Collateral-adjusted CIP Arbitrages*

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Abstract

I show that a no-arbitrage consistent but costly collateral rental yield explains about two-thirds of the apparent standard Covered Interest Rate (CIP) violations. I proxy this yield with the difference between the risk-free and overnight index swap rates between the cross bilateral currencies and apply it to both short and long-term CIP violations. Further, the results suggest an important direct collateral channel through which costly collateralization explains CIP violations, independent of previously documented global risks and intermediary frictions.

JEL classification: C33, C4, F31, G1, E4, F31.

Keywords: CIP Violation, Collateral, FVA, Funding Rates, MtM (Mark-to-Market), No-Arbitrage.

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1 Introduction

Since the global financial crisis (GFC) in 2008, funding rates for derivative transactions have differed from those of cash markets, resulting in persistent cash-derivative bases that present arbitrage opportunities. A notable arbitrage is the violation of the covered interest rate parity (CIP), empirically measured by the bases on currency swaps performed using FX forwards (short-term) and cross-currency (xccy) swaps (long-term). These are referred to as the "xccy basis" (Du, Tepper, and Verdelhan, 2018). A currency swap is when two parties exchange loans of equal value but in different currencies.

After the GFC, a negative basis arose for lending US dollars against many G-7 currencies (see Figure 1). Thus, borrowing US dollars directly through the cash market became cheaper than through the currency swaps market, a surprising discrepancy for such a massive market. During the first half of 2019, the total outstanding national amount of currency swaps was \$98 trillion, with an average daily turnover of \$3.3 trillion (BIS, 2019). Further, the soundness of the no-arbitrage CIP condition holds economic importance globally, especially for market efficiency and international capital and trade flows.

Important literature about CIP establishes that there are CIP violations attributed to global risk factors and limits to arbitrage mainly due to intermediaries' frictions. These range from balance sheet constraints, regulation costs, funding costs, counterparty risk, finite capital, to FX hedging demand and market segmentation (summarized in Du and Schregner, 2021).

In this study, I reflect on what is a fair risk-free CIP violation after incorporating necessary collateralization features that remove counterparty risk in the over-the-counter (OTC) derivative markets. Thus, I depart from prior work that uses limits to arbitrage frictions and instead focus on no-arbitrage consistent collateral features to rationalize the apparent standard CIP violations.

The contributions are threefold. First, I propose and provide evidence that accounting for no-arbitrage-consistent but costly collateral wedges, which are institutional features of currency derivative contracts, may help resolve a big part of the apparent standard CIP violations across the maturity horizons. Collateral in currency swaps is time-varying due a mark-to-market (MtM) feature and arises mainly because of three institutional features: the collateral (1) is posted daily to cover the MtM of the currency swap, (2) is required to be posted predominantly in cash in US dollar, and, crucially, (3) is compensated at a non-market collateral rate that is different from the risk-free rate of return usually compensated for cash. Second, these wedges must be accounted for when pricing currency swaps and, therefore, when measuring CIP violations. I do this by quantifying and summarizing these wedges in a single metric called *collateral rental yield* using no-arbitrage. When calculating CIP violations, this yield should simply be deducted from the xccy basis.

Third, the results not only suggest that the apparent CIP violations reflect costly collateralization in the FX derivative contracts, but also point to an important direct collateral channel through which this costly collateralization contributes to the apparent CIP violations, which is independent of global risk factors and intermediary frictions documented in the literature thus far. However, the evidence also suggests that collateral is not frictionless because it is affected separately by intermediary frictions such as those imposed by quarter- and year-end, capital, and leverage regulations. In this study's no-arbitrage framework, frictionless collateral is rationalized because demand or supply for safe collateral assets, as well as frictions, could affect the proxies and modeling of the risk-free rate that comprises the collateral rental yield. Furthermore, the collateral's opportunity cost may deter intermediaries with high regulatory constraints and targets from expanding their balance sheets with currency derivatives.

Otherwise, according to the framework, it is also hypothetically possible for the collateral to be frictionless; however, this occurs only if such intermediary frictions do not affect the common risk-free rate (the rates proxying it) and if there is no residual counterparty credit risk in the derivatives traded. The results, however, indicate that this is not the case and that the collateral is not completely frictionless. Furthermore, the results indicate that some residual counterparty credit and funding risks are priced into the aggregate FX derivative prices. This is evidenced by the relevant Libor-OIS spreads contributing to the

CIP violation over and above the collateral costs. Such a result is expected because, while the currency derivatives market is largely collateralized, it is not entirely collateralized.

Considering the collateral features of currency swaps is necessary for two reasons. First, since the GFC, the use of collateral agreements has gradually become substantial. For instance, according to the ISDA Margin Survey (2014), 91% all OTC derivative trades (cleared and non-cleared) were subject to collateral agreements at the end of 2013, compared with 30% in 2003. In the FX derivatives market, bulk of the transactions beyond 1-week tenor are collateralized. Collateral mitigates the credit risk but also introduces additional collateral cash-flows and costs that cannot be ignored when performing CIP via currency swaps.

Second, trading a currency swap entails intense counterparty credit exposure, which comes with a great need for collateral posting. This is a consequence of the MtM feature since it is sensitive to not only interest rate fluctuations but also non-trivial FX rate fluctuations. FX rate fluctuations tend to be large in magnitude and more volatile, as well as affect currency swaps through the exchange of principal amounts in different bilateral currencies at maturity. Therefore, the collateral costs associated with currency swaps are much larger compared with, for instance, mere interest rate swaps.

In this paper, I introduce a collateral rental yield as an empirical measure of collateralization costs. I proxy it with the difference between the risk-free rate and OIS rate[1] between bilateral currencies in the currency swap contract. To maintain simplicity, I design the collateral rental yield in a risk-neutral way; hence, it features a hypothetical risk-free rate that is unique and prevailing in the market. In practice, however, there is substantial debate about the right single risk-free rate, and each has pros and cons.

I do not attempt to settle this debate; rather, I consider three proxies for a risk-free rate: the general collateral (GC) repo, BOX, and T-bill rates. GCs exhibit volatility due

[1] An OIS is an interest rate swap wherein the overnight rate is exchanged for a fixed interest rate. The OIS uses an overnight rate index—such as the FedFunds rate for the US dollar, Eonia rate for EUR, or Sonia rate for GBP—as the underlying rate for the floating leg, whereas the fixed leg is set at a rate agreed on by both counterparties/market for the tenor.

to the conditions in collateral markets and dealer balance sheet management.[2] The three-month T-bill rate often reflects default risk as well as convenience premiums.[3] The BOX rate from van Binsbergen, Diamond, and Grotteria (2019) is available only in US dollars. This is a risk-free rate implied by equity put-call parity prices. It purposefully excludes convenience premiums but can potentially be subject to idiosyncrasies of the underlying derivative instruments.

Nevertheless, all three proxies lead to similar results–the collateral rental yield explains a significantly large portion (about two-thirds on average) of the apparent standard CIP violations across maturity horizons. This is because my key purpose is to account for the sizable spread between the risk-free rate and collateral rate. Moreover, the results hold throughout the COVID-19 crisis (up to May 2020) as well as the tranquil period before it but after the GFC, but not during the GFC. It is noticeable that the collateral rental yield is far more relevant in the sample covering the period outside the GFC, which is consistent with collateralization becoming gradually more prevalent in the derivatives' market only in the aftermath of the GFC.

In practice, accounting for collateral costs in derivatives is linked to controversial cross-value adjustment metrics. Banks introduced these metrics after the GFC as part of their derivative management paradigm shift from hedging to balance sheet optimization. One metric is the funding value adjustment (FVA) discussed by Fleckenstein and Longstaff (2020) and Anderson, Duffie, and Song (2019). In general, FVA refers to an adjustment incorporated into the market price of a derivative to compensate the dealer for the cost of funding cash flows, including collateralization, throughout the life of the asset. The FVA has now become a standard in the industry. Due to widespread collateralization, the current main source of funding cost for the banks is dominated by the cost and benefit of the collateral (Ruiz, 2015).

Overall, the results point to an important direct collateral channel through which col-

[2] A recent example is the December 2018 spike, which occurred because of a glut in the Treasury markets interacting with the year-end window-dressing of banks (Schrimpf and Sushko, 2019).

[3] For example, Krishnamurthy and Vissing-Jorgensen (2012).

lateral contributes to explaining apparent CIP violations that is independent of some previously documented intermediary frictions and regulations. This helps reconcile with the existing explanations in the CIP literature. It also shows that the xccy bases are not arbitrarily determined, as may be the case given all plausible constraints. From a microeconomic point of view, they are fairly priced, reflecting the collateral costs in the context of the collateral-adjusted CIP, or the limits-to-arbitrage from the perspectives of those in favor of the constraints. From a macroeconomic point of view, the collateral costs in the currency derivatives market, which is one of the largest markets globally, are welfare deadweight losses giving rise to CIP violations. These violations, in turn, create distortions in the US dollar investment, funding, and hedging decisions of both financial and trade parties globally. Additionally, because the collateral costs are common among many derivative instruments, the commonality may extend to other asset class cash-derivative bases, which is a topic left for further research.

2 Related Literature

This study contributes and is related to three streams of literature. The first is the CIP violation conundrum, which triggered a wave of empirical studies in an effort to explain xccy bases and their determinants. During both the GFC and the European sovereign debt crisis, a common narrative emerged of foreign (mostly European) banks facing difficulties in borrowing dollar in short-term money markets and turning to FX swaps to cover for the dollar shortfall, as in Baba and Packer (2009a). Much of this early research explains the negative xccy basis as a temporary side effect of financial uncertainty and credit risk, while still connecting it to credit spreads (Baba and Packer 2009a, 2009b; Genberg, Hui, Wong, and Chung, 2008). Later studies pointed to funding liquidity issues and capital constraints (Genburg, Hui, and Chung, 2011; Coffey, Hrung, and Sarkar, 2009). Mancini-Griffoli and Ranaldo (2011) and Ivashina, Scharfstein, and Stein (2015) emphasize the effect of pullbacks in bank lending.

Starting in 2014, the basis grew tremendously even as financial markets enjoyed a period of relative calm and stability. Thus, initial explanations such as counterparty credit risk or temporary money market turbulence appeared less likely and credit risk-free arbitrage opportunities were identified in a seminal paper by Du, Tepper, and Verdelhan (2018). A second wave of studies emerged to re-evaluate the deviations from the CIP and offer new explanations, the predominant being balance sheet constraints.

Some sources attribute violations to diverging macroeconomic factors. Iida and Sudo (2018) and Du, Tepper, and Verdelhan (2018) link shifts in the level of CIP to diverging central bank policy. Sushko, Borio, McCauley, and McGuire (2016) identify shifts in the basis from imbalances in FX hedging demand. Few recent studies have pointed to differences in funding liquidity risks across currencies as the source for the basis (Rime, Schrimpf, and Syrstad, 2017; Wong and Zhang, 2018; Kuhler and Muller, 2019). This study differs by documenting that these macro factors play a role in the violations through the channel of the cost of US dollar collateral, especially during US dollar appreciation.

The second stream of literature investigates balance sheet constraints and the limits of funding supply arising from financial regulation. New non-risk weighted asset requirements, such as the LCR ratio or global systemically important bank (GSIB) score calculations, make balance-sheet intensive activities such as FX swaps more costly. Correa, Du, and Liao (2020) and Du, Tepper, and Verdelhan (2018) support this claim by documenting the strong premia for FX swaps present on end-of-quarter reporting dates. Cenedese, Corte, and Wang (2020) use transaction-level data to connect heterogeneity in dealer bank leverage ratio and xccy bases, whereas Avdjiev, Du, Koch, and Shin (2019) show that leverage constraint frictions driven by the strength of the dollar drive xccy bases. Augustin, Chernov, Schmid, and Song (2020) further document the role of financial intermediaries in the violation of the no-arbitrage conditions across term structures. This study takes a different approach by documenting that the CIP violations reflect institutional details of collateralization in the derivative contracts via a direct collateral channel that is independent of the previously documented intermediary frictions.

Ultimately, the studies so far do not offer conclusive explanations for both the emergence and persistence of the xccy basis. To reconcile these divergent explanations, the key to this pursuit is collateralization in derivatives, which has become central for pricing financial instruments post-GFC and is the third line of related literature. The first pricing effect of collateralization is to reduce counterparty credit risk (Brigo, Capponi, and Pallavicini, 2014; Fujii and Takahashi, 2012). The second pricing effect is to introduce additional stochastic collateral cash flows and costs, which can affect prices, as documented in the interest rate swap market (Johannes and Sundaresan, 2007) or index option markets (Leippold and Su, 2015). Moreover, collateralization can introduce complications due to imbedded "cheapest-to-deliver options" or netting (Fujii, 2010; Fujii and Takahashi, 2013).

The effects of collateralization lie within the growing family of cross value adjustments (xVAs), a set of new financial intermediaries' pricing considerations resulting from increased perception of counterparty risk management (and the credit risk, financial regulation, and collateralization that followed) since the GFC.[4] In recent years, more literature has sprung up regarding the legitimacy and proper definitions and derivations of various xVAs (see: Hull and White, 2012; Albanese, Caenazzo, and Crépey, 2017; Albanese and Crépey, 2017; Albanese, Andersen, and Iabichino, 2015; Ruiz, 2015; Albanese and Andersen, 2014).

In particular, FVA broadly incorporates collateralization. Recent research emphasizes FVA as a debt overhang problem, wherein profitability must exceed the firm's credit spread for shareholders to benefit from a particular trade, which has been proposed as an explanation for the CIP basis (Andersen, Duffie, Song, 2019; Fleckeinstein and Longstaff, 2019; Albanese, Chataigner, and Crepey, 2020). This study attempts to answer both unsolved questions regarding CIP, as well as further develop evidence on the effects of post-GFC collateral value adjustments.

[4] Examples of XVAs include: (1) provisions for the credit or debt valuation adjustment (CVA), an adjustment subtracted from the mark-to-market (MtM) of a derivative position to account for the potential loss due to counterparty default, DVA, an adjustment added back to the MtM of a derivative position to account for the potential gain from the (insurer or contract writer) institution's own default. DVA is basically a CVA from the perspective of the other counterparty. If one counterparty incurs a CVA loss, the other counterparty incurs a corresponding DVA gain; (2) the capital valuation adjustment (KVA), the cost of holding regulatory capital for derivatives trading business, and (3) funding value adjustment (FVA) is an adjustment incorporated into the market price of a derivative to compensate the dealer for the cost of funding cash flows.

3 Institutional Background: CIP and Collateralization

3.1 CIP

Based on the literature, the violation to the CIP is empirically measured by the xccy basis calculated using FX forwards (short-term) and xccy swaps (long-term) (Du, Tepper, and Verdelhan, 2018). An FX forward fixes the money to be transacted in the bilateral currencies at the start of the trade. In a xccy swap, two parties exchange interest payments on loans, usually 3-month Libor during the life of the swap, as well as the principal amounts at the beginning and end.

The textbook CIP condition states that the forward exchange rate is:

$$F_{t+1} = S_t \times e^{r^{\$}_{t+1} - (r^i_{t+1} + \underbrace{x^i_{t+1}}_{=0})} \tag{1}$$

where the spot S_t and the time $t+1$ forward F_{t+1} exchange rates are expressed as the price in (\$) - domestic currency (US dollar) for one unit of (i) - foreign currency (e.g., one EUR).

Moreover, in logs, the annualized continuously compounded forward premium is then equal to the bilateral currencies' annualized continuously compounded risk-free interest rates differential:

$$\ln \frac{F_{t+1}}{S_t} = f_{t+1} - s_t = r^{\$}_{t+1} - (r^i_{t+1} + \underbrace{x^i_{t+1}}_{=0}) \tag{2}$$

The CIP holds in the absence of arbitrage and is grounded in three key concepts. First, to prevent arbitrage opportunities, the xccy basis, x^i_{t+1}, should equal 0. Otherwise, there is a deviation from the CIP condition, which is measured by the annualized continuously compounded xccy basis: (expressed in foreign currency terms due to market convention)

$$x^i_{t+1} = r^{\$}_{t+1} - \left(r^i_{t+1} - (f_{t+1} - s_t)\right) \tag{3}$$

In the case of a negative basis, $x < 0$, assuming no counterparty risk and collateralization costs, a dollar arbitrageur can borrow the US dollar via the cash market domestically and lend them via the synthetic FX swaps market (0 net cash investment) and pocket x basis points per annum risk-free (see Figure 2 for standard CIP arbitrage cash flows).

Second, the lending and borrowing rates in each currency, $r^{\$}$ and r^{i}, should exist and be unique risk-free rates in the market. Third, the lending and borrowing rates should be accessible to any counterparty in the market. Implicitly, the CIP condition excludes the possibility of counterparty credit risk. As a result, measuring the CIP deviation necessitates explicit knowledge of the risk-free rates used to discount future cash flows in each currency, as well as costless counterparty risk hedging, which has proven difficult post-GFC.

3.2 The Risk-free Rate Conundrum

Finding rates to represent risk-free interest rates post-GFC is challenging. The empirical literature uses Libor rates as proxies. However, Libor rates are not risk free after the GFC because they misrepresent actual trading rates (no transaction costs, prone to distortion, incorporate credit risk, etc.). The next obvious candidates are OIS rates (for US dollar the FedFunds, for GBP the Sonia, for EUR the Eonia, etc., collectively called OIS rates), but they are uncollateralized money market rates and thus, not risk free. The rates of government bonds are affected by the regulation of risk management, taxation, embed sovereign credit risk, and receive convenience premiums (Krishnamurthy and Vissing-Jorgensen, 2012). GC repo rates could potentially work, but they exhibit volatility because of conditions in collateral markets and dealer balance sheet management. Additionally, data are incomplete or unavailable for some currencies and can include stale observations.

Practitioners usually assume no-arbitrage conditions and infer implied risk-free rates from the market for the derivative instruments they are trying to value, but those inferred rates are not readily tradable. An academic product of a similar exercise are the US dollar

BOX risk-free rates extracted from the equity options market by Binsbergen, Diamond, and Grotteria (2019). These BOX rates are difficult to estimate for currencies other than the US dollar.

Because none of the discussed discount rates is unquestionably risk free, how can one make any of them default free? The answer is to introduce collateralization. However, eliminating credit risk via collateralization is not costless. Standard theory assumes that market participants can trade the risk-free discount rate, ignoring the intricacies of repo or collateralization markets. In practice, market participants are mindful that collateralization introduces costs and adjustments to discounting, forward prices, and implied volatilities, depending on the particularities of the collateral and its posting terms (Piterbarg, 2010). Black (1972), among others, considers an economy to be without a risk-free rate. However, traditional derivative pricing theory (e.g., Duffie, 2001) assumes the existence of such a unique risk-free rate as a matter of principle. Until the GFC, this assumption was plausible; however, not any more. An asset that is costlessly fully collateralized on a continuous basis is close to a risk-free asset (assuming no market segmentation or liquidity premiums, jumps in asset prices and intricacies of collateral posting and monitoring preventing full elimination of credit risk).

3.3 Institutional Features of Collateral

The use of FX forwards and xccy swap prices to measure CIP in the literature so far does not consider that these derivative instruments are collateralized. Indeed, the measurement of the CIP should include costly non-market payments on collateral. Additionally, certain cash flows in xccy swaps are mechanical, such as the exchange of Libor rates, which are not risk-free rates, and hence should be taken into account (i.e., discount its mechanical impact) when measuring true CIP deviations. Otherwise, what the CIP deviation might be reflecting is simply risks of exchanged mechanical Libor cashflows.

The above is important especially since the use of collateral agreements is substantial nowadays. According to ISDA, by the end of 2013, 91% of all OTC derivatives trades (cleared and non-cleared) were subject to collateral agreements compared to only 30% in 2003. In the FX derivatives market, bulk of the transactions beyond 1-week tenor are collateralized, but less so are the transactions with very short maturities of less than 1-week.

In the post-GFC world, swaps are generally collateralized under a Credit Support Annexe (CSA), in which one counterparty receives collateral from the other counterparty when the present value of the contract is positive and needs to pay the interest (collateral rate) on the outstanding collateral amount to the collateral payer. These CSAs regulate the collateral under the ISDA Master Agreement by defining the exact terms and conditions under which collateral is posted to mitigate counterparty credit risk.

Most of the transactions in the xccy derivatives market are bilaterally collateralized under standardized CSA terms that the collateral is rehypothecable but should be in the form of cash to cover the value of the daily MtM (ISDA Margin Survey, 2014). The base and most common choice of collateral currency is the US dollar if the currency pair is against the US dollar; thus, counterparties need to fund the US dollar denominated collateral on their xccy swap positions. Crucially, the collateral is compensated at a non-market collateral rate that is different from the risk-free rate of return. That rate is the CSA contract specified standard overnight (OIS) rate, which is usually lower that the risk-free rate.

Collateralization has profound effects on the valuation of financial instruments. Not only does it reduce the counterparty credit risk but it also changes the funding costs of derivative trades because of the introduction of stochastic intermediate collateral cash flows (Johannes and Sundaresan, 2007). The first point is readily apparent, however, the importance of the second point became acknowledged only after the GFC. Additionally, collateralization can reduce regulatory capital charges. However, this comes at the costs of higher collateral costs since in practice, it is not costless to eliminate counterparty credit risk, hence, collateral is costly for counterparties.

If a derivative contract is not fully collateralized, its funding cost is either directly linked to the Libor (if the counterparty is a part of the Libor panel banks) or to the counterparty's overall funding rate (Duffie and Singleton, 1999; Fleckenstein and Longstaff, 2020; and Andersen, Duffie, and Song, 2019). However, if the contract is fully collateralized by cash, the funding rate should be linked to the collateral rate provided by the overnight (OIS) rate of the collateral currency, which is specified in the CSA collateral agreement, a point illustrated in more detail in Internet Appendix A.

4 Empirical Strategy

4.1 Defining a Collateral Rental Yield

I define a simplified measure of the cost of collateralization applicable to the marginal investor in the FX forward and cross currency market. I rationalize it by assuming continuous full cash collateralization, which means that counterparties continuously need to post cash collateral in the full amount of their FX derivative contract's current MtM until expiration.[5]

Collateral, in the form of cash, is easily invested or loaned out because it is rehypothecated. The cash collateral is default-free and remunerated with a risk-free rate if deposited in a money market account, such as a collateral account. However, in practice, the remuneration rate on this collateral account differs from the risk-free rate. Hence, I define the following important single-currency collateral opportunity cost rate:

$$y_t = r_t - o_t \tag{4}$$

where r_t and o_t are the time t *risk-free rate* and CSA specified *contractual collateral rate*, respectively. A common market practice, under a standard ISDA CSA, is for o_t to equal the overnight (OIS) rate.

[5] In practice, daily margining is common; hence, assuming continuous collateralization is a reasonable approximation. There is no remaining credit risk, known as "gap risk," which is a sudden jump of the underlying asset and/or the collateral values at the time of counterparty default. A key assumption is the existence of a common hypothetical risk-free rate (money market account) and that is not affected by constraints and frictions, a point later relaxed and discussed in the empirical section.

Economically, from the view point of a collateral receiver, the collateral wedge can be interpreted as a dividend yield because, for instance, the collateral receiver would place the cash collateral in a money market account earning a risk-free rate, r_t, while paying a contractual collateral rate, o_t, to the collateral payer, keeping the difference between the two. However, from the viewpoint of a collateral payer, it can be considered as collateral funding cost as the reverse is the case.[6]

For the xccy derivatives analyzed in this study, in terms of (\$) - domestic currency (US dollar) swapped for (i) - foreign currency where the former is used as the collateral, I define the following collateral rental yield:

$$y_t^{i/\$} = y_t^i - y_t^\$ \tag{5}$$

where

$$y_t^i = r_t^i - o_t^i \qquad y_t^\$ = r_t^\$ - o_t^\$ \tag{6}$$

which represents the difference in collateral opportunity costs between currency (i) and (\$). The above identity is applicable for the case when rates are deterministic and in a discrete single-period time setting. Throughout the paper, I use this simplified definition of the measure, which I call collateral rental yield, to analyze the CIP violations.

4.2 Empirical Measure of CIP Violation

4.2.1 Short-term Horizon CIP Violation

The textbook CIP condition from (1) states that the FX forward contract is:

$$F_{t+1} = S_t \times e^{r^\$_{t+1} - r^i_{t+1}} \tag{7}$$

Furthermore, the previously defined measures of collateralization in each currency in Eq.

[6] Moreover, the return from a risky investment or borrowing costs from outside markets can be quite different from the risk-free rate. However, in this study's simplified formulation I use the risk-free rate as the net return after hedging these risks, assuming that hedging is costless.

(6) show that:

$$r_{t+1}^{i} = y_{t+1}^{i} + o_{t+1}^{i} \qquad r_{t+1}^{\$} = y_{t+1}^{\$} + o_{t+1}^{\$} \tag{8}$$

As a result, when a single currency, such as the domestic currency ($), is required as collateral and interest rates are deterministic, the collateralized FX forward price in a one-period setting at time t can be expressed as follows by substituting for the above Eq. (8) into Eq (7):

$$F_{t+1} = S_t \times e^{(y_{t+1}^{\$}+o_{t+1}^{\$})-(y_{t+1}^{i}+o_{t+1}^{i})} \tag{9}$$

Finally, substituting the defined cross-currency collateral rental yield from Eq. (5) to Eq. (9):

$$F_{t+1} = S_t \times e^{o_{t+1}^{\$}-(o_{t+1}^{i}+y_{t+1}^{i/\$})} \tag{10}$$

Comparing the above collateralized FX forward pricing Eq. (10) with the textbook CIP Eq. (1), notice that if the CIP violation is measured using xccy basis using OIS rates in each currency, then the so-called "OIS-based" xccy basis, $x_{t+1}^{i,OIS}$, is allowed to deviate from 0, and the deviation is simply equal to collateral rental yield, $y_{t+1}^{i/\$}$, embedded in collateralized FX forwards. This means that, consistent with no-arbitrage laws, the fully collateral-adjusted xccy basis, x_{t+1}^{adj}, should equal zero:

$$\begin{aligned} x_{t+1}^{adj} &= \left[o_{t+1}^{\$} - (o_{t+1}^{i} - (f_{t+1} - s_t))\right] - y_{t+1}^{i/\$} = 0 \\ &= x_{t+1}^{i,OIS} - y_{t+1}^{i/\$} = 0 \end{aligned} \tag{11}$$

where $(f_{t+1} - s_t)$ denotes the log forward premium obtained from the log of the forward and spot exchange rates.

Furthermore, because of the continuous MtM-ing feature and collateral posting in a single currency, such as US dollars, the illustration becomes slightly more complicated in a multi-period case because the collateral posting and collateral rental yield are stochastic. However, this case follows the same logic as the simplified single period case described above I refer the reader to frameworks such as Fujii and Takahashi (2012) Fujii and Takahashi (2013), Fujii, Shimada, Takahashi (2010a), Brigo, Capponi, and Pallavicini (2014), and Johannes and Sundaresan (2007) that model such stochastic collateralization features.

It is worth noting that in the stochastic multi-period case, the earlier defined collateral rental yield in (5) and (9) must be adjusted for a change in currency measure.[7] This is because, in a multi-period setting, if we have daily MtM that must be paid in US dollars, the counterparty with a negative MtM must fund the MtM in its own currency at the risk-free rate, convert the funds to US dollars, place them in the collateral account, and receive US dollar collateral rate remuneration (which is the OIS rate based on the CSA agreement). This is done continuously. The collateral receiver is the polar opposite. As a result, each counterparty faces daily exchange rate risk on the collateral account as the MtM fluctuates, necessitating a change of measure when pricing FX derivatives that are collateralized in a single currency, such as the US dollar.

4.2.2 Long-term Horizon CIP Violation

Because the liquidity of FX forwards is limited to short-term tenors of less than one year, the literature uses xccy swaps to evaluate the CIP conditions for longer tenors because they are more liquid. Based on Du, Tepper, and Verdelhan (2018), the CIP violation

[7] It can be represented by:

$$y^{i/\$}(s) = E_t^{Q^i}[(y^i(s)ds] - E_t^{Q^\$}[y^\$(s)ds] = E_t^{Q^i}[(y^i(s) - y^\$(s))ds] \tag{12}$$

where $E_t^{Q^i}[\cdot]$ and $E_t^{Q^\$}[\cdot]$ are the time t conditional expectation under the risk-neutral measure of currency (i) and $(\$)$ respectively, where the money market account of each currency respectively is used as a numeraire.[8] Notice that I am changing the measure using the Radon-Nikodym density:

$$\frac{dQ^\$}{dQ^i}|_t = \frac{\beta_t^\$ S^{(i/\$)}(0)}{\beta_t^i S^{(i/\$)}(t)} \tag{13}$$

where $S^{i/\$}$ is the spot FX rate in terms of the domestic currency (\$) per unit of foreign currency (i).

based on Libor (Libor-based CIP violation) does not involve any calculations and is given by the spread on the standard Libor xccy basis swap since the swap is viewed as a series of short-term FX forwards. If this Libor xccy basis spread is zero, then there is no violation of the CIP condition.

Due to the presence of collateralization, however, the structure of a standard Libor xccy basis swap cannot be viewed as a series of FX forwards and thus as a measure of CIP violation without some modifications. Libor xccy basis swaps have a non-linear payoff in Libor interest because they exchange Libor-indexed cashflows, which are then discounted to present value at the contractual collateral remuneration rates (OIS). To have zero CIP violations, the Libor and OIS rates must be equal to each other and be risk-free.[9] However, Libor and OIS rates are uncollateralized and, in practice, neither are risk-free or equal to each other. As a result, even if the OIS discount rates are risk-free, the Libor xccy basis may end up being non-zero, falsely signaling a violation of the CIP conditions; however, it will simply be reflecting mechanically the dynamics of the specific Libors' index cashflows (e.g., credit, liquidity, etc.) because those are the cashflows exchanged by the standardized contract terms of the xccy swap.

To avoid this situation, I must parse the Libor cash flows, replace them with OIS rate indexed cash flows, and recalculate the prices of the xccy basis swaps. As a result, I will be able to measure the CIP violations in the same standardized manner as for the short-term case earlier, as I will be able to consider the xccy basis swaps as a series of short-term FX forwards.

Therefore, rather than using the standard annualized continuously compounded Libor-based xccy basis below:

[9] Another possibility is that the Libor-based xccy basis equals zero if the Libor and OIS rates in each currency are equal. However, this does not imply that the CIP violation is zero. Again, for this to hold, the Libor and OIS rates must not only be equal, but they must also be risk-free. Also, if the counterparties are of Libor credit quality and do not have a collateral agreement, there will be no collateral adjustment. The xccy swap Libor-indexed cash flows will be discounted at the same Libor rates, the present value of each leg of the swap will be par, and a zero xccy basis will be observed, which does not necessarily imply that there are no violations to the strict CIP non-arbitrage conditions since the strict CIP requires discounting at risk-free rates rather than Libor rates.

$$x_{t+1}^{i,Libor} = (IRS_{t+1}^{\$,Libor} - \left(IRS_{t+1}^{i,Libor} - (f_{t+1} - s_t)\right) \tag{14}$$

as a measure of long-term CIP violations, I will instead use the annualized continuously compounded OIS-based xccy basis shown below:

$$x_{t+1}^{i,OIS} = (IRS_{t+1}^{\$,OIS} - \left(IRS_{t+1}^{i,OIS} - (f_{t+1} - s_t)\right) \tag{15}$$

where log of the spot s_t and the time $t+1$ forward f_{t+1} exchange rates are expressed as the price in domestic currency (US dollar) for one unit of foreign currency. IRS^{Libor} is the Libor-indexed floating to fixed interest rate swap (IRS) to swap floating Libor cashflows into fixed rate cash flows in a single currency and IRS^{OIS} is the OIS-indexed floating to fixed IRS to swap floating OIS cash flows into fixed rate cashflows in a single currency.

The price of a OIS-based xccy basis swap now involves going long an OIS-based loan in one currency (e.g. domestic currency leg), while simultaneously going short an OIS-based loan in a foreign currency (e.g. foreign currency leg) that is exchanged at the current spot FX exchange rate (market condition). Internet Appendix B illustrates the procedure I follow to first extract the Libor and OIS yield curves from market prices of Libor xccy, IRS, and OIS swaps and then to recalculate OIS-based xccy basis swap prices by replacing the Libor-indexed cashflows with OIS-indexed cashflows. Thus, I create synthetically calculated OIS-based xccy basis swap prices. Figure 3 further illustrates the cash flows of a collateralized OIS-based xccy basis swap.[10]

Overall, the discussion above explains how the collateral currency (e.g., US dollar), MtM collateralization, and the wedge between the non-market collateral remuneration rate and

[10] Furthermore, Internet Appendix B shows closed form pricing derivations for xccy swaps when the collateral posting and collateral rental yield are stochastic due to the continuous MtM-ing feature. I also refer the reader to frameworks such as Fujii and Takahashi (2012) Fujii and Takahashi (2013), Fujii, Shimada, Takahashi (2010a), Brigo, Capponi, and Pallavicini (2014), and Johannes and Sundaresan (2007) for more information on pricing exchange rate and interest rate swaps with stochastic collateralization features.

the risk-free rate affect the price of FX forwards and xccy swaps and how this changes how we can measure CIP violations.

4.3 Empirical Proxies for the Collateral Rental Yield

To evaluate the impact and contribution of collateralization to the xccy basis, and thus contribution to CIP violations, I obtain empirical estimates of the collateral rental yield embedded in the pricing of FX forwards and xccy swaps. I study the CIP violation over both the short and long-term horizons; the same measure applies to the short-term OIS-based xccy bases and the long-term synthetic OIS-based xccy bases calculated by replacing Libor-indexed cashflows with OIS-indexed cash flows.

Moreover, to identify a robust observable proxy for xccy collateral rental yield, $y_n^{i/\$}$, in Eq. (5), I use three interchangeable proxies for the risk-free rate, r_n, and one proxy for the collateral rate, o_n, in each currency. I proxy the contractual collateral rate with the OIS zero rate since it is the standardized ISDA CSA contractual collateral rate used in the OTC derivatives market.

The first risk-free rate proxy is the GC repo rate denoted $r_{n,gc}$. This rate is collateralized, easily tradable, and transaction-based. In addition, because of regulatory and market efforts to reduce counterparty credit risk in interbank exposures, banks have also tilted their funding mix toward less risky sources of wholesale funding (in particular, GC repos). This is especially so to fund collateralized derivatives positions such as xccy swaps. Moreover, derivatives market reforms (such as the mandatory shift to central clearing of standardized OTC derivatives, and a move towards more comprehensive collateralization of OTC derivatives positions) have also increased the importance of funding with no credit risk using the GC market.

However, GCs exhibit volatility owing to conditions in collateral markets and dealer balance sheet management. A notable recent example is the December 2018 spike, which was because of a glut in Treasury markets interacting with banks' year-end window-dressing (Schrimpf and Sushko, 2019). Therefore, I would expect that the collateral rental yield proxy constructed using GCs as reference risk-free rates exhibits similar volatility related to conditions in collateral markets as well as dealer balance sheet management which are passed on to the FX and xccy derivative contracts traded. Additionally, data on GCs are also not available for some currencies, are incomplete, and can have stale observations.

Applying Eq. (5), the proxy for the collateral rental yield using GC repo rates rates is calculated as:

$$y_{n,gc}^{i/\$} = (r_{n,gc}^{i} - o_{n}^{i}) - (r_{n,gc}^{\$} - o_{n}^{\$}) \tag{16}$$

where n stands for $1m$ (1-week), $1m$ (1-month), and $3m$ (3-month).

The second alternative proxy for the risk-free rate is the 3-month T-bill rate for each currency denoted r_{tbill}. This rate is often criticized as potentially reflecting default risk as well as convenience premiums (Krishnamurthy and Vissing-Jorgensen, 2012). I use this proxy only for the 3-month maturity horizon analysis and it is calculated as:

$$y_{tbill}^{i/\$} = (r_{tbill}^{i} - o_{3m}^{i}) - (r_{tbill}^{\$} - o_{3m}^{\$}) \tag{17}$$

The third proxy, available only for the US dollar, is the 6-month BOX rate from van Binsbergen, Diamond, and Grotteria (2019). This rate is the interest rate implicit in the $S\&P$ 500 option box spread. It excludes convenience premiums; however, it could potentially reflect costs and frictions associated with holding and trading the underlying equity derivatives. Also, I use this proxy only for the 3-month maturity horizon analysis. It is calculated as:

$$y_{BOX}^{i/\$} = (r_{tbill}^{i} - o_{3m}^{i}) - (r_{BOX}^{\$} - o_{3m}^{\$}) \tag{18}$$

The above proxy is a combination of the foreign 3-month risk-free rate proxied by the foreign 3-month T-bill rate and the US 3-month risk-free rate proxied by the 6-month BOX rate (since data on 3-month US BOX rate or foreign currency BOX rate was not available).

4.4 Residual Counterparty Credit Risks and Intermediary Frictions

Every counterparty in the OTC market is inclined to reflect their own funding, counterparty credit risk, or investment conditions, rather than the risk-free rate conditions when pricing and trading FX forward and xccy basis contracts. In determining the risk-neutral collateral rental yield, I used the risk-free rate conditions to identify the cost of collateralization as frictionless and distinct from the aforementioned costs or risk-based returns. However, empirically, this will be the case only if the proxies chosen for the risk-free rate truly reflect the theoretical risk-free rate conditions, which means they are not affected by any of the other conditions mentioned, such as counterparty funding conditions or credit risk conditions, as well as any other intermediation frictions.

Because the FX forward and xccy markets are not completely collateralized in practice, it is natural to expect that there will be residual credit or counterparty risk premiums that will be priced in the aggregate FX forward and xccy contracts. This will be especially pronounced for short-term deviations from the CIP because the less than three-month FX forward market is less collateralized than the longer-dated market. As a result, the empirical analysis that follows, I account for and control for any remaining counterparty credit risk, as well as other balance sheet and regulatory intermediation frictions that could affect not only the FX forward and xccy prices directly, but also the proxies used in this study for the risk-free rate. This approach also allows me to establish evidence on the presence of a direct collateral channel that is independent of global risk factors, balance sheet constraints, and regulatory frictions documented in the literature so far that affects CIP violations.

I further describe the data before presenting the results and their implications for the CIP violations.

5 Data

I focus on the G-7 currencies. These currencies are all against US dollars and are denoted by their abbreviations: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY). I use panel data for the 1-, 5-, and 10-year cross currencies, interest rates, tenors, and OISs. Additionally, I use data on 1-week, 1-month, and 3-month FX forwards and FX spot, ask, bid, and closing prices. I also obtain panel data on 3- and 6-month Libor and 1-week, 1-month, and 3-month GC and OIS rates for each currency. All of the above data, apart from the EUR GC repo rates obtained from BNP Paribas, are from Bloomberg. The sample period is from September 1, 2008, to May 31, 2020, covering both the GFC and the COVID-19 crises, as well as the tranquil period in between. GC repo rates from Bloomberg are obtained from Tullet Prebon, Swiss Stock Exchange, and the Bank of England.

I use the US dollars 6-month BOX rates from van Binsbergen, Diamond, and Grotteria (2019) as well as 3-month T-bill rates from Bloomberg. These data are used as alternative proxies of the risk-free rates when constructing different observable measures for the 3-month collateral rental yields. I also obtain data on the leverage of security broker dealers from Adrian, Etula, and Muir (2014) (AEM) and on leverage and capital factors of bank holding companies from He, Kelly, and Manela (2017) (HKM) to investigate their covariation with the collateral rental yields. (Internet Appendix E provides further information on the data.)

Finally, I also obtain transactional data on xccy basis swap derivatives trades (459,143 reports) executed between January 1, 2013 and March 31, 2020, which are publicly distributed by the Depository Trust & Clearing Corporation (DTCC) Data Repository (U.S.) LLC (DDR). On December 31, 2012, the Commodity Futures Trading Commission (CFTC) implemented mandatory real-time reporting and public dissemination of OTC swap trades as part of the Dodd-Frank Wall Street Reform and Consumer Protection Act. Swap transactions must be reported to a record-keeping facility known as a swap data repository (SDR), which then disseminates transaction details to the public (e.g., trade price, trade size, timestamp, and trade characteristics[11] related to the Dodd-Frank reforms).

[11]DDR's Real Time Dissemination Dashboard User Guide provides a complete list of data fields in publicly disseminated trade reports (https://pddata.dtcc.com/gtr/cftc/dashboard.do).

6 Results

6.1 Prevalence of Collateralization

Figure 4 reports the level of collateralization in the xccy basis market based on transactions data from the DTCC Data Repository. Panel A presents the distribution across the different types of transaction collateralizations for the total sample period between 2013-2020. A massive 76.68% of the xccy basis swap transactions are backed by some form of collateralization. Specifically, 26.2% are fully collateralized which means that require counterparties to post initial and variation margin (FC), 47.6% require counterparties to provide variation margin only (PC), and 2.1% of the sample requires only one of the counterparties to post margin. About 24.1% of the transactions are uncollateralized (UC).

Furthermore, Panel B zooms in on these collateralization compositions over time, and it is evident that the share of collateralization increased over the years, while the share of uncollateralized trades gradually decreased, from 44.8% in 2013 to only 3.8% in 2020. In particular, the share of fully collateralized (FC) trades increased the most from 10.4% in 2013 to 59.7% of all cross-currency swap transactions in 2020.

Finally, the proportion of trades in the sample that are not cleared through a clearing house is 99.7%. This suggests that the clearing status does not really correlate with the evidenced increase in collateralization over time. Hence, the central clearing, which is supposed to be an effective way to reduce counterparty risk is not at play in this asset class derivatives market.

6.2 Short-Term Collateral-Adjusted CIP Violations

Recalculating the CIP violation while adjusting for the collateral rental yield in Eq. (11) across various proxy measures, called "collateral-adjusted xccy basis", reveals a substantial reduction in the magnitude of the CIP violations when compared to measurement approaches that ignore a collateral rental yield, i.e., that do not adjust for collateral opportunity costs. Table 1 provides the mean and standard deviation of the unadjusted versus collateral-adjusted CIP violations across tenors from 1-week to 3-months for the

G-7 currencies since 2008. It reports these moments for the full sample excluding the crisis sub-periods ("Post-Crisis") and for a subset of crises (collectively "Crisis"). Similar to Du and Schregner (2021), the Crisis sub-periods include August 2008 - December 2009 (GFC), November 2011 - February 2012, and March 2020 - May 2020 (Covid), and the Post-Crisis sub-period runs from January 1, 2010 to May 31, 2020 and excludes the Crisis period.

In the tranquil Post-Crisis sample period, the collateral adjustment to the short-term OIS-based xccy basis reduces the magnitude of the basis by about 12, 16, and 15 basis points for the 1-week, 1-month, and 3-month GC-adjusted xccy basis respectively, and 10 basis points for the 3-month T-bill-adjusted xccy basis. It even makes the BOX-adjusted collateral xccy basis become positive by about 7 basis points. Taken together, these results equate to between one-third to complete, or on average, across tenors and measures, about a two-third reduction in the magnitude of the OIS-based CIP deviation due to collateral adjustment.[12]

During the Crisis sample period, however, the collateral-adjusted xccy basis is not significantly different from the OIS-based xccy basis, with the exception of the BOX-based collateral adjustment. This suggests that the BOX-based collateral rental yield captures additional financial and economic stress factors that are present during crises. Overall, in times of crisis, however, the results suggest that collateralization becomes of secondary importance for FX forward prices.

In terms of cross-sectional evidence, Figure 5 reports the mean xccy basis on the vertical axis as a function of the average collateral rental yield using different measures on the horizontal axis for the 2009–2020 period. The xccy basis is positively correlated with the collateral rental yield across different proxies. The cross-sectional relationship works particularly for the GC-based collateral rental yield.

[12] In the table, using Eq. (11), the GC-adjusted collateral xccy basis, $x^{adj}_{n,gc}$, is re-calculated using the maturity matched proxy collateral rental yield utilizing GC rates, $y^{i/\$}_{n,gc}$, from Eq. (16) where n stands for $1w$ (1-week), $1m$ (1-month), and $3m$ (3-month). The T-bill-adjusted collateral xccy basis, x^{adj}_{Tbill}, is re-calculated using the proxy collateral rental yield utilizing 3-month T-bill rates, $y^{i/\$}_{Tbill}$ from Eq. (17), and the BOX-adjusted collateral xccy basis, x^{adj}_{BOX}, is re-calculated using the proxy collateral rental yield utilizing foreign 3-month T-bill and US 6-month BOX rates , $y^{i/\$}_{BOX}$, from Eq. (18).

Turning to formal tests, Table 2 shows results from panel regressions of the short-horizon OIS-based xccy basis, x_n^{OIS}, on each of the three alternative proxies for the collateral rental yield respectively for 1-week, 1-month, and 3-month tenors and other covariates from the empirical literature. These include specifications where all variables are in levels (Panel A) and in changes (Panel B). Because the data for the proxy variables of the collateral rental yield might be stale[13], I consider the results in levels and not just changes. For specifications in levels, stationarity is ruled out (based on augmented Dickey-Fuller and other stationarity tests).

If the proxy collateral rental yield measures collateral costs effectively and the FX forward market in aggregate is fully collateralized, Eq. (11) suggests a slope coefficient of 1 and an R^2 of 1. From Table 2 Panel A, each proxy's slope coefficient is statistically significant (at 1%) and close to 1 (apart for the 3-month horizon), and the R^2 are large, especially for the 1 and 3-months horizon regressions.

The collateral rental yield between the bilateral currencies is associated with more, almost one-for-one, negative xccy basis, which is economically meaningful. In particular, for the 1-week and 1-month tenors, the coefficient estimate for the GC-based collateral rental yield (in columns 1 and 3 of Table 2 Panel A) implies that the marginal impact of one basis point (0.01%) decrease in the collateral rental yield and is associated with 1.1 and 1.4 basis point decrease in the xccy basis respectively. Results for the 3-month basis are qualitatively similar but smaller in magnitude.

Moreover, the coefficient estimates for the collateral rental yield are similar in magnitude between the three proxies. Therefore, the proxies used for the collateral rental yield are robust and are not sensitive to the choice of the risk-free rate proxy, alleviating the potential criticism of identifying a post-GFC risk-free rate as discussed in the literature. Remarkably, for all specifications, all proxies of the collateral rental yield also survive the inclusion of other factors documented to contribute to the variation of the xccy basis in the literature.

Residual credit counterparty and funding risk in the FX forward contracts' market

[13] Especially for GC rates, for example.

is not ruled out. Formally, the counterparty default risk explanation of CIP deviations relies on cross-country differences in the credit worthiness of different Libor panel banks. According to Du, Tepper, and Verdelhan (2018), looking at the other extreme, of having no collateralization in the market and assuming no-arbitrage, the xccy basis should equal the difference between credit risk spreads (above the theoretical risk-free rate) in the foreign currency and US dollar Libor panels. In Table 2 Panel A, the Libor-OISs spreads are persistently significant across specifications. The results in changes in Table 2 Panel B show similar results and conclusions.

An important caveat is how well the Libor-OISs spread can represent the funding and counterparty credit risks involved in xccy prices, in other words, how applicable Libor is for participants to borrow on an unsecured basis for xccy swaps. Admittedly, the Libor-OIS spread is not a perfect measure of the credit risks for the xccy market. First, the Libor scandal is well known, and therefore its reliability as a measure of the cost of funding accessible by banks in general seems questionable (Hou and Skeie, 2014). Second, there is a considerable difference in the composition between the Libor and xccy markets. The Libor market mainly consists of banks, while the xccy swaps market comprises of a wide range of financial and non-financial institutions, including banks, insurers, investment managers, hedge funds, and large corporations. It is clear, therefore, that most of the xccy market participants are unable to access funds at Libor on an uncollateralized basis. As a result, the risks are likely to be underestimated. Yet, most likely, if counterparty risk is very high, parties will opt for full collateralization. Therefore, the spread is still arguably the best available measure that can serve as a reasonably good approximation of residual counterparty risks or collateralization presence in the market.

Furthermore, to obtain evidence of residual regulatory constraints, I test whether short-horizon CIP violations are more pronounced at the end of the quarters versus any other point in time in a manner similar to Du, Tepper, and Verdelhan (2018). $Qend$ is an indicator variable that equals 1 if the date is within 6 days of the quarter end, and 0 otherwise and $Yend$ is an indicator variable that equals 1 if the date is in the last month of the year, and 0 otherwise. In Table 2 Panel A, the quarter-end coefficient is negative and significant, indicating larger CIP violations. It is -25 basis points for the 1-week and -8 basis points for the 1-month horizon, but it is not significant for the 3-month horizon. This is expected since a 3-month forward contract always shows up in a quarterly report regardless of when it is executed within the quarter. Additionally, the year-end coefficient is also significant over and above the quarter-end for all maturities, including the 3-month horizon. The effect is quite large, -40 basis points for the 1-week and -51 basis points for the 1-month horizon, however, as the maturity increases the magnitude of this effect becomes smaller.

The result is consistent with the key role of banks' balance sheet constraints binding on quarter and year-end reporting dates. I do not discern which part of the regulation matters most, but the result suggests that banking regulations driving the quarter and year-end anomalies in the xccy markets, driven by *window dressing* for better regulatory ratios, are consistent with other asset markets, for example, the quarter-end sharp decline in the US Triparty repo volume (Munyan, 2017) and the quarter-end spike increases in the GC repo rates. These GC rates are used in one of the proxies for the collateral rental yield.

The strength of the US dollar is also significant for the xccy basis for the 3-month horizon in Table 2 Panel A. According to this study's narrative, this is a result of the need to collateralize the daily MtM, chiefly in US dollar. Greater US dollar strength is associated with higher cost of collateral and more negative xccy basis. The trade weighted US dollar index[14] created by the US Federal Reserve System, is significant across specifications apart from in the 1-week and 1-month tenors. The longer the tenor, the more prevalent the collateralization, the higher the counterparty exposure intensity, and hence the more the currency of the collateralization matters. While Avdjiev, Du, Koch, and Shin (2019) link

[14]The trade-weighted US dollar index is used to determine the US dollar's purchasing value and summarize the effects of dollar appreciation and depreciation against foreign currencies. Trade-weighted dollars give importance, or weight, to currencies most widely used in international trade, rather than comparing the value of the US dollar to all foreign currencies. EUR is, by far, the largest component of the index, making up almost 58% (officially 57.6%) of the basket. The weights of the rest of the currencies in the index are JPY (13.6%), GBP (11.9%), CAD (9.1%), SEK (4.2%), and CHF (3.6%) (Investopedia, 2019).

the broad dollar index to the xccy basis through a cross-border bank lending channel, this study's narrative connects the two via the need to post US dollar-denominated collateral channel. Additionally, the forward FX bid-ask spread liquidity frictions also seem to affect the OIS-based xccy basis, albeit not consistently across tenors.

It is worth noting that, according to the study's collateralization but no-arbitrage narrative, the strength of the US dollar should affect the xccy basis only through the collateral channel and thus be absorbed by the collateral rental yield measure. Based on this hypothesis, it should not appear as significant here separately if no-arbitrage is maintained. However, for the empirical analysis, I use simple proxies for the collateral rental yield that do not entail a change in measure between the bilateral currencies, reflecting the institutional features that the collateral is MtM continuously and denominated in US dollars. Thus, the strength of the US dollar covaries with the xccy basis independently of collateral rental yield proxies.

Furthermore, Table 3 presents results from a difference-in-difference panel regression of the OIS-based xccy basis on an interaction with a dummy, denoted *Post-Crisis*, indicating 1 for the sample period from January 1, 2010 to May 31, 2020 excluding two crisis periods for which it is indicating 0. Those crisis periods are the GFC, from August 2008 - December 2009, and the Covid, from March 2020 - May 2020 (subsamples are similar to Du and Schregner, 2021).

Apart from the collateral rental yield proxy using BOX rates, the proxies calculated using GC and T-bill rates are significant and important in magnitude only during the tranquil post-crisis times as evident by their significant coefficients on the interaction with the Post-Crisis dummy. However, the same are not significant during crisis periods. This suggest that the collateral rental yield is not very relevant in crisis times when many other factors might be responsible for creating dislocation and mispricing in the in the xccy basis market, and that collateralization matters more when conditions normalize. The results further support that the BOX-based rental yield captures additional factors reflecting financial stress present mainly during crises.

In sum, the collateral rental yield is significant and accounts for, on average, about two-thirds of the short-term OIS-based CIP deviations, regardless of the choice of proxy for the risk-free rate for each of the alternative measures. The results also suggest that, in crisis times, collateralization becomes of secondary importance for xccy basis prices.

6.3 Long-Term Collateral-Adjusted CIP Violations

Majority of xccy basis swaps traded in the market are based on Libor. However, as discussed in Section 4.2.2, in order to analyze the CIP violations consistently across tenors, the xccy basis swaps must be OIS-based. OIS-based xccy swaps exist but they are not liquid or readily tradeable in the market, and they are available only in few currencies, so there is no consistent data on them. As a result, I generate OIS-based xccy basis swap prices by parsing the mechanical Libor-index risk embedded in the market prices of Libor-based xccy basis swaps. I compute a synthetic OIS-based xccy swap price using Eq. (15) as described in Section 4.2.2 and Internet Appendix B.[15] This allows me to analyze CIP violations across tenors in an appropriate and consistent manner, while avoiding contamination from mechanical Libor-indexed cash flows.

To show the importance of this particular detail, Figure 6 compares the synthetic OIS-based xccy swap basis to the Libor-based xccy swap basis for each currency pair's 3-month, 1-year, 5-year, and 10-year tenors. Observe that the OIS-based xccy swap basis is much smaller across the term structure for all currency pairs, with the reduction being more pronounced for the long horizons ($>$ 3-months). Because xccy basis swaps above 3-month tenors exchange mechanical Libor-indexed cashflows, parsing out these cashflows and replacing them with OIS-indexed cashflows reduces the portion of the xccy basis attributable to purely mechanical factors, such as swapping contractually market standardized Libor cashflows.

Turning to formal empirical tests, Table 4 presents panel regression results from regress-

[15] A simpler method would be to combine a Libor-based currency basis swap with Libor-OIS swaps in each bilateral currency. The end result will be an OIS-based xccy basis swap. However, because Libor-OIS swaps are not available in every currency in the sample and are not very liquid, I chose to use the more involved procedure of creating synthetic OIS-based xccy swap prices.

ing the synthetic OIS-based xccy swap basis on three different proxies for the collateral rental yield (GC-based in Panel A, T-bill-based in Panel B, and BOX-based in Panel C) and other factors from the empirical literature for 1-year to 10-year tenors. It includes specifications wherein all variables are in levels. If the proxy collateral rental yield effectively measures collateral costs and the xccy basis swaps market as a whole is perfectly and fully collateralized, the framework suggests a slope coefficient of 1 (because the synthetic xccy swap prices are OIS-based). However, given that the xccy swap market is not fully collateralized in practice, there are still counterparty credit risk premia, and the proxies for the collateral rental yield are composed of short-term rates (due to a lack of data on matched tenor proxies), I would expect the coefficient to be less than one.

Table 4 shows that for each horizon, the coefficient on each proxy for the collateral rental yield is less than one, but still as high as one half, and statistically significant. The collateral rental yield is associated with a more negative xccy basis, which is economically significant. The magnitude of the coefficient estimates is similar across the three proxies and decreases as the tenor increases. The magnitude decrease is expected given that the tenor mismatch between the OIS-based xccy basis and the proxy measures for the collateral rental yield increases as the horizon increases because the short-term proxy does not capture perfectly the whole term structure. This also explains why the R^2 is small.

The remaining contribution to the variation in the xccy basis is due to the Libor-OISs spread because of residual counterparty credit risk (not related to mechanical Libor cashflows) because the xccy basis swaps market, while heavily collateralized, is not exactly fully collateralized. The strength of the US dollar has an independent contribution to the xccy basis here, as it did in the previous short-term basis analysis. Naturally, the same reasoning applies. The collateral rental yield proxies do not involve a change in measure between the bilateral currencies, reflecting the fact that the collateral is MtM continuously and denominated in US dollars. As a result, the effect of the collateral's required US dollar currency denomination is not absorbed in the collateral rental yield and appears to affect the xccy basis outside of it, according to the proposed hypotheses in this study.

Other intermediary frictions and regulatory constraints, including the regulatory year-end, leverage, and capital factors, are also persistently related to the long-term synthetic OIS-based xccy basis across the tenors independently of the collateral rental yield, which is in line with the existing empirical evidence (Cenedese, Corte, and Wang, 2020; Du, Tepper, and Verdelhan, 2018; Baba and Packer, 2009a, 2009b). Despite the inclusion of these factors in the regressions, the collateral rental yield proxies remain significant, indicating that collateral affects xccy base prices through an independent and direct collateral channel.

In sum, the above analysis shows that collateral rental yield proxies are significant and help to explain long-term OIS-based CIP violations on average across tenors. Compared to the analysis on the short-term CIP violations, the results on the long-term CIP violations show that the intermediary frictions have independent effects on the CIP, suggesting that the collateral rental yield affects the CIP independently of these frictions, which I investigate in more detail next.

6.4 Global Risks, Intermediary Frictions, and The Collateral Channel

The literature has related the CIP violations to global risks and frictions facing intermediaries (e.g., Cenedese, Corte, and Wang, 2020; Avdjiev, Du, Koch, and Shin, 2019; Du, Tepper, and Verdelhan, 2018; Sushko, Borio, McCauley, and McGuire, 2016; Baba and Packer, 2009a, 2009b). To understand if there is evidence that these risks and frictions affect the CIP violations via a collateral transmission channel, Table 5 shows panel regression results from regressing the each of the proxy collateral rental yield on several counterparty and global risk proxies as well as on intermediary frictions. In particular, I examine the covariation of the various collateral rental yields with the regulatory year-end reporting constraints, the leverage of broker dealers factor from AEM, the leverage and capital factors of bank holding companies from HKM, the measures of US dollar risks, and the counterparty credit and funding risks.

In the specification in levels in Panel A, consistent with the key role of banks' balance sheets on year-end reporting dates, I find that the GC-based collateral rental yield is statistically significant and systematically larger for contracts that cross year-end reporting dates. The GC-based collateral rental yield is on average 6.4 basis points more expensive on year-end across tenors. Apart from the BOX-based collateral rental yield, the HKM regulatory leverage and capital factors are not significant across proxies, indicating that leverage and capital regulation do not affect directly the collateral funding costs (the AEM leverage factor was tested and because it was insignificant was removed due to limited number of quarterly observations).

Furthermore, the US Libor-OISs spreads are significant for both the T-bill and BOX-based collateral rental yields but not for the GC-based collateral rental yield suggesting that the T-bill and BOX-based proxies capture residual counterparty credit risks or general credit conditions in the economy, and that they are relatively poorer proxies for the true and frictionless theoretical risk-free rate. Instead, GC repo rates appear to be superior proxies for the risk-free rate.

The result that the collateral rental yield is not persistently related to proxies for intermediary frictions is not surprising. Based on this study's framework, the collateralization is rationalized, developed, and implemented in a frictionless risk-neutral setting, assuming that every counterparty in the market can fund at a common risk-free rate. However, in practice, there is no single risk-free rate, the market is not fully collateralized, and regulatory frictions are unavoidable. Furthermore, the proxies used to calculate the risk-free rate are imperfect. As a result, the analysis suggests that it is plausible that the collateral not only directly and independently affects the prices of xccy basis, but that it can also be affected by some of the same factors that affect these xccy prices separately. In other words, the collateral is not completely frictionless.

Furthermore, the results that the collateral rental yield does not covary with the strength of the US dollar, despite the fact that it should based on the framework due to the need to post US dollar collateral, are supported empirically here because the simple proxies for the collateral rental yield do not entail a change in measure in the bilateral currencies. However, the log FX volatility and exchange rate, and forward FX bid-ask spread liquidity frictions appear to affect the collateral rental yield, albeit not consistently across proxies.

Overall, the collateral rental yield is related to the CIP violations directly and independently via a direct collateral channel; however, it can covary with measures of residual counterparty credit and funding risk, as well as the regulatory intermediary frictions. These frictions also affect the CIP violations independently of the collateral rental yield.

7 Conclusions

In this study, I introduce and implement costly collateralization to short and long-term violations of the CIP no-arbitrage conditions. Such collateral considerations drive the opportunity costs associated with collateral investment and funding. Taken together, the empirical results suggest that collateralization details in derivative contracts are an important and persistent factor contributing (about two-thirds on average) to the violations of the standard CIP conditions. Due to the presence of collateral when trading FX forwards and xccy swaps, the CIP arbitrage measurement formula requires an adjustment for collateral opportunity costs and currency to be consistent with no-arbitrage laws.

Furthermore, the results suggest an important collateral channel through which costly collateralization contributes directly and independently to explaining standard CIP violations. The evidence shows that the documented collateral channel is independent of some of the previously documented global risks and intermediary frictions, which also contribute to explaining the standard CIP violations. This helps reconcile with the existing explanations in the CIP literature. Finally, because the collateral rental yield is common among many derivative instruments, one should expect a commonality among other asset class cash-derivatives bases, which is a topic left for further research.

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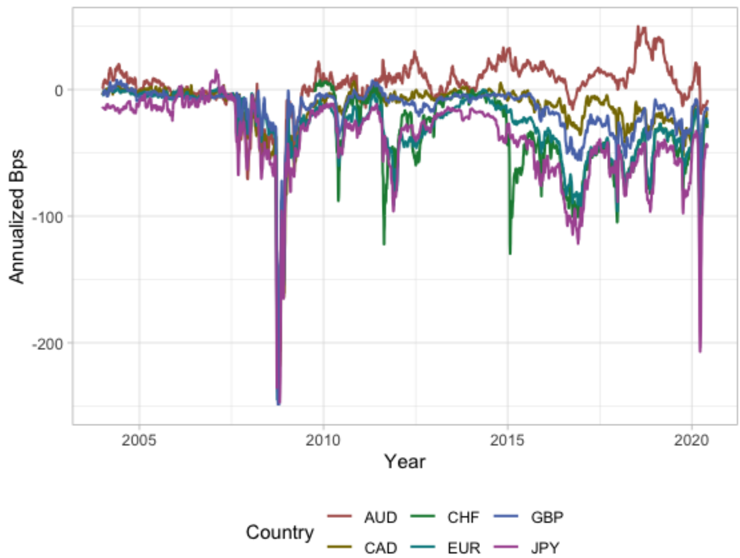
Figure 1: Historical Behavior of the Xccy Basis for G7 currencies against the US dollar. The countries and currencies are denoted by the abbreviations: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY).

Panel A: Short-Term OIS-Based Deviations from CIP

This figure plots the 7-day moving averages of the 3-month OIS-based xccy basis measured in basis points, for G7 currencies. The OIS-based xccy basis is calculated as: $o^{\$}_{t,t+1} - (o^{i}_{t,t+1} - \frac{1}{n}(f_{t+1} - s_t))$, where $o^{\$}_{t,t+1}$ and $o^{i}_{t,t+1}$, denote the US and foreign 3-month OIS rates and $(f_{t+1} - s_t)$ denotes the forward premium obtained from the forward and spot exchange rates. The CIP implies that the basis should be zero.



Panel B: Long-Term Libor-Based Deviations from CIP

This figure plots the 7-day moving averages of the 5-year Libor-based xccy basis measured in basis points, for G7 currencies, which is obtained from xccy basis swap contracts directly.

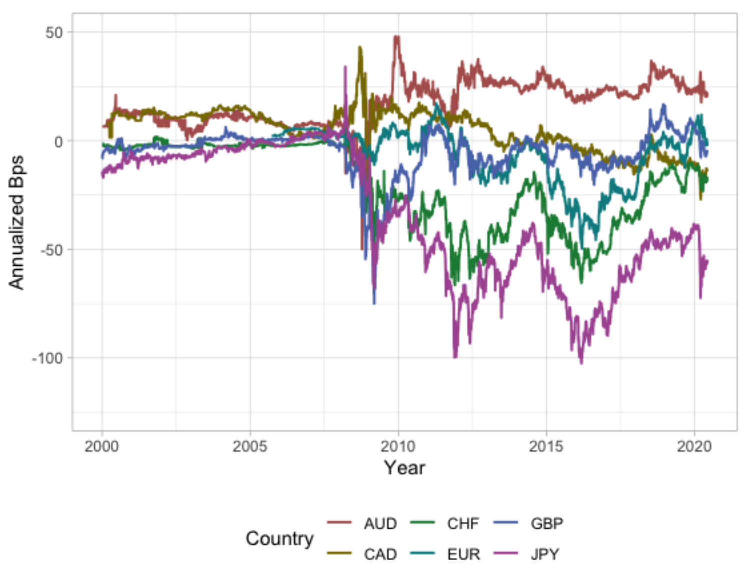
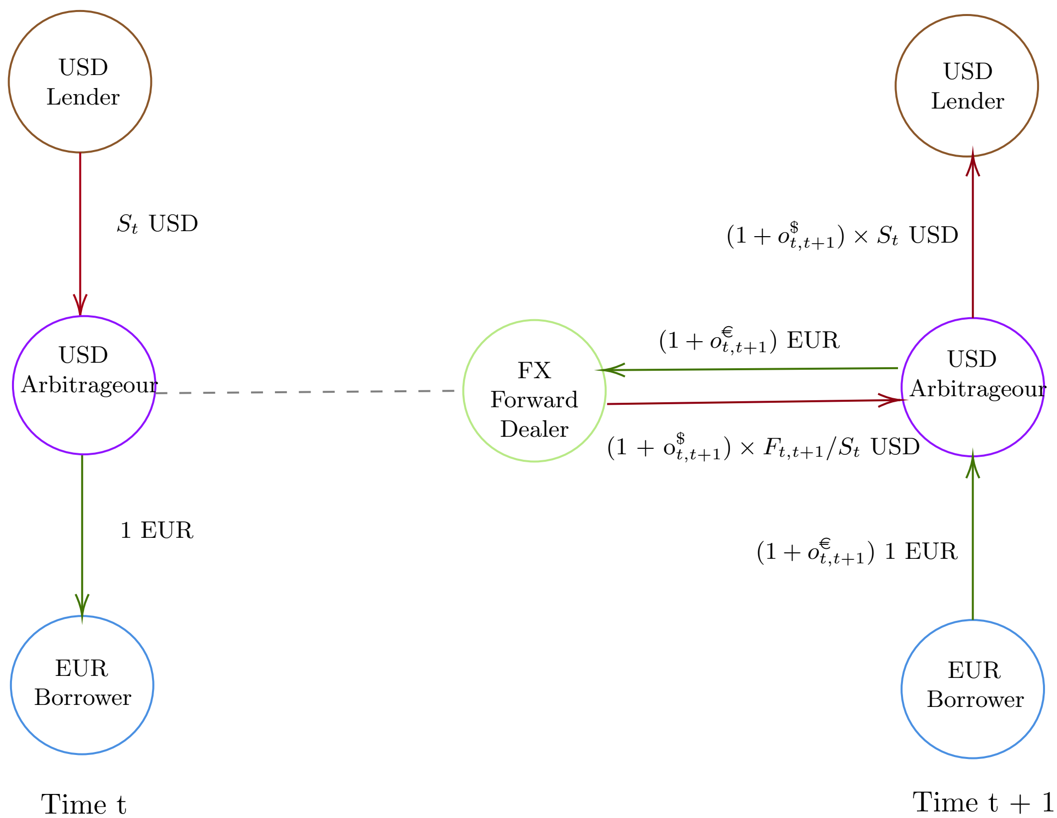


Figure 2: Cash Flow Diagram for Standard CIP Arbitrage in US dollars.
This figure plots the cash flow exchanges of an arbitrageur trying to profiting from a negative cross-currency basis ($x_{t,t+1} \leq 0$) between the euro and the US dollar not facing collateralization in US dollars. To arbitrage the negative standard OIS-based cross-currency basis, the US dollar arbitrageur will borrow S_t US dollars at the interest rate $o^{\$}_{t,t+1}$, convert and will lend 1 euro at the interest rate of $o^{€}_{t,t+1}$, and simultaneously will sign a non-collateralized forward contract at date t. There are net zero cash flows at time t. At date $t+1$, the arbitrageur will receive $e^{o^{€}_{t,t+1}} \approx (1+o^{€}_{t,t+1})$ euro, and convert them into $e^{o^{€}_{t,t+1}} F_{t,t+1}/S_t \approx (1+o^{€}_{t,t+1})F_{t,t+1}/S_t$ US dollars thanks to the forward contract. At time $t+1$, the arbitrageur repays her debt in US dollars and is left with a profit equal to the negative of the cross-currency basis $x_{t,t+1}$. Essentially, the arbitrageur goes long in the euro and short in the US dollar loan, with the euro cash flow fully hedged by the non-collateralized forward contract.



Arbitrageour's
Net Cash Flow: 0 USD $-(1+o^{\$}_{t,t+1}) \times S_t/F_{t,t+1} + (1+o^{€}_{t,t+1}) \approx -x_{t,t+1} \geq 0$ USD

Figure 3: Cash Flows of a Collateralized OIS-Based Cross Currency Basis Swap.
This diagram illustrates the cash flows generated from collateralized cross currency swap. Under the swap a counterparty is borrowing € and lending \$ synthetically. The counterparty receives the 3-month OIS $O^{\$}(T_{n-1}, T_n)$ accrued every δ fraction of a year (3-months - being quarter of a year or 0.25) on the $S_0^{\$}$ notional and pays the 3-month OIS plus the xccy basis $(O^{€}(T_{n-1}, T_n) + x_n)$ accrued every δ fraction of the year on the €1 notional. The notional face amounts are exchanged both at time 0 and at time T, converted at the spot FX rate, S_0, one unit of € for \$ currency. $h_{\$}$ is the MtM in \$ currency that the counterparty needs to pay if it is negative or that the counterparty needs to receive if it is positive. $o_{t-1}^{\$}$ is the collateral rate set at $t-1$ and paid at t , e.g. the annualized overnight \$ FedFunds (OIS) rate. This rate accrues from $t-1$ to t, representing by the day fraction ϕ of 1/365.

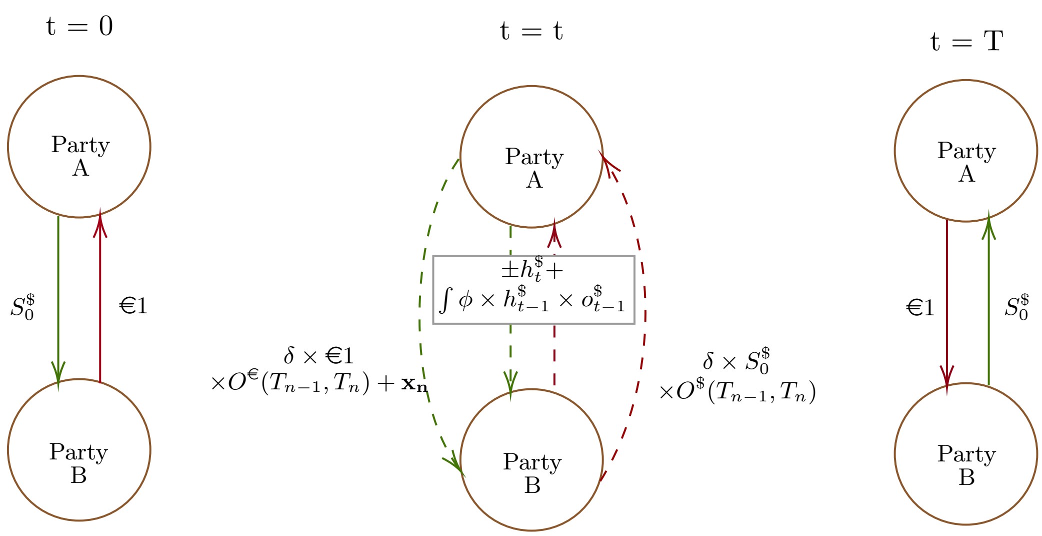


Figure 4: Composition of Collateralization

This figure reports the level of collateralization in the reported executed xccy basis trades between January 1, 2013 and March 31, 2020, which are publicly distributed by the Depository Trust & Clearing Corporation (DTCC) Data Repository (U.S.) LLC (DDR). Fully collateralized (FC) require counterparties to post initial and variation margin, partially collateralized (PC) require counterparties to provide variation margin only (PC), one-way collateralized (OC) require only one of the counterparties to post margin, and uncollateralized (UC) does not require any margin posting. Panel A presents the distribution of reports across different types of transaction collateralizations for the total sample period between 2013-2020 while Panel B zooms in on these collateralization compositions over time.

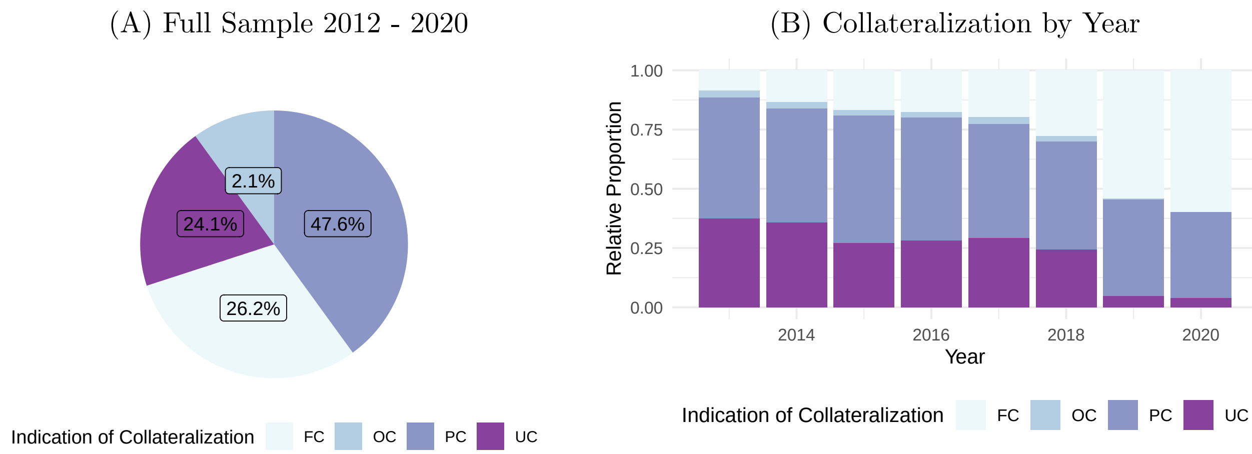


Figure 5: Cross-Section of Currency Basis and Collateral Rental Yield (2009-2020). This figure shows the cross-sectional relationship between the xccy basis on the y-axis and the various collateral rental yield proxies on the x-axis for the short-term (Panel A) and long-term (Panel B) tenor. The 3-month OIS-based xccy basis is calculated as: $o^{\$}_{t,t+1} - (o^{i}_{t,t+1} - \frac{1}{n}(f_{t+1} - s_t))$, where $o^{\$}_{t,t+1}$ and $o^{i}_{t,t+1}$, denote the US and foreign 3-month OIS rates and $(f_{t+1} - s_t)$ denotes the forward premium obtained from the forward and spot exchange rates. The GC-based collateral rental yield is the difference in the differenced foreign currency 3-month GC repo and OIS rates and the differential less the US dollar 3-month GC repo and OIS rates; the T-bill-based collateral rental yield is the difference in the differenced foreign currency foreign currency 3-month T-bill and OIS rates less the US dollar 3-month T-Bill and OIS rates; and the BOX-based collateral rental yield is the difference in the differenced foreign currency 3-month T-bill and OIS rates less the US dollar 6-month BOX and OIS rates. The countries and currencies are denoted by the abbreviations: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY).

Short-Term OIS-based CIP - 3-month horizon

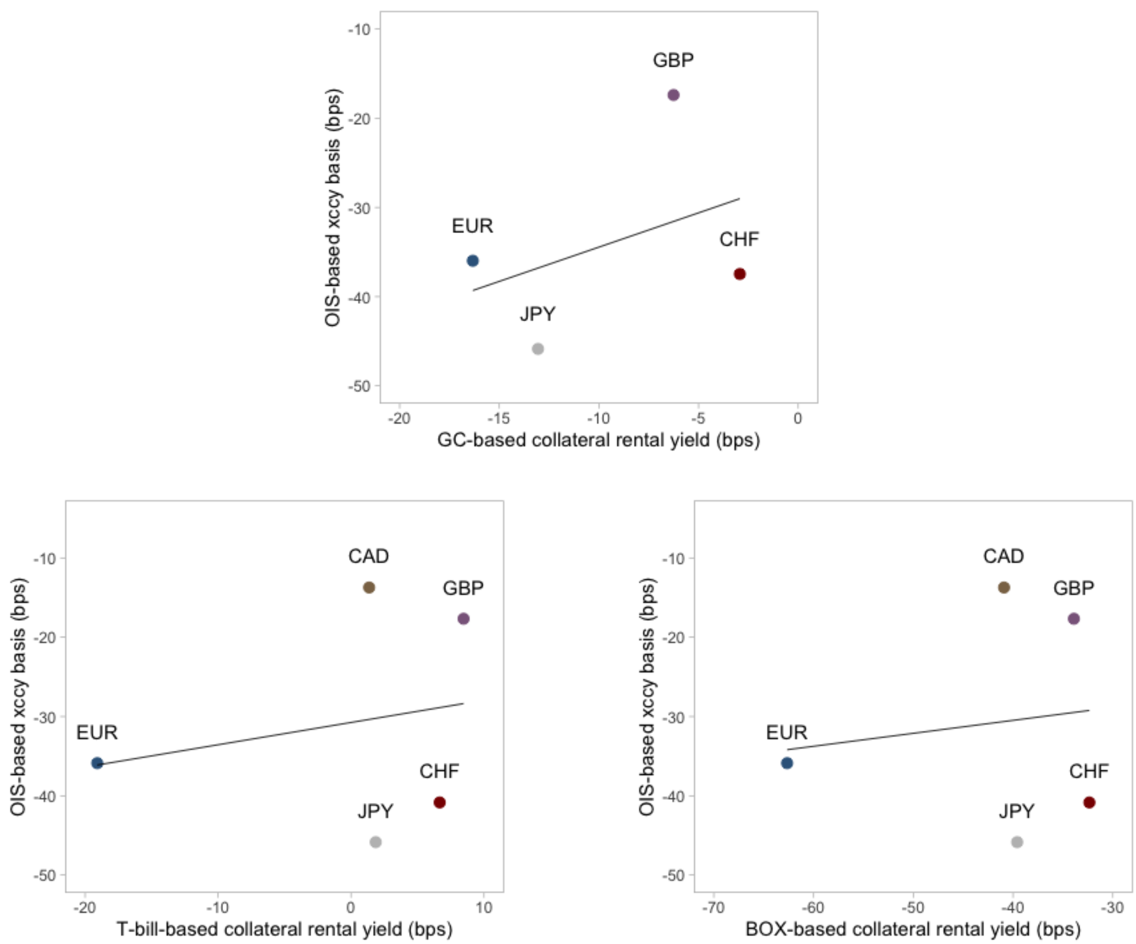
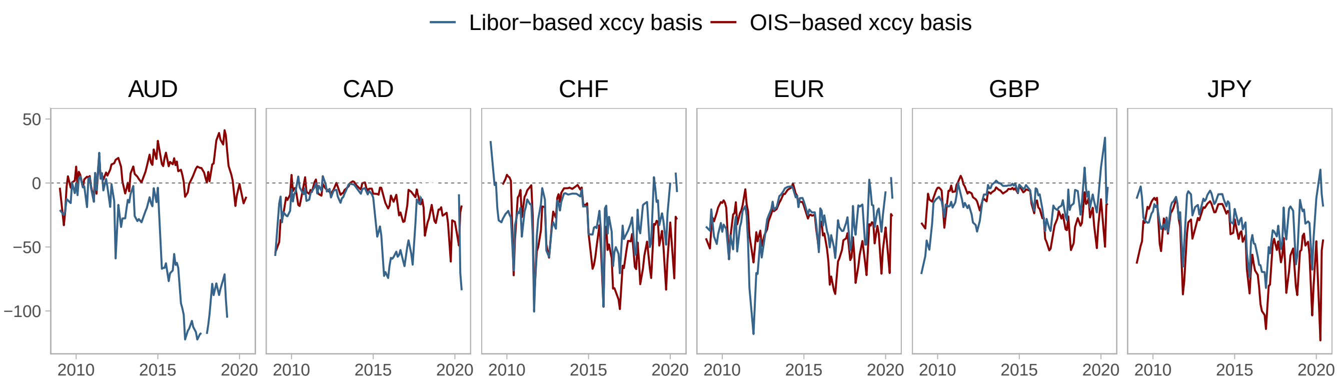
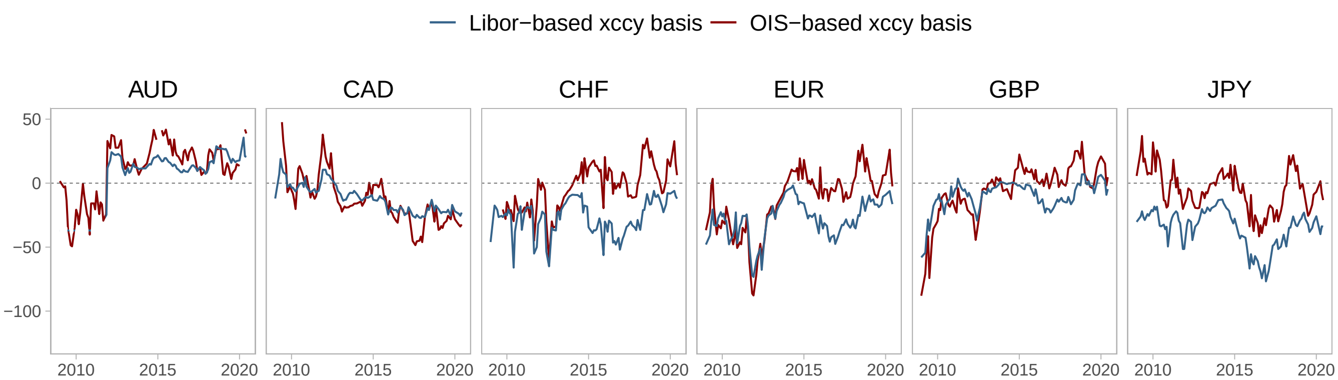


Figure 6: Standard Libor Versus OIS-Based CIP Deviations.
This figure shows the monthly Libor-based xccy basis versus the OIS-based xccy basis for G7 currencies for the full sample 1/1/2009-5/31/2020. The 3-month standard OIS-based basis is calculated as: $o^{\$}_{t,t+1} - (o^{i}_{t,t+1} - \frac{1}{n}(f_{t+1} - s_t))$, where $o^{\$}_{t,t+n}$ and $o^{i}_{t,t+1}$, denote the US and foreign 3-month OIS rates and $(f_{t+1} - s_t)$ denotes the forward premium obtained from the forward and spot exchange rates. The standard Libor-based xccy basis is obtained from xccy basis swap contract prices directly. The OIS-based xccy basis stands for the re-calculated xccy basis following the procedure in Internet Appendix B.

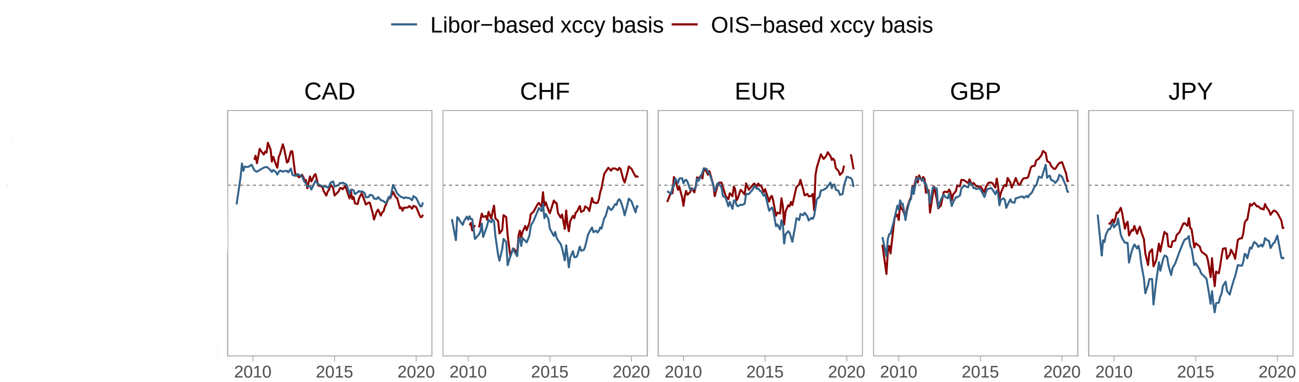
Panel A: 3-month Horizon



Panel B: 1-year Horizon



Panel C: 5-year Horizon



Panel D: 10-year Horizon

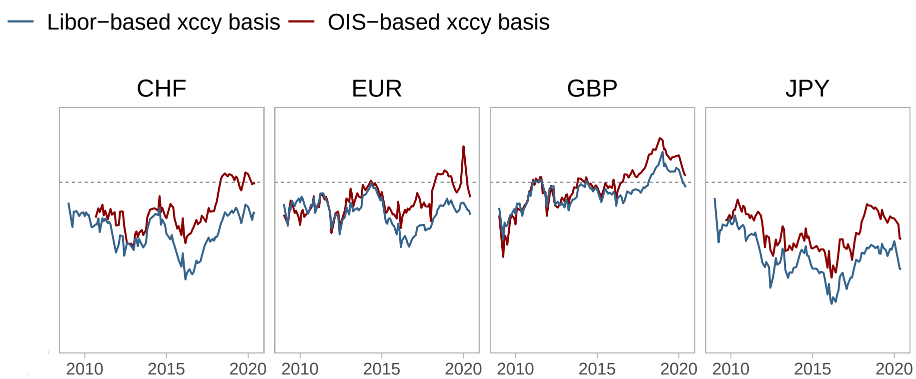


Table 1: Short-term Standard OIS-based vs. Collateral-Adjusted CIP Deviations

This table reports the mean of daily short-term OIS-based xccy basis versus their maturity matched collateral-adjusted xccy bases for G7 currencies for two different periods. Similar to Du and Schregner (2021), the two samples are the "Crisis" periods, which include August 2008 - December 2009 (GFC), November 2011 - February 2012, and March 2020 - May 2020 (Covid), and the "Post-Crisis" period that runs from January 1, 2010 to May 31, 2020 and excludes the Crisis period. Standard deviations are shown in the parentheses. The short-term n-month OIS-based basis is calculated as: $o^{\$}_{t,t+n} - (o^{i}_{t,t+n} - \frac{1}{n}(f_{t,n} - s_t))$, where $o^{\$}_{t,t+n}$ and $o^{i}_{t,t+n}$, denote the US and foreign n-month OIS rates and $(f_{t,n} - s_t)$ denotes the forward premium obtained from the forward $f_{t,t+n}$ and spot s_t exchange rates. The n stands for $1w$ (1-week), $1m$ (1-month), and $3m$ (3-month); $x^{adj}_{n,gc}$ stands for the re-calculated OIS-based xccy basis adjusted for the GC-based collateral rental yield $y^{i/\$}_{n,gc}$, which the is difference in the differenced foreign currency n-month GC repo and OIS rates and the differential less the US dollar n-month GC repo and OIS rates; $x^{adj}_{3m,tbill}$ stands for the re-calculated OIS-based xccy basis adjusted for the T-bill-based collateral rental yield $y^{i/\$}_{3m,tbill}$, which is difference in the differenced foreign currency foreign currency 3-month T-bill and OIS rates less the US dollar 3-month T-Bill and OIS rates; and $x^{adj}_{3m,BOX}$ stands for the re-calculated OIS-based xccy basis adjusted for the BOX-based collateral rental yield $y^{i/\$}_{3m,BOX}$, which is difference in the differenced foreign currency 3-month T-bill and OIS rates less the US dollar 6-month BOX and OIS rates. The countries and currencies are denoted by the abbreviations: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY).

Short-Term Mean CIP deviations

		1W		1M		3M			
	Currency	x^{OIS}_{1w}	$x^{adj}_{1w,gc}$	x^{OIS}_{1m}	$x^{adj}_{1m,gc}$	x^{OIS}_{3m}	$x^{adj}_{3m,gc}$	$x^{adj}_{3m,tbill}$	$x^{adj}_{3m,BOX}$
Post-Crisis	EUR	-26.20	-14.33	-35.66	-21.02	-35.47	-19.64	-10.50	20.15
		(62.79)	(61.91)	(29.13)	(25.83)	(21.1)	(17.74)	(15.62)	(14.88)
	JPY	-35.45	-23.28	-43.68	-27.52	-45.21	-26.38	-41.08	-10.88
		(59.21)	(55.91)	(34.78)	(28.55)	(24.55)	(17.18)	(20.4)	(16.08)
	CHF	-42.85	-27.35	-53.97	-29.57	-37.37	-28.38	-40.54	-12.53
		(90.04)	(88.5)	(41.78)	(38.95)	(27.83)	(23.41)	(25.52)	(24.89)
	GBP	-15.3	-2.83			-16.61	-1.89	-18.8	11.73
		(107.81)	(108.25)			(14.12)	(16.11)	(15.32)	(13.77)
	CAD					-11.88		-6.98	23.8
						(10.79)		(11.92)	(11.59)
	AUD					10.95			
						(12.18)			
	Mean	-27.05	-14.58	-41.3	-24.87	-33.67	-19.07	-23.53	6.51
		(82)	(81.08)	(33.84)	(29)	(24.81)	(21.52)	(23.45)	(22.78)
Crisis	EUR	-54.34	-55.90	-59.80	-50.83	-55.68	-39.28	-38.12	32.76
		(99.2)	(97.12)	(80.32)	(66.63)	(61.52)	(45.52)	(55.49)	(40.06)
	JPY	-56.02	-50.70	-71.12	-57.03	-71.18	-53.05	-84.50	-13.64
		(84.62)	(86.35)	(94.97)	(83.39)	(75.81)	(63.03)	(96.71)	(50.46)
	CHF	-62.84	-46.2	-71.39	-51.16	-24.97	-25.51	-39.07	-13.57
		(80.28)	(73.83)	(67)	(53.36)	(39.78)	(25.58)	(33.17)	(9.19)
	GBP	-30.28	-60.28			-38.54	-56.17	-61.12	8.25
		(64.26)	(83.31)			(54.4)	(73.38)	(77.28)	(35)
	CAD					-50.54		-51.45	17.94
						(53.7)		(56.05)	(23.62)
	AUD					-33.48			
						(64.3)			
	Mean	-47.66	-55.16	-65.92	-53.74	-52.11	-47.13	-57.27	10.11
		(84.47)	(88.42)	(86.73)	(74.12)	(64.35)	(59.94)	(73.06)	(41.38)

Table 2: Panel Regression Results for the Short-Term OIS-based Xccy Basis on the Observable Proxies for the Collateral Rental Yield

This table shows panel regression results for the daily level/monthly changes (Panel A/Panel B) in the OIS-based xccy basis (dependent variable), x_n^{OIS}, on level/monthly changes (Panel A/Panel B) in the maturity matched, n, collateral rental yield proxy, $y_n^{i/\$}$, and other controls in the period between 1 January 2009 and 31 May 2020, where $n = 1w$ (1-week), $1m$ (1-month), and $3m$ (3-month). The n-month OIS-based basis is calculated as: $o^{\$}_{t,t+n} - (o^{i}_{t,t+n} - \frac{1}{n}(f_{t,n} - s_t))$, where $o^{\$}_{t,t+n}$ and $o^{i}_{t,t+n}$, denote the US and foreign n-month OIS rates and $(f_{t,n} - s_t))$ denotes the forward premium obtained from the log of the forward $f_{t,t+n}$ and spot s_t exchange rates. The independent variables are: $y^{i/\$}_{n,GC}$, spread between the differential between foreign currency n-month GC repo and OIS rates and the differential between the US dollar n-month GC repo and OIS rates (in basis points); $y^{i/\$}_{Tbill}$, spread between the differential between foreign currency 3-month T-bill and OIS rates and the differential between the US dollar 3-month T-bill rates and OIS rates (in basis points); $y^{i/\$}_{BOX}$, spread between the differential between foreign currency 3-month T-bill and OIS rates and the differential between the US dollar 6-month BOX implied rates and OIS rates (in basis points); $Qend$ is an indicator variable that equals 1 for the last 6 days of the quarter and equals 0 if otherwise ; $Yend$ is an indicator variable that equals 1 for the last month of the year and equals 0 if otherwise; $LiborOISs$, the difference of the spread between the 3-month Libor and 3-month OIS of the foreign currency and the spread between the 3-month Libor and 3-month OIS of the US dollar (in basis points); $FXbidask$, the ask normalized spread between the bid and ask of the bilateral n-month FX forward exchange rate (in pips); $US\ factor$ is the trade weighted US dollar index created by the FED; $\Delta lnFX$, the change in the log FX bilateral spot exchange rate of the US dollar against the foreign currency; $lnVol$, the log of implied volatility on effective 3-month at-the-money FX options; $lnVix$, the log of the VIX index. The currencies included are: Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY) of Currency and year fixed effects are included in all specifications. Robust, two-way clustered standard errors by currency and time are shown in the parenthesis for specifications in changes. HAC-adjusted SE at 90 lags for daily specification in levels. Data source: BNP Paribas, Bloomberg, Tullet Prebon, Swiss Stock Exchange, Bank of England. Significance: *** p<0.01, ** p<0.05, * p<0.1.

PANEL A: *In Levels*

	Dependent variable: x_n^{OIS}									
	$n = 1w$		$n = 1m$		$n = 3m$					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$y^{i/\$}_{n,GC}$	1.10***	0.91**	1.42***	1.23***	0.51***	0.18***				
	(0.38)	(0.36)	(0.32)	(0.22)	(0.11)	(0.07)				
$y^{i/\$}_{3m,Tbill}$							0.56***	0.50***		
							(0.06)	(0.05)		
$y^{i/\$}_{3m,BOX}$									0.60***	0.43***
									(0.04)	(0.05)
$Qend$		−25.78***		-8.24**		1.90		0.61		0.58
		(7.19)		(3.74)		(1.41)		(1.21)		(0.97)
$Yend$		−36.11**		−43.07***		−2.62**		−3.25**		−3.80**
		(14.73)		(9.66)		(1.07)		(1.37)		(1.59)
$LiborOISs$		0.33*		0.68***		0.63***		0.22***		0.25***
		(0.18)		(0.14)		(0.07)		(0.02)		(0.03)
$FXbidask$		−43.99*		16.68		−11.90**		−18.80***		−22.06***
		(22.85)		(10.60)		(5.89)		(4.54)		(6.49)
$US\ factor$		0.10		0.32		−1.04***		−1.30***		−0.82***
		(0.79)		(0.60)		(0.25)		(0.28)		(0.24)
$\Delta lnFX$		150.13		30.05		57.80*		41.54		26.03
		(124.38)		(56.69)		(31.46)		(25.67)		(24.60)
$lnVol$		23.02**		8.11		−0.92		−2.79		−0.90
		(9.51)		(8.96)		(2.42)		(2.58)		(3.35)
$lnVix$		−5.40		2.22		−6.42*		−8.80**		−3.39
		(8.64)		(7.02)		(3.70)		(4.14)		(4.04)
Currency pairs	4	4	3	3	4	4	5	5	5	5
Within Adj-R^2	0.02	0.08	0.37	0.46	0.09	0.33	0.15	0.38	0.39	0.51
Observations	8,440	7,576	5,458	4,854	10,491	9,520	14,604	13,355	11,234	11,127

PANEL B: *In Changes*

	Dependent variable: Δx_n^{OIS}									
	$n = 1w$		$n = 1m$		$n = 3m$					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\Delta y_{n,GC}^{i/\$}$	0.52***	1.12***	0.81**	0.54**	0.34**	0.12**				
	(0.12)	(0.16)	(0.36)	(0.22)	(0.13)	(0.04)				
$\Delta y_{3m,Tbill}^{i/\$}$							0.39***	0.37***		
							(0.08)	(0.08)		
$\Delta y_{3m,BOX}^{i/\$}$									0.31***	0.20***
									(0.06)	(0.06)
$Yend$		−40.32***		−51.29***		−2.45***		−2.87**		−3.80**
		(9.57)		(12.68)		(1.27)		(1.34)		(1.60)
$\Delta LiborOISs$		0.15		−0.52		0.43***		0.28***		0.20**
		(0.19)		(0.41)		(0.11)		(0.07)		(0.08)
$\Delta FXbidask$		25.72		−107.44*		−7.69		0.29		0.73
		(20.45)		(59.64)		(11.21)		(9.16)		(10.98)
$\Delta US\ factor$		−2.11**		−3.43		−1.85***		−1.56***		−0.96*
		(1.03)		(2.34)		(0.67)		(0.49)		(0.51)
$\Delta lnFX$		30.27		45.01		34.03		24.92		48.72*
		(54.06)		(138.34)		(32.26)		(24.53)		(24.92)
$\Delta lnVol$		30.35***		7.55		−4.49		−1.67		4.66
		(11.52)		(31.26)		(7.08)		(5.20)		(5.60)
$\Delta lnVix$		−6.94		−34.15*		−9.40**		−9.11***		−8.70**
		(7.41)		(17.63)		(4.74)		(3.34)		(3.72)
Currency pairs	4	4	3	3	4	4	5	5	5	5
Within Adj-R^2	0.01	0.25	0.01	0.22	0.01	0.18	0.02	0.26	0.05	0.19
Observations	272	206	175	130	340	262	444	356	296	296

Table 3: Difference-in-Difference of the Short-Term Collateral Rental Yield Pre and Post-Crisis

This table reports the results from a difference-in-difference panel regression of daily short-term OIS-based xccy basis on its maturity matched collateral rental yield proxy and a dummy denoted "Post-Crisis" indicating 1 for the period from January 1, 2010 to May 31, 2020 excluding the Crisis periods which are the GFC from August 2008 - December 2009, and the Covid from March 2020 - May 2020 and 0 otherwise (subsamples are similar to Du and Schregner (2021)). The short-term n-month OIS-based xccy basis is calculated as: $o^{\$}_{t,t+n} - (o^{i}_{t,t+n} - \frac{1}{n}(f_{t,n} - s_t))$, where $o^{\$}_{t,t+n}$ and $o^{i}_{t,t+n}$, denote the US and foreign n-month OIS rates and $(f_{t,n} - s_t))$ denotes the forward premium obtained from the forward $f_{t,t+n}$ and spot s_t exchange rates. The n stands for $1w$ (1-week), $1m$ (1-month), and $3m$ (3-month). The collateral rental yield proxies are: $y^{i/\$}_{n,gc}$, the difference in the differenced foreign currency n-month GC repo and OIS rates and the differential less the US dollar n-month GC repo and OIS rates; $y^{i/\$}_{tbill}$, the difference in the differenced foreign currency foreign currency 3-month T-bill and OIS rates less the US dollar 3-month T-Bill and OIS rates; and $y^{i/\$}_{BOX}$, the difference in the differenced foreign currency 3-month T-bill and OIS rates less the US dollar 6-month BOX and OIS rates. The countries and currencies used are: Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY). Currency and year fixed effects are included in all specifications. HAC-adjusted SE at 90 lags. Data source: BNP Paribas, Bloomberg, Tullet Prebon, Swiss Stock Exchange, Bank of England. Significance: *** p<0.01, ** p<0.05, * p<0.1.

	Dependent variable: x_n^{OIS}				
	$n = 1w$	$n = 1m$	$n = 3m$		
	(1)	(2)	(3)	(4)	(5)
$y^{i/\$}_{n,gc}$	0.12	0.53	0.39		
	(0.25)	(0.48)	(0.30)		
$y^{i/\$}_{n,gc} \times PostCrisis$	0.93**	1.14**	0.49**		
	(0.38)	(0.45)	(0.20)		
$y^{i/\$}_{tbill}$				−0.23	
				(0.21)	
$y^{i/\$}_{tbill} \times PostCrisis$				0.91***	
				(0.20)	
$y^{i/\$}_{BOX}$					0.86***
					(0.07)
$y^{i/\$}_{BOX} \times PostCrisis$					0.16**
					(0.08)
$PostCrisis$	28.08*	21.06*	28.75***	22.50**	−3.82
	(15.12)	(11.39)	(4.52)	(11.21)	(3.04)
Currency pairs	4	3	4	5	5
Within Adj-R^2	0.03	0.30	0.21	0.16	0.52
Observations	8616	5546	10667	14954	11565

Table 4: Panel Regression Results for the Long-Term Synthetic OIS-Based Xccy Basis on the Various Collateral Rental Yield Measures and Several Frictions and Factors

This table shows panel regression results for the monthly level in the synthetic OIS-based xccy basis (dependent variable), x_n^{OIS}, on the level proxy for the GC-based collateral rental yield $y^{i/\$}_{3m,GC)}$ (Panel A), for the T-bill-based collateral rental yield $y^{i/\$}_{3m,Tbill)}$ (Panel B), and for the BOX-based collateral rental yield $y^{i/\$}_{6m,BOX)}$ (Panel C) expressed in basis points, and other controls in the period between 1 January 2009 and 31 May 2020. The other independent variables are factors related to regulation, which are $Yend$ is an indicator variable that equals 1 for the last month of the year and equals 0 if otherwise, the factors for leverage of security broker dealers form Adrian, Etula, and Muir (2014) (AEM) and for leverage and capital of bank holding companies of He, Kelly, and Manela (2017) (HKM); $LiborOISs$, the difference of the spread between the 3-month Libor and 3-month OIS of the foreign currency and the spread between the 3-month Libor and 3-month OIS of the US dollar (in basis points); $FXbidask$, the ask normalized spread between the bid and ask of the bilateral 3-month FX forward exchange rate (in pips); $US\ factor$ is the trade weighted US dollar index created by the FED; $\Delta lnFX$, the change in the log FX bilateral spot exchange rate of the US dollar against the foreign currency; $lnVol$, the log of implied volatility on effective 3-month at-the-money FX options; $lnVix$, the log of the VIX index. The currencies used are: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY). Currency and year fixed effects are included in all specifications. Robust, two-way clustered standard errors by currency and time are shown in the parenthesis for the specifications in changes. HAC-adjusted SE at 5 lags for specification in levels. Significance: *** p<0.01, ** p<0.05, * p<0.1.

PANEL A: *For GC-based collateral rental yield proxy (in levels)*

	Dependent variable: x_n^{OIS}					
	1-year xccy basis		5-year xccy basis		10-year xccy basis	
	(1)	(2)	(3)	(4)	(5)	(6)
$y^{i/\$}_{3m,GC}$	0.41***	0.19***	0.44***	0.21***	0.34***	0.25***
	(0.07)	(0.06)	(0.09)	(0.08)	(0.05)	(0.10)
$Yend$		−6.28***		−3.12		−1.61
		(2.18)		(2.20)		(2.31)
$HKM\ leverage$		−0.02**		−0.05***		−0.04***
		(0.01)		(0.01)		(0.01)
$HKM\ capital$		−19.27**		−41.65***		−35.35***
		(9.65)		(11.97)		(12.72)
$LiborOISs$		−0.05		−0.16**		−0.14*
		(0.06)		(0.07)		(0.07)
$US\ factor$		−0.26***		−0.65***		−0.72***
		(0.11)		(0.23)		(0.29)
$\Delta lnFX$		−16.69		−17.57		−15.50
		(19.52)		(19.60)		(21.09)
$lnVol$		−10.23***		−8.30**		−5.33
		(3.89)		(3.83)		(4.06)
$FXbidask$		23.14*		19.87*		26.43**
		(12.00)		(10.78)		(12.39)
$lnVix$		−8.58**		−3.38		−1.05
		(3.84)		(3.82)		(4.03)
Currency pairs	4	4	4	4	4	4
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Within Adj-R^2	0.01	0.11	0.01	0.22	0.01	0.13
Observations	344	264	335	257	331	253

PANEL B: *For Tbill-based collateral rental yield proxy (in levels)*

	Dependent variable: x_n^{OIS}					
	1-year xccy basis		5-year xccy basis		10-year xccy basis	
	(1)	(2)	(3)	(4)	(5)	(6)
$y^{i/\$}_{3m,Tbill}$	0.46***	0.42***	0.45***	0.43***	0.36***	0.28***
	(0.08)	(0.09)	(0.09)	(0.11)	(0.07)	(0.08)
$Yend$		−6.12***		−4.38**		−3.17
		(1.94)		(1.91)		(2.07)
$HKM\ leverage$		−0.01**		−0.03***		−0.03***
		(0.01)		(0.01)		(0.01)
$HKM\ capital$		−17.73**		−25.84**		−28.83**
		(8.34)		(10.52)		(11.38)
$LiborOISs$		−0.08		−0.18***		−0.07***
		(0.06)		(0.03)		(0.03)
$US\ factor$		−0.36**		−0.74***		−0.85***
		(0.18)		(0.29)		(0.30)
$\Delta lnFX$		−34.53*		−25.16		−12.23
		(18.33)		(18.16)		(19.31)
$lnVol$		−6.80*		−2.80		−4.61
		(3.69)		(3.56)		(3.75)
$FXbidask$		29.81**		25.19**		26.45**
		(12.32)		(11.77)		(11.91)
$lnVix$		−9.59***		−5.79*		−5.00
		(3.57)		(3.42)		(3.75)
Currency pairs	5	5	5	5	4	4
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Within Adj-R^2	0.01	0.14	0.02	0.16	0.02	0.13
Observations	465	369	448	355	355	281

PANEL C: *For BOX-based collateral rental yield proxy (in levels)*

	Dependent variable: x_n^{OIS}					
	1-year xccy basis		5-year xccy basis		10-year xccy basis	
	(1)	(2)	(3)	(4)	(5)	(6)
$y_{6m,BOX}^{i/\$}$	0.52***	0.43***	0.49***	0.38***	0.46***	0.35***
	(0.09)	(0.10)	(0.08)	(0.08)	(0.09)	(0.10)
$Yend$		−4.19**		−2.74		−1.21
		(1.87)		(1.98)		(2.12)
$HKM\ leverage$		−0.02**		−0.04***		−0.03***
		(0.01)		(0.01)		(0.01)
$HKM\ capital$		−18.16**		−29.23***		−21.39*
		(9.99)		(10.72)		(11.48)
$LiborOISs$		−0.09		−0.15***		−0.10**
		(0.07)		(0.04)		(0.05)
$US\ factor$		−0.41**		−0.87***		−0.93***
		(0.21)		(0.32)		(0.36)
$\Delta lnFX$		−40.50**		−20.80		−10.90
		(17.53)		(18.50)		(19.48)
$lnVol$		−0.72		−0.04		−1.62
		(3.64)		(3.76)		(3.93)
$FXbidask$		18.51		17.98		13.05
		(13.23)		(13.51)		(13.64)
$lnVix$		−3.40		0.23		2.09
		(3.90)		(4.01)		(4.33)
Currency pairs	5	5	5	5	4	4
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Within Adj-R^2	0.05	0.23	0.01	0.15	0.04	0.16
Observations	344	344	330	330	261	261

Table 5: Panel Regression Results for the Various Collateral Rental Yield Measures on Several Factors

This table shows regression results for the monthly level/changes (Panel A/Panel B) in the various measures of the collateral rental yield (dependent variable), $y_n^{i/\$}$, on the level/changes (Panel A/Panel B) of global and counterparty risk proxies and bank balance sheet constraint variables (independent variables) in the period between 1 January 2009 and 31 May 2020 for up to 6 currency pairs: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British Pound (GBP), and Japanese yen (JPY). The dependent variables are: $y_{3m,GC}^{i/\$}$, the monthly level/change of the spread between the differential between foreign currency 3-month GC repo and OIS rates and the differential between the US dollar 3-month GC repo and OIS rates; $y_{Tbill}^{i/\$}$, the monthly level/change of the spread between the differential between foreign currency 3-month T-bill and OIS rates and the differential between the US dollar 3-month T-bill rates and OIS rates; $y_{BOX}^{i/\$}$, the monthly level/change of the spread between the differential between foreign currency 3-month T-bill and OIS rates and the differential between the US dollar 6-month BOX implied rates and OIS rates. The independent variables are: factors relating to regulation, which are $Yend$, an indicator variable that equals 1 if the month is the last month of the year and equals 0 if otherwise, the factors for leverage of security broker dealers form Adrian, Etula, and Muir (2014) (AEM) and for leverage and capital of bank holding companies of He, Kelly, and Manela (2017) (HKM); $LiborOISs$, the difference of the spread between the 3-month Libor and 3-month OIS of the foreign currency and the spread between the 3-month Libor and 3-month OIS of the US dollar (in basis points); $FXbidask$, the ask normalized spread between the bid and ask of the bilateral 3-month FX forward exchange rate (in pips); $US\ factor$ is the trade weighted US dollar index created by the FED; $\Delta lnFX$, the change in the log FX bilateral spot exchange rate of the US dollar against the foreign currency; $lnVol$, the log of implied volatility on effective 3-month at-the-money FX options; $lnVix$, the log of the VIX index; Currency and year fixed effects are included in all specifications. HAC-adjusted SE are at 5 lags for monthly specification in levels. Robust, two-way clustered standard errors by currency and time are for the specifications in changes. Significance: *** p<0.01, ** p<0.05, * p<0.1

PANEL A: *In Levels*

	$y_{3m,GC}^{i/\$}$	$y_{Tbill}^{i/\$}$	$y_{BOX}^{i/\$}$
	(1)	(2)	(3)
$Yend$	−6.44***	−1.87	−3.08
	(1.96)	(2.01)	(2.37)
$HKM\ leverage$	−0.01	0.01	−0.04***
	(0.01)	(0.01)	(0.01))
$HKM\ capital$	1.23	3.15	−31.96**
	(10.78)	(10.78)	(12.62)
$LiborOISs$	0.11	0.13***	0.28***
	(0.23)	(0.04)	(0.04)
$US\ factor$	−0.22	−0.30	−0.39**
	(0.25)	(0.26)	(0.16)
$\Delta lnFX$	−7.55	−15.11**	−12.92*
	(5.96)	(5.99)	(6.95)
$lnVol$	11.58***	−4.41	−14.40***
	(3.53)	(3.82)	(4.55)
$FXbidask$	−22.97**	−28.76**	−30.40*
	(10.98)	(12.73)	(16.77)
$lnVix$	−8.91**	0.65	−0.93
	(3.51)	(3.72)	(4.97)
Currency pairs:	4	5	5
Within Adj-R^2	0.16	0.02	0.26
Observations	264	369	344

PANEL B: *In Changes*

	$\Delta y^{i/\$}_{3m,GC}$	$\Delta y^{i/\$}_{Tbill}$	$\Delta y^{i/\$}_{BOX}$
	(1)	(2)	(3)
$Yend$	-6.12^{***}	-2.88^{*}	-1.18
	(2.43)	(1.61)	(2.34)
$HKM\ leverage$	-0.001	0.01	0.01
	(0.01)	(0.01)	(0.01)
$HKM\ capital$	18.82	0.44	5.34
	(13.72)	(9.12)	(13.16)
$\Delta LiborOISs$	0.07	0.05	0.54^{***}
	(0.09)	(0.05)	(0.08)
$\Delta US\ factor$	-0.11	-0.22	-0.17^{**}
	(0.18)	(0.76)	(0.08)
$\Delta lnFX$	18.53	20.07	42.71^{*}
	(24.26)	(17.58)	(25.10)
$\Delta lnVol$	2.47	1.97	-18.69^{***}
	(5.64)	(3.88)	(5.58)
$\Delta FXbidask$	-13.77	-13.77^{**}	-26.00^{**}
	(8.70)	(6.72)	(11.16)
$\Delta lnVix$	-8.49^{**}	-3.43	0.38
	(3.61)	(2.44)	(3.89)
Currency pairs:	4	5	5
Within Adj-R^2	0.01	0.01	0.16
Observations	234	321	296