD outstanding and the share held by MMFs, also interacted with a dummy for positive arbitrage opportunities ($d^{Arb}_t$).

Distinguishing between supply and demand is always a challenging task. Our approach seeks to identify the slope of the supply curve based on shifts in individual bank demand. To do so, we first control for day fixed effects to exclude aggregate demand and supply effects. This exclusion takes out the average CD-OIS spread each day such that we are left with the daily variation across transactions around the mean spread.[45] Furthermore, we condition the sample on banks with top ratings (A-1/P-1), and then control for unobservable bank characteristics that may affect supply and demand across issuers differently by adding bank fixed effects. Even with this specification, there may be a chance that these unobservable bank characteristics change over the sample and hence that the issuer faces a time-varying individual supply curve that we have not controlled for. To mitigate this issue, in the spirit of Khwaja and Mian (2008) we interact the bank fixed effect with either month or week fixed effects where the data allow us to do so. In these specifications, we compare a specific issuer's transactions within the month/week after controlling for the daily mean price.

Table 6 reports the results. We find that a US$100 million increase in CD issuance volume corresponds to a 0.6- to 0.8-bp increase in funding costs.[46] One central reason behind the "upward-sloping" USD supply curve is that the marginal investors in unsecured short-term bank liabilities, that is, U.S. MMFs, care about concentration risk. For instance, if a high-rated bank increases issuance of short-term debt, typical investors may not be able to meet this

44 In our regression analysis, we exclude issuances below US$10 million to make sure that very small issuances, in particular those issued by small U.S. banks, do not contaminate our results.

45 Aggregate demand or supply shocks that may move the mean price will hence not affect our results.

46 Table IA.VI in the Internet Appendix shows that US$100 million is smaller than the average size of a CD issuance in the primary market. The largest issuances have exceeded US$4 billion.

**Table 6**
**CD issuances and USD funding costs**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Issued amount | 0.61*** | 0.60*** | 0.78*** | 0.27 | −1.02** | −1.35*** |
| | (2.72) | (3.02) | (4.12) | (1.26) | (−2.70) | (−3.62) |
| MMF share | | | | −2.86*** | −4.07*** | −4.40*** |
| | | | | (−7.33) | (−4.26) | (−6.83) |
| (MMF share)$^2$ | | | | 35.55*** | 19.53** | 20.16** |
| | | | | (5.04) | (2.41) | (2.52) |
| CD outstanding | | | | −0.03 | −0.05 | −0.07* |
| | | | | (−1.32) | (−1.30) | (−1.98) |
| Issued amount × Arb | | | | | 0.04*** | 0.05*** |
| | | | | | (3.54) | (3.66) |
| MMF share × Arb | | | | | 0.04** | 0.06*** |
| | | | | | (2.61) | (3.97) |
| CD outstanding × Arb | | | | | 0.002** | 0.001 |
| | | | | | (2.48) | (1.05) |
| Constant | 0.36*** | 0.37*** | 0.38*** | 0.48*** | 0.45*** | 0.46*** |
| | (125.24) | (140.25) | (160.99) | (27.18) | (13.26) | (25.51) |
| $Day \times Maturity$ FE | X | X | X | X | X | X |
| $Week \times Bank$ FE | | | X | | | |
| $Month \times Bank$ FE | | X | | | | |
| $Bank$ FE | X | | | | X | |
| Observations | 6,348 | 5,717 | 4,020 | 4,973 | 4,881 | 4,888 |
| Adj.$R^2$ | .62 | .73 | .84 | .60 | .61 | .53 |

This table presents panel regressions for the impact of CD issuance volume on the CD-OIS spread, following Equation (7). Maturities included are 1, 3, and 6 months. All issuances considered are larger than US$10 million. Coefficients measure impact in basis points for a US$100 million issue and 100 million CD outstanding. The Arb variable captures the level of arbitrage based on high-rated banks CP rate in USD swapped into JPY and invested at BoJ deposit facility rate. Arb is measured in basis points, and the average value is 25 bps. The average MMF share is 3.65%, the average issued amount is US$138 million, while the average CD outstanding is US$4,470 million. t-values, based on standard errors clustered at the bank and time level, in parentheses, singleton observations removed iteratively. Sample: January 2013 to June 2017. *Sources*: Bloomberg and Crane Data. *$p$ <.1; **$p$ <.05; ***$p$ <.01.

demand due to limits on how much they can be exposed to a specific bank. Such concentration risk is a concern even when the bank issuing the debt has a high credit rating.

To dig deeper, in column 4, we add two explanatory variables: The issuer's outstanding amount of CDs prior to the issuance, and the average CD exposure across all MMFs to the issuer. We define the exposure measure as a specific MMF's holdings of CP/CD by a specific issuer, divided by the same MMF's total CP/CD holdings across all issuers, and then compute the average exposure over all MMFs for each issuer. Since the MMF data are available only on a monthly basis, we assign each CD issuance with the latest month-end exposure. As explained in Section 3.1, MMFs have strict concentration limits (max. 5% of total assets in any A-1/P-1-rated issuer) imposed by regulators.[47] The effect of a high concentration in holdings from the most important investor group is likely to be nonlinear, with a larger effect on the CD-OIS spread the higher the

47 Note that our exposure measure is not fully comparable to the regulatory measure, because we divide by total CP/CD holdings instead of by total assets.

average exposure becomes. To capture this, we include a squared term of the exposure variable. In column 5, we interact our three explanatory variables with a variable capturing the arbitrage profit from borrowing in the U.S. CP market (for high-rated banks) and placing the funds at the BoJ's deposit facility.

To understand the results in column 4, the coefficients for the exposure measure (MMF share) and the squared exposure ($MMFshare^2$) must be investigated together. The former coefficient is negative, while the latter is positive, meaning that a greater MMF exposure gives rise to lower funding spreads, but the effect decreases as MMF exposure becomes larger. At some point, the impact of MMF exposure on funding spreads becomes zero. This turning point, that is, when the total impact is zero, is reached when the MMF exposure to the issuer approaches 4% from below. When moving to column 5, we see that the coefficient for the interaction with the level of arbitrage (in basis points) is positive and significant for the exposure measure. That is, the higher the arbitrage opportunities, the lower this turning point becomes. This is consistent with the notion that periods with more pronounced arbitrage opportunities are associated with general funding constraints for banks, for instance, as MMFs reallocate their holdings toward government securities. High dependence on USD funding from MMFs thus eventually becomes a drag on funding costs. Moreover, we see that the coefficient for the issued amount becomes negative and significant in this specification, while the coefficient for the interaction with the arbitrage variable is positive. These results imply that a higher issued amount leads to lower funding spreads when the level of CIP arbitrage opportunities is below its sample average (i.e., $<$ 25 bps), but leads to an increase in funding costs in episodes of elevated arbitrage opportunities.

These findings are consistent with the observation that CIP-arbitrage opportunities and funding constraints in USD are two sides of the same coin. They also illustrate a trade-off between taking advantage of low funding costs in normal times (i.e., by having good funding relationships with MMFs), and the cost and availability of raising *additional* funding in stressed periods (i.e., when CIP arbitrage opportunities edge up). These results hold also without bank fixed effects, that is, across issuers, as well, as depicted in column 6.

### 4.5 Exemptions of reserves from the leverage ratio and the cross-currency basis

It is well-known that the pricing in short-term funding markets, including FX swaps, reacts strongly to reporting dates. The price reaction around reporting dates is connected to the quarterly snapshots of a large share of international banks that have to disclose for the purposes of LR regulation.

Amid the market turmoil of the COVID-19 crisis, and effective from the second quarter of 2020 onward, regulators across a range of jurisdictions decided to exempt CB reserves and/or Treasury securities from the exposure measure in the calculation of the LR.[48] Because the investment leg of the CIP arbitrage trade involves CB reserves and because such a large share of international banks was affected by the change, this exemption provides a natural setting to study the effects on banks' incentives to take advantage of the CIP arbitrage.

To study those effects, we treat the exemption of CB reserves as an exogenous event and compare the levels of CIP-arbitrage opportunities in short-term contracts (1-week) within a simple difference-in-differences framework:

$$Arb_{i,t} = \beta_1 \cdot d_t^{EoQ} + \gamma_1 \cdot d_t^{PostSLR} + \gamma_2 \cdot d_t^{EoQ} \cdot d_t^{PostSLR} + FE_{i,t} + \varepsilon_{i,t}, \qquad (8)$$

where $Arb_{i,t}$ is the 1-week arbitrage opportunities calculated based on the CP borrowing cost for high-rated (A-1/P-1) banks and invested at the CB deposit facility in currency $i$ after hedging the currency risk. Dummy $d^{EoQ}$ captures dates when the 1-week FX swap contract crosses quarter end, $d^{PostSLR}$ is a dummy for the period after CB reserves were exempted from the LR calculation, and $FE_{i,t}$ represents different fixed-effect specifications.[49] We also estimate versions of Equation (8) with dummies that compare jurisdictions that did, and did not, exempt reserves from the LR calculation, and those that prior to the COVID-19 crisis did not have QE programs. All coefficients refer to the impact on the 1-week arbitrage opportunities in basis points.

Columns 1 and 2 in Table 7 report the results. In these specifications, we include only CAD, CHF, and JPY, that is, currencies where CB reserves were exempted in Q2 2020. In column 2, we keep the same three currencies but exclude the month of December because the GSIB surcharge was kept unchanged, and hence there are reasons to believe that the year-end turn would remain a pressure point due to the impact of leverage and cross-jurisdictional claims on the GSIB score.

Table 7 shows, after excluding March and Q2 2020 from the sample due to the potential impact of the financial turmoil in this period, that the exemption did not lead CIP-arbitrage opportunities to shrink outside quarter-end periods (illustrated by the estimated coefficient for the $PostSLR$ dummy). In contrast, the arbitrage opportunities actually increased. However, as the interaction effect illustrates, CIP-arbitrage opportunities have become substantially more muted during end-of-quarter periods after CB reserves were exempted from the LR. The fall in end-of-quarter spikes is more pronounced, and estimated more precisely, when removing the year-end turn. The GSIB surcharge still acted as

48 Jurisdictions that excluded CB reserves from the LR include Canada, the euro area, Japan, Switzerland, and the United States (from September 2020). In the United Kingdom, CB reserves already had been exempted from the LR calculation since June 2017.

49 Most jurisdictions that decided on an exemption made the announcement in Q2 2020. The euro area, which was an exception, is either excluded from the sample altogether or included in separate specifications. Because of different announcement dates, we simply remove Q2 2020 and March 2020 from the sample and let the $d^{PostSLR}$ take the value of one after July 1, 2020, and zero before March 1, 2020, to avoid the main financial turmoil during the height of the COVID-19 crisis.

**Table 7**
**CIP arbitrage and the exemption of reserves from the leverage ratio**

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Constant | 10.19*** | 10.62*** | 2.18*** | 2.63*** | 1.36*** |
| | (15.21) | (15.46) | (4.56) | (5.36) | (16.19) |
| $d^{EoQ}$ | 71.43*** | 56.23*** | 54.13*** | 40.52*** | |
| | (7.51) | (8.32) | (6.82) | (7.27) | |
| $d^{PostSLR}$ | 6.04*** | 5.08*** | 11.56*** | 9.96*** | |
| | (6.31) | (5.64) | (12.73) | (14.23) | |
| $d^{EoQ}$ | −25.22 | −39.47*** | −1.86 | −28.52*** | |
| $\times d^{PostSLR}$ | (−1.28) | (−5.68) | (−0.08) | (−5.02) | |
| $d^{NewQE}$ | | | | | 45.43*** |
| $\times d^{PostSLR}$ | | | | | (38.40) |
| Currency FE | X | X | X | X | X |
| Time FE | | | | | X |
| Observations | 2,092 | 1,917 | 4,184 | 3,825 | 3,872 |
| Adj.$R^2$ | .40 | .43 | .50 | .59 | .76 |

The Table presents the results from difference-in-differences regressions, following Equation (8), to tease out the effect of exempting central bank reserves from the leverage ratio exposure measure on the level of 1-week CIP arbitrage opportunities. In columns 1 and 2, the sample currencies are CHF, JPY and CAD (all against USD) as the respective jurisdictions exempted central bank reserves from the second quarter reporting in 2020. The difference between the two columns is that the second one excludes all year-end turns. Dummy $d^{EoQ}$ takes the value of one when the 1-week FX swap contract crosses quarter end and zero otherwise. Dummy $d^{PostSLR}$ takes the value of one after central bank reserves were exempted from the leverage ratio from July 1, 2020. The dummy takes a value of zero prior to March 1, 2020. We exclude Q2 2020 and March 2020 from the sample to ensure that the financial turmoil in this period does not affect our results. In column 3, we extend our sample to all our currencies (AUD, CAD, CHF, EUR, GBP, and JPY) independent of the jurisdiction exempted central bank reserves from leverage ratio. In column 4, all year-end turns are excluded from the sample. In column 5, $d^{NewQE}$ takes the value of one for AUD and CAD as these two currencies embarked on QE for the first time after COVID-19, and zero for the other currencies (CHF, GBP, JPY, EUR). t-values, based on standard errors clustered at the time level, in parentheses. Data are on daily frequency. Sample: January 2018 to December 2020. $^{*}p$ <.1; $^{**}p$ <.05; $^{***}p$ <.01.

a major constraint in preventing banks from arbitraging CIP deviations around year-end. As such, the impact of the exemption becomes clearer when year-end is not included in the analysis.

Columns 3 and 4 are identical to columns 1 and 2, respectively, except that in the former two columns we expand the number of currencies to all our six currencies independently of the jurisdiction exempted central bank reserves from the LR. The results illustrate that the pattern revealed in columns 1 and 2 holds after extending the number of currencies. Not surprisingly, the end-of-quarter effects are substantially larger for the jurisdictions that exempted central bank reserves, as illustrated by a much smaller interaction effect in column 4.

It is particularly interesting to also zoom in on two currency areas, AUD (no exemption) and CAD (exemption), where the respective CBs for the first time embarked on large-scale asset purchases at the same time as reserves became exempted from the LR in many jurisdictions. As we argued above, the increase in the supply of reserve balances due to asset purchases is a primary factor in influencing funding conditions and FX swap market outcomes. Hence, we treat these two currencies separately ($d^{NewQE}$ takes the value of one if the currency is AUD or CAD, and takes the value of zero otherwise) in column 5 and basically replace $d^{EoQ}$ with $d^{NewQE}$ in Equation (8). Interestingly, we find a large and positive effect for these two currencies, in the sense that CIP-arbitrage opportunities have increased by almost 45 bps. The situation for both currencies has thus shifted from a situation where CIP-arbitrage opportunities used to be largely absent to a situation with arbitrage opportunities for high-rated banks (borrowing directly in USD, swapping into AUD or CAD, and placing the funds at the respective CB deposit facility).

The results presented in Table 7 strengthen the case that the LR is undoubtedly an important factor constraining arbitrage, in particular at quarter ends. That said, regulation does not seem to be the only constraint preventing banks from arbitraging the cross-currency basis, because we see no change for arbitrage opportunities in-between quarter ends. Moreover, broadly in line with our framework, FX swap pricing has dramatically changed for AUD and CAD once the respective CBs for the first time engaged in large-scale balance-sheet expansion. Indeed, following the introduction of QE programs, both currencies have shifted from a situation with no arbitrage to one with positive CIP-arbitrage opportunities, in line with the framework of Section 3.

## 5. Conclusion

Common measures suggest that CIP, the most basic no-arbitrage condition in international finance, is broken. We argue that a new perspective is needed to understand the CIP conundrum. In the postcrisis environment, characterized by fragmented USD funding markets and a substantial heterogeneity in funding costs (both across banks and across currency areas), it is no longer possible for the law of one price to hold for the full spectrum of interest rates simultaneously.

Our main contribution is to provide a thorough treatment of the real-world frictions giving rise to FX swap market dislocations and the constraints hampering arbitrage. The main angle is how the incentives of the main players in international money markets and FX swap markets are crucially shaped by their funding costs. We present evidence that the law of one price holds remarkably well for the majority of market participants, but that economically attractive CIP arbitrage opportunities do exist for a limited set of high-rated global banks. The key reason CIP arbitrage for these top-tier banks is profitable is their favorable access to USD commercial paper and certificates of deposit markets where banks can raise funding from nonbank institutional investors at the lowest cost. Moreover, through their global operations, these banks have access to safe investment vehicles in foreign currency, particularly central bank deposit facilities.

These findings raise the fundamental question of how a situation with riskless arbitrage profits, even only for a limited set of banks, can persist over a prolonged period. We illustrate how such arbitrage opportunities emerge in a world with large heterogeneity in bank quality and large surplus of central bank reserves in the most prominent currencies across the globe. Non-U.S. banks with lower ratings face difficulties to raise large quantities of USD directly in the U.S. money market and resort to easily accessible funding in their local currency brought into USD via the FX swap market. This creates a large demand pressure to obtain U.S. dollars through the FX swap market. Dealers in turn need to adjust the price to avert imbalances, in turn resulting in arbitrage opportunities for the banks that can raise USD cheaply directly in the U.S. money market.

Such arbitrage opportunities for a few high-rated banks can persist because the arbitrage positions are difficult to scale. Drawing on issuance data for USD certificates of deposits, we show that funding rates adjust as soon as arbitrageurs increase their positions, in turn significantly reducing profits. All in all, the evidence presented in this paper suggests that the main paradigm of CIP, that is, the nonexistence of riskless arbitrage profits after accounting for the risks and relevant costs incurred by the arbitrageur, still remains largely valid in postcrisis financial markets, at least for the majority of market participants.

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