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Covered interest rate parity, relative funding liquidity and cross-currency repos

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Abstract

Deviations from the covered interest rate parity (CIP) are considerably smaller or even zero when calculated based on a particular set of repo rates, so-called cross-currency repo rates, instead of standard interest rates, such as overnight indexed swap or Interbank Offered rates. We attribute this (partial) solution of the CIP puzzle to the nearly identical risk characteristics of foreign exchange swaps and cross-currency repos: both are virtually devoid of counterparty credit risk but incorporate a relative funding liquidity premium. In practice, CIP deviations can thus be exploited on a truly riskless basis using cross-currency repo transactions, which is not the case for other interest rates.

JEL classification: E43, F31, G12, G14, G15.

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1. Introduction

This paper analyses a key building block in international finance: covered interest rate parity (CIP). CIP postulates that the difference between foreign exchange (FX) spot and FX forward rates is equal in size to the interest rate differential between the currency areas of the FX transaction. Otherwise, investors could exploit deviations without incurring any risk by borrowing in one currency and lending in the other, while covering all currency risk with an FX forward contract of equal maturity. While CIP held tightly before the global financial crisis (GFC), it has been widely reported to have failed thereafter. On the trading floor, CIP deviations are referred to as the “FX basis”.¹

This paper challenges the consensus view according to which CIP is broken by showing that it holds remarkably well if only the right interest rates are applied. More specifically, the interest rate differential in the CIP test equation must reflect relative funding liquidity risk, which we define along the lines of Rime, Schrimpf, and Syrstad (2017) and Brunnermeier and Pedersen (2009) as the premium for funding in one currency as opposed to another. In fact, we find that CIP deviations over nonquarter-ends are almost nonexistent when calculated on the basis of multicurrency SIX Repo or GC Pooling (GCP) Repo rates as opposed to overnight-index swap (OIS), London Interbank Offered Rate (LIBOR) or Euro Interbank Offered Rate (EURIBOR) rates (henceforth, IBOR rates). We attribute this finding to the fact that OIS rates hardly incorporate any funding premium because OIS is not a funding instrument. IBOR rates are inadequate because they are subject to counterparty credit risk and have other shortcomings. Some studies such as Du, Tepper, and Verdelhan (2018) use conventional repos in their CIP test equation, but we argue that these rates fail to properly reflect funding liquidity risk. After all, an investor must source collateral in the first place before he can enter a conventional repo transaction. We propose using so-called cross-currency (CCY) repo rates which allow the exchange of cash in one currency against collateral in another. Due to the difference in the currency denomination of the cash and collateral leg, CCY repo reflect relative funding liquidity conditions.

The CCY repo contracts on the SIX Repo and on the GCP Repo platform, the markets analyzed in this paper, are equipped with a collateral reuse optionality, i.e., the collateral obtained in one transaction can be used in a transaction with a third party. It is thus possible to replicate the flows of an FX swap with two CCY repo transactions where one borrows in the first and lends in the second. In contrast to OIS-, IBOR- or conventional repo transactions, CCY repos thus allows a CIP arbitrage scheme to be established in practice.

Our findings have several policy and market implications. First, regulators should treat

¹We use these two terms synonymously hereafter.

FX swaps and CCY repos equally because the two instruments are subject to the same risk dynamics. Second, central bank swap lines designed as CCY repos contribute efficiently towards alleviating funding stress and should be part of every central bank's liquidity assistance framework. Third, the FX basis affects both cash and collateral markets, which participants in cross-currency securities lending and borrowing schemes need to take into account when pricing such transactions.

The remainder of this paper is organized as follows. Section 2 embeds our research into the broader literature. Section 3 defines the CIP relationship while Section 4 focuses on practical aspects of CIP arbitrage and associated risks. Section 5 looks at institutional details of the CCY SIX Repo and the GCP Repo market. We discuss the data and the empirical results subsequently in Sections 6 and 7, respectively. Section 8 identifies implications for policymakers and scope for future research, and Section 9 concludes.

2. Literature

The CIP relationship held tightly prior to the GFC (see, for instance, Taylor (1987) or Akram, Rime, and Sarno (2008)). Large and persistent deviations came to the fore only during and after the GFC. CIP showed extreme dislocations in the wake of Lehman Brothers' failure on September 15, 2008, which were attributed to an acute shortage of US dollar liquidity in the interbank market and to heightened counterparty credit risk (see, for instance, Baba, Packer, and Nagano (2008)). According to Coffey, Hrungrung, and Sarkar (2009), the introduction of central bank swap line facilities, which allowed non-US banks to access US dollar liquidity through their home central bank, finally led to an alleviation of these tensions. While deviations from CIP normalized from their extreme levels seen in autumn 2008 towards the beginning of 2009, the parity relationship never returned to precrisis levels. Another sharp spike occurred when the sovereign debt crisis was at its worst towards the end of 2011 and the European banking system found itself with a shortage of US dollar liquidity again (see Allen and Moessner (2013)). Since mid-2014, the CIP relationship came into the spotlight amid widening deviations without there being any obvious sign of market stress.

Several explanations have been brought forward for the recent breakdown. Avdjiev, Du, Koch, and Shin (2016) point to correlation between US dollar spot movements and CIP deviations. They argue that the shadow price of bank leverage tends to rise as the US dollar appreciates thereby reducing banks' risk bearing capacity, which allows for wider CIP deviations. Andersen, Duffie, and Song (2019) argue that so-called funding value adjustment (FVA) costs have entered a wedge into the CIP relationship. CIP deviations must exceed FVA cost for arbitrage to be profitable. FVA costs reflect debt-financing costs for equity

shareholders of large dealer banks. Du et al. (2018) point to widening deviations towards quarter-end reporting dates which they interpret as evidence that regulation impedes arbitrageurs from taking advantage of CIP deviations. Borio, McCauley, McGuire, and Sushko (2016) and Sushko, Borio, McCauley, and McGuire (2016) argue along the same lines, while they also point to one-sided FX hedging demand causing CIP violations in the first place. While not negating that regulation might play a role in impeding arbitrage, in particular towards quarter-ends, our paper stresses the usage of the right interest rates with the appropriate risk characteristics for CIP testing purposes. Our contribution is thus related to another strand of the literature. Along with Baba et al. (2008), Baba and Packer (2009), McGuire and von Peter (2012), Mancini-Griffoli and Ranaldo (2010) and more recently Rime et al. (2017) and Wong, Leung, and Ng (2016), we argue that CIP deviations are usually overstated. This is because market risk premia are not properly taken into account when putting the CIP relationship to the test, relying for instance on widely used IBOR or OIS interest rates.

Rime et al. (2017) stress the large degree of segmentation in money markets and, related to that, the difficulty in choosing the appropriate interest rate when evaluating CIP arbitrage opportunities. They run their analysis on commercial paper rates, which are argued to reflect banks' true marginal funding cost and find that CIP arbitrage opportunities are confined to a relatively small set of highly rated global banks with access to cheap financing in the US commercial paper market. The large deviations found when using OIS rates are primarily attributed to the existence of funding liquidity risk, which OIS rates fail to capture. Making use of LIBOR-OIS spreads, Wong et al. (2016) decompose CIP violations into counterparty credit and funding liquidity risk. They also argue that funding liquidity risk plays a dominant role in explaining CIP violations. Our paper contributes to this discussion by showing a straightforward way to disentangle counterparty credit risk from funding liquidity risk.

Our paper is also related to Du et al. (2018), who rely on repo rates, among others, in order to test the CIP. Using (indicative) 1-week (1W) general collateral (GC) repo rates in US dollars, euro, yen, Danish kroner and Swiss franc, they report substantial CIP deviations.² We claim that CIP should not be tested based on conventional (indicative) repo rates as in Du et al. (2018) because such rates do not allow CIP arbitrage to be conducted in practice.

3. Covered interest rate parity

The CIP relationship states that the price of an FX swap consisting of an FX spot and an FX forward rate is equal to the interest rate relation between the two currencies exchanged:

²GC repos are collateralized funding instruments defined in more detail below.

$$\frac{F_{t,t+1}}{S_t} = \frac{1 + i_{t,t+1}^p}{1 + i_{t,t+1}^b}. \quad (1)$$

$F_{t,t+1}$ corresponds to the FX forward rate in price currency units per base currency at time t for value date at time $t + 1$ and S_t is the corresponding spot rate. The price and the base currency interest rates are represented by $i_{t,t+1}^p$ and $i_{t,t+1}^b$, respectively. Since all variables in Equation (1) are known at time t , CIP is an arbitrage relationship whose violation opens risk-less profit opportunities. To see that more clearly, assume that Equation (1) failed to hold such that:

$$\frac{F_{t,t+1}^{bid}}{S_t^{ask}} \times (1 + i_{t,t+1}^{b,bid}) - (1 + i_{t,t+1}^{p,ask}) = \epsilon_{t,t+1}, \quad (2)$$

with $\epsilon_{t,t+1} > 0$ representing CIP deviations. Note that Equation (2) includes transaction costs in terms of bid-ask spreads. An arbitrage profit can thus be reaped by running the following trading strategy:

- Borrow one unit of price currency at the ask interest rate $i_{t,t+1}^{p,ask}$.
- Change the borrowed amount at the spot rate $1/S_t^{ask}$ into base currency units.
- Lend the borrowed amount at the base currency bid interest rate $i_{t,t+1}^{b,bid}$.
- At $t + 1$, change the $(1 + i_{t,t+1}^{b,bid})$ units of base currency into price currency at the forward rate $F_{t,t+1}^{bid}$ agreed in t and repay $(1 + i_{t,t+1}^{p,ask})$ units of price currency.

Assuming efficient markets, all deviations from CIP should be arbitrated away immediately so that $\epsilon_{t,t+1}$ remains zero at all times. Due to the segmentation of the money market landscape, a broad range of money market rates could be plugged into the above arbitrage equation. Obviously, CIP cannot hold for all simultaneously. The money market rates chosen must be such that the risk characteristics on the left- and on the right-hand side of Equation (1) correspond to each other. Moreover, borrowing and lending at the respective rate must be feasible so that the trading strategy can be implemented in practice.

4. Cross-currency repos and CIP arbitrage

A repo is a money market instrument where one party sells high-quality, liquid fixed-income securities (usually government bonds) to another, while committing itself to repurchase them at a prespecified price at some future date. In essence, a repo amounts to a

collateralized loan. A CCY repo only differs from a conventional repo in that the cash and the collateral leg of the transaction can be denominated in different currencies. Instead of securing a US dollar loan with US Treasuries as in a conventional repo, German or Swiss government bonds could be delivered, for instance.

We argue that OIS, IBOR or conventional repo instruments are inappropriate to use in CIP arbitrage schemes and that an arbitrageur should instead opt for CCY repos. Our assertion is based on an arbitrage argument, which we corroborate with a risk premia discussion below.

4.1. Arbitrage view

The CCY repo markets analyzed in this paper allow collateral to be reused, i.e., the party receiving collateral can use the very same securities as collateral to a third party. Due to this feature, an FX swap can be replicated with two CCY repo transactions. Assume an investor giving a loan in Swiss francs against collateral. The collateral securities received can be used in another CCY repo transaction, say, to borrow US dollars.³ While the investor in this example started with Swiss francs, he ends up with US dollars for the term of the CCY repo, just as if he had entered a USDCHF FX swap transaction. The two CCY repo transactions leave him without any collateral at all and consequently without entitlement to interest or dividend payments or exposure to price fluctuations on collateral securities.⁴ Neither is the investor exposed to a collateral premium.⁵

Given that this strategy perfectly replicates an FX swap, the pricing of the CCY repo interest rate relation and the pricing of the FX swap should be identical. If not, arbitrage would immediately attract speculative flow until the CCY repo rates were in line with the swap pricing.⁶

By contrast, arbitrageurs run into practical difficulties when trying to set up an arbitrage strategy based on standard money market instruments. It is impossible to conduct CIP arbitrage based on conventional repo rates because the collateral received in the first transaction is not eligible to borrow in the second due to the currency mismatch. To execute

³See Fuhrer, Guggenheim, and Schumacher (2016) for an in-depth discussion of the reuse of collateral.

⁴Although he is the beneficial owner of the collateral provided, all proceeds need to be channeled to the borrowing counterparty on the other side of the second transaction.

⁵The collateral premium should be insignificant for GC repos anyway. The primary motive of conventional and CCY repos is cash lending and borrowing and the collateral delivered to secure the transaction often plays a subordinate role as long as it is compliant with eligibility criteria. In other words, in contrast to special repos, collateral premia hardly affect conventional and CCY repo rates.

⁶We thereby expect arbitrage gains to be offset through an adjustment of the CCY repo rates analyzed. This is due to the relative size of the two markets. The average daily turnover observed in the CCY repo markets would hardly be sufficient to affect the pricing of FX swaps. See Section 5 for a more detailed discussion.

the second transaction (borrowing US dollars), US dollar collateral had to be funded in the first place, which Du et al. (2018) neglect. Sourcing US dollar collateral comes with a cost that should in theory offset all arbitrage profits as discussed in Section 8.3 below.

Numerous studies have analyzed CIP on the basis of IBOR, which reflects the interest rate at which prime banks are able to borrow on an unsecured basis. The representative content of IBOR for the wider market is questionable though because IBOR is based on quotes of submitting prime banks and other financial market participants may likely face different borrowing costs. Moreover, there was a general decline in the underlying market of unsecured interbank transactions during and after the GFC.⁷ A detailed description of the characteristics of IBOR is provided in Appendix A.

As discussed in Rime et al. (2017) and in the Appendix A, it is not possible to conduct CIP arbitrage based on OIS rates neither. An OIS represents a derivative instrument to hedge interest rate risk by exchanging a floating interest rate on a certain principal value against a fixed interest rate agreed upon at the beginning of the transaction. The floating leg of the agreement is usually tied to an overnight rate. At the end of the contract, the net difference between the average realized overnight interest rate and the predefined term interest rate is settled. Given its structure, an OIS contract does not involve any exchange of notional and is hence not a funding instrument. CIP arbitrage based on OIS rates is consequently not possible.

4.2. *Risk view*

Another way to reflect on CIP is to think about the risks involved in an FX swap transaction on one hand and in money market transactions on the other. For CIP to hold, the pricing and hence the underlying risk drivers on both sides of Equation (1) must correspond to each other. We differentiate between counterparty credit risk, defined as the risk of a debtor defaulting on its contractual obligations, and (relative) funding liquidity risk. Funding liquidity risk is defined according to Brunnermeier and Pedersen (2009) as the ease at which funding can be obtained. Relative funding liquidity risk correspondingly describes the difference in premia between funding in two currencies (see Rime et al. (2017)). The funding liquidity premium is related to the liquidity characteristics of an asset. An investor demands compensation for an asset that cannot be converted into cash easily, i.e., which is illiquid. Instead of measuring the liquidity characteristics relative to cash, the relative

⁷Reports of manipulative behavior add to reservations. During the GFC some contributors resorted to understating their borrowing costs in order to avoid the perception that their default risk had deteriorated. Others manipulated contributions with the goal of making a profit on derivative positions referencing to the IBOR (see, for instance, Duffie and Stein (2015)).

funding liquidity premium of a currency is measured relative to a reference currency.

Other premia might exist, for instance stemming from regulation, which could enter a wedge into the CIP relationship. However, this only holds if these premia affect the pricing of the FX swap on one hand and the interest rate differential on the other differently. Regulatory aspects are discussed in more detail in Section 8.

According to Table 1, which summarizes the results of the subsequent discussion, only CCY repo differentials match the risk structure of an FX swap, while conventional repo, OIS and IBOR interest rate differentials fail to do so. These risk considerations are closely related to the arbitrage argument from above because genuine arbitrage is only possible in a system without any residual risk.

Table 1: Risks associated with CIP arbitrage

Instrument	Rel. counterparty risk	Rel. funding liquidity risk	Arbitrage
FX swap pricing	-	✓	
OIS rate diff.	-	-	-
LIBOR rate diff.	✓	✓	-
Repo rate diff.	-	-	-
CCY repo rate diff.	-	✓	✓

Table 1 displays the risks incorporated in the pricing of FX swaps as well as the money market interest rate differentials for the instruments under consideration. It also displays whether arbitrage is feasible or not. Note that the representation is in relative terms and is depicted for instruments with a maturity larger than overnight.

4.2.1. Risks in an FX swap transaction

Assume an investor entering an FX swap transaction by selling the base against the price currency in the spot market at S_t (sell USDCHF spot) while simultaneously buying the same amount of the base against the price currency in the forward market at $F_{t,t+1}$ (buy USDCHF forward). In addition to the fact that such a position is immune to FX risk,⁸ it does not involve counterparty credit risk. If the counterparty were to default, the investor would be left with the price currency as collateral.⁹ At first sight, an FX swap transaction does not involve much funding liquidity risk neither. Liquidity is not tied up during the

⁸All gains and losses on the spot leg of the transaction are offset by gains and losses of equal size but opposite sign on the forward leg

⁹Counterparty credit risk exposure could arise from price movements resulting in an unrealized profit on the far leg of the transaction. However, such profits tend to be small in comparison to the notional amount exchanged at the beginning of the transaction. Moreover, swap positions are normally subject to marking-to-market procedures under two-way credit support annex (CSA) agreements, resulting in margin calls if profits or losses accrue along the way.

contract's term but merely exchanged for liquidity in another currency. The initial currency could be procured again, should need arise, for instance, by offsetting the initial position with an FX swap transaction in the opposite direction bearing the same maturity date as the original swap. In our example, the investor would enter a buy and sell USDCHF FX swap transaction. Such a reversal would cost dearly though, if at the time of the reversal, US dollar funding conditions deteriorated relative to Swiss franc. The price for the offsetting FX swap would reflect this shift in preference. The dislocation of the FX swap market during the GFC is a prime example of how US dollar liquidity suddenly became scarce and funding cost increased relative to most other currencies.¹⁰ As summarized in Table 1, an FX swap hardly incorporates any counterparty credit risk but reflects relative funding liquidity conditions.

4.2.2. Risks in money market rates

The CCY repo relation can be considered as being secured and thus almost exempt from counterparty credit risk because both cash legs are collateralized with high-quality, liquid securities. By contrast, CCY repos reflect relative funding liquidity risk, which arises because cash in one currency is exchanged against collateral in another. The risk structure of a CCY repo and an FX swap are thus alike concerning counterparty credit and funding liquidity premia. That does not hold for conventional repo, IBOR or OIS rates.

While also being devoid of counterparty credit risk, conventional repo rates fail to reflect (relative) funding liquidity risk because the cash and the collateral leg are denominated in the same currency.

OIS rates fail to match the risk structure of an FX swap as well because there is no exchange of notional values and thus there is no (relative) funding liquidity risk premium incorporated in these rates. Due to the lack of exchange of notional values combined with the fact that OIS agreements are usually subject to margin calls, OIS rates incorporate hardly any counterparty credit risk premium.¹¹

Finally, IBOR incorporates funding liquidity risk because liquidity is tied up during the transaction. However, IBOR also incorporates a counterparty credit risk premium (see also Wong et al. (2016)).¹²

¹⁰Alternatively, the original currency could be acquired in the FX spot market. This would however involve substantial exchange rate risk because at the FX swap contract's maturity, the investor is contractually obliged to return the currency received from its counterpart.

¹¹For assigning the different risks to the money market instruments, we implicitly assume that the maturity is longer than overnight. Otherwise, OIS rates would need to have the same risk structure as IBOR rates because OIS rates are usually based on overnight unsecured funding rates that represent the variable leg of the OIS contract.

¹²Proponents of the IBOR might argue that the premium is likely to affect domestic as well as foreign interest rates and thus cancels out on the right-hand side of Equation (1). However, the composition of

5. Cross-currency repo markets

The CCY repo rates analyzed in our empirical analysis are derived from the multicurrency SIX Repo and GCP Repo markets, which are the leading secured money markets in Switzerland and the euro zone.¹³ The major segment of the SIX Repo and GCP Repo market are repos where the cash leg is in Swiss franc and euro, respectively. However, other currencies and, in particular, US dollars can be traded on these platforms as well. Trades are conducted electronically and settlement of both the cash and the collateral leg is fully automated. While the SIX Repo market is organized as a triparty repo market, the GCP Repo market is a central counterparty cleared market. Participants in both markets are primarily European or Swiss banks, some with global reach while others are more focused on their respective domestic markets. The SIX Repo and the GCP Repo markets are GC repo markets. Thus, the main focus of the repo trade is not to acquire specific securities, which would be the case in special repos, but to acquire funding against collateral. The collateral must fulfill certain credit and liquidity requirements and all deliverable securities form a so-called collateral basket.

5.1. Collateral in the SIX and the GCP Repo markets

On the SIX Repo platform, the collateral standards applied to interbank repo transactions correspond to those applied by the Swiss National Bank (SNB) in its monetary policy operations. All securities fulfilling SNB's eligibility criteria constitute the so-called SNB GC basket. Note that this basket is used as the standard, irrespective of the currency of the cash leg. Between July 31, 2013 and December 29, 2017, which corresponds to the sample period in our main empirical analysis, 99% (99%) of the transacted Swiss franc (US dollar) volume was collateralized by SNB GC basket securities.

Securities in the SNB GC basket are denominated in one of the following currencies: Swiss franc, euro, US dollar, pound sterling, Danish krone, Swedish krona and Norwegian kroner.¹⁴

the IBOR panel differs from currency to currency so that the counterparty credit risk component in the two currencies underlying the FX swap is usually not equal in size (see Tuckman and Porfirio (2004)). Empirically, there is a cross-sectional difference between IBOR-OIS spreads for different currencies, which is evidence that the relative counterparty credit risk premium is nonzero.

¹³See Appendix B for a more detailed description of the SIX Repo and the GCP Repo market. Moreover, see Berentsen, Kraenzlin, and Müller (2018) for more background on the SIX Repo market and European Central Bank (2012) and Mancini, Ranaldo, and Wrampelmeyer (2016) for more background on the GCP market.

¹⁴The potential volume of SNB eligible collateral stood at 8,915 billion Swiss francs as of the end of September 4, 2017. Approximately 66% of the potential outstanding volume is denominated in euros, 21% in pounds sterling, 3% in Swiss francs, 3% in Swedish kronor, 3% in Danish kroner, 2% in US dollars and 1% in Norwegian kroner. A detailed description of SNB's collateral framework can be found in Fuhrer, Müller, and Steiner (2017) and Swiss National Bank (2015).

By default, no haircut is applied in the SIX Repo market, i.e., no overcollateralization of the cash loan is required.

Since we have data on collateral securities on an ISIN-by-ISIN basis at our disposal, we are able to assess whether the repo transactions under consideration are indeed CCY in nature, i.e., whether the cash leg is in a different currency from the collateral leg. For the period analyzed, only 2.1% of the US dollar transaction volume was secured by US dollar-denominated securities. The vast majority of the transaction volume was instead collateralized with securities denominated in Swiss francs (40%), Danish kroner (38%), and euros (16%). For Swiss franc transactions, the vast majority was collateralized with securities denominated in Swiss franc (76%), Danish kroner (16%), and euros (6%). US dollar repo transactions thus generally correspond to CCY repo transactions while most Swiss franc repos were conventional repo transactions.

In the case of the GCP Repo market, the GCB ECB Basket is the standard collateral basket, and this is irrespective of the currency of the cash leg. The GCB ECB Basket represents a subset of the collateral eligible in the monetary policy operations of the European Central Bank (ECB).¹⁵ Since January 2010, 55% (96%) of the transacted euro (US dollar) volume was collateralized by the GCP ECB Basket.¹⁶ Since 2015, collateral in the GCP ECB Basket is exclusively denominated in euros. Before 2015, a selection of noneuro denominated securities including US dollar-denominated securities were eligible as well. After 2015, we thus know for sure that we are dealing with CCY repos in the case of repo transactions with the US dollar as cash leg while before, we rely on anecdotal evidence suggesting that US dollar-denominated collateral was very rarely used.

The reuse of collateral is possible in both markets. That is, the cash lender can make use of the collateral received in a first transaction to borrow against collateral in a second. A participant could, for instance, lend Swiss francs and receive collateral that could be reused to borrow US dollars by providing exactly the same securities. The standard in the SIX Repo market is a haircut of zero, while for the GCP ECB Basket, ECB haircuts apply and, depending on the risk assessment by Eurex Clearing, an additional margin might be required. Given that haircuts are small, reuse activity is only partly hindered.¹⁷

¹⁵The eligibility requirements for the GCP ECB Basket are stricter than those applied by the ECB in its monetary policy operations. Collateral quality concerns, for instance raised in Fecht, Nyborg, Rocholl, and Woschitz (2016), should thus hardly have an impact on our results.

¹⁶The GCP ECB Basket consists of securities denominated in euros, issued by central banks, central, regional or local governments, supranational institutions and covered bonds. The potential volume of securities eligible for the GCP ECB Basket stood at 5,868 billion euros as of September 4, 2017.

¹⁷The list of eligible collateral and the respective haircuts can be found on the GCP website (<https://www.eurexrepo.com/repo-en/products/gcpooling>).

5.2. *Relative importance of CCY repos compared to the FX swap market*

The SIX and the GCP Repo market are both small in terms of traded volumes compared to the FX swap market. The daily turnover in the global FX swap market was estimated to be USD 2.4 trillion in 2016. Daily turnover in USDCHF and EURUSD stood at USD 120 billion and USD 652 billion, respectively (see Bank for International Settlements (2016)). Between the end of July 2013 and the end of December 2017, the daily average turnover in the Swiss franc segment of the SIX Repo market was CHF 3.6 billion and USD 2.5 billion in the US dollar segment. Daily average turnover in the euro segment of the GCP Repo market was EUR 17.5 billion euros and USD 0.9 billion in the US dollar segment. This makes us believe that the pricing of repo rates in the US dollar segment relative to the Swiss franc and the euro segments tends to be inherited from the FX swap market and not vice versa. Arbitrage opportunities stemming from CIP deviations should thus primarily lead to a repricing of CCY repo rates as opposed to FX swap points.

6. Data

6.1. *Currency pairs and maturity*

This paper analyzes CIP deviations between the US dollar and the Swiss franc on the one hand and between the US dollar and the euro on the other. We have chosen these two currency pairs because we have access to a proprietary dataset of CCY repo transactions in Swiss francs, euros and US dollars on the SIX and GCP Repo markets.

Our empirical investigation looks at 1W CIP deviations due to a trade-off between market activity on one the hand and risk characteristics and relevance on the other. Trading on the SIX and GCP Repo platforms is busiest in the overnight and in the tomorrow-next segment, while it is still decent for 1W contracts before decreasing quickly for longer maturities. From a data availability perspective, we should thus opt for the very short-end of the money market curve.¹⁸ From a risk premium perspective, however, long maturities should be chosen because counterparty credit and funding liquidity risk hardly exist for intraday or overnight contracts. Moreover, overnight and tomorrow-next pricings are very volatile. Given these trade-offs, focusing on 1W deviations looks like the optimal choice.

¹⁸FX market liquidity is also highest at the short-end. In fact, according to the Bank for International Settlements Triennial Survey 2016, approximately 70% of the FX swap turnover is in the maturity segment of up to seven days (see Bank for International Settlements (2016)).

6.2. *Data types and sources*

Our analysis is based on working daily data. We use end-of-day rates (close prices) of the New York trading session for USDCHF and EURUSD FX spots and forwards. The FX data are downloaded from Bloomberg. To account for transaction costs, FX forward bid and ask rates are taken into consideration.¹⁹ To compare USDCHF and EURUSD CIP deviations across money markets, we run all calculations for CCY repo, IBOR and OIS rates, respectively.

IBOR analysis: For the US dollar and the Swiss franc, LIBOR rates fixed at 11 a.m. London time are downloaded from Bloomberg. For the euro, the corresponding EURIBOR rates are used. IBOR rates represent ask interest rates. We use IBOR rates as a proxy for general unsecured lending and borrowing conditions in our analysis.

OIS analysis: End-of-day bid and ask interest rates for US dollar, Swiss franc and euro OIS rates are downloaded from Bloomberg. The floating leg of the US dollar interest rate is the Federal Funds Effective Rate. For the euro, the floating leg is the Euro Overnight Index Average and for the Swiss franc the TOIS fixing. All floating legs are unsecured money market rates with day-to-day maturity.

CCY repo analyses: CCY repo rates are calculated as volume-weighted average interest rates using transaction data from the SIX Repo and the GCP Repo markets. The USDCHF analysis relies on US dollar and Swiss franc CCY repo rates from the SIX Repo market. The EURUSD analysis uses euro and US dollar CCY repo rates from the GCP Repo market. For both markets, we consider trades conducted against the standard collateral basket in the respective markets, i.e., against the SNB GC Basket and against the GCP ECB Basket.

An overview of the data used and their sources is provided in Table 2.

6.3. *Data sample and turnover*

The sample period of our main analysis ranges from July 31, 2013 to December 29, 2017. 1W US dollar GCP Repo transactions have been traded on a regular basis since July 2013, which is why the start date of our sample is chosen to be the end of July 2013.²⁰ The sample

¹⁹Note that it is market practice to conduct the spot leg of an FX swap transaction at mid prices. Bid-ask spreads only apply to FX forward points and hence FX forward rates.

²⁰The GCP Repo market has been in operation since 2005, but it was not possible to trade US dollar repos on that platform before January 2010. The first trade in the 1W maturity was recorded on June 4,

Table 2: Data used and sources

Instrument	Currencies	Source
Spot/forward exchange rates	USDCHF, EURUSD	Bloomberg
IBOR rates	USD, CHF, EUR	Bloomberg
OIS rates	USD, CHF, EUR	Bloomberg
CCY SIX Repo rates	USD, CHF	SIX Repo Ltd
CCY GCP Repo rates	USD, EUR	Eurex Repo Ltd

Table 2 provides an overview of the data used. The data described in rows one to three are retrieved from Bloomberg. SIX and GCP Repo rates are obtained from SIX Repo Ltd. and Eurex Repo Ltd., respectively. Both repo rates are calculated as daily volume-weighted average transaction interest rates. The underlying transaction data are not publicly available.

period of our analysis ends on December 29, 2017 because the TOIS fixing was replaced after that date by the so-called SARON. This has led to a structural break in the Swiss franc OIS curve.

In the sample period analyzed, the daily average turnover in the SIX Repo market amounted to 0.1 billion Swiss francs in the Swiss franc 1W segment and 0.1 billion US dollars in the US dollar 1W segment. In the GCP Repo market, the daily average turnover amounted to 0.6 billion euros in the euro 1W segment and 0.1 billion US dollars in the US dollar 1W segment.

Table 3 displays the number of observations by type of interest rate. IBOR and OIS rates are available for almost every day between July 31, 2013 and December 29, 2017. Due to a lack of CCY repo transactions on certain days, the CCY series is not as rich. To avoid falling prey to a selection bias, the dataset is limited to include only those days where we are able to calculate CIP deviations for all types of interest rates, which leaves us with the number of observations shown in Column (4).

7. Empirical analysis

7.1. Methodology

Our calculations are based on the trading strategy described in Section 3, which yields CIP deviations denoted as $\epsilon_{t,t+1}$. CIP deviations are reported in basis points (bp) on an annualized basis. To analyze these deviations, we rely on three simple dummy variable regression specifications. Each regression is run six times for CIP deviations in USDCHF and in EURUSD for OIS-, IBOR- and CCY repo rates, respectively.

2013.

Table 3: Number of observations

	(1)	(2)	(3)	(4)
	CCY repo	IBOR	OIS	Dataset
USDCHF analysis				
Overall	452	964	964	452
Non Q-end	411	875	875	411
Q-end	41	89	89	41
EURUSD analysis				
Overall	496	1007	1007	496
Non Q-end	465	91	916	465
Q-end	31	916	91	31

Table 3 displays the number of observations for the main analysis covering the period between July 31, 2013 and December 31, 2017.

In the first specification, CIP deviations are regressed on an intercept only. The estimate for the intercept represents the average CIP deviation over the sample period, i.e., between July 31, 2013 and December 31, 2017. In the second specification, we replace the intercept with two dummy variables defined as follows:

$$y_t = \beta_1 \cdot non-Q-end_t + \beta_2 \cdot Q-end_t + \epsilon_t. \quad (3)$$

The dependent variable, y_t , represents CIP deviations. The independent variable dummy $non-Q-end_t$ captures nonquarter-end effects while the $Q-end_t$ -dummy measures quarter-end dynamics. The latter (former) dummy has a value of one (zero) in the period from nine days to one day before the turn of a quarter and is zero (one) otherwise. This is because the analysis is based on 1W instruments, which settle at $t + 2$ (near leg) and at $t + 9$ (far leg). β_1 and β_2 correspond to average CIP deviations over nonquarter-ends and quarter-ends, respectively. The second regression runs again over the period between July 31, 2013 and December 31, 2017.

In the third specification, we focus on USDCHF where we have a longer data history at our disposal.²¹ The data allow us to calculate CIP deviations for the precrisis period defined as running from January 2006 to June 2007, the GFC ranging from July 2007 to December 2009, the sovereign debt crisis between January 2010 to December 2013, and the postcrisis period from January 2014 to December 31, 2017. Each of these subperiods is analyzed separately for quarter-end and nonquarter-end contracts by running the following

²¹The key characteristics outlined in Section 5 also hold true for the longer sample: the vast majority of transactions are secured with the SNB GC collateral basket and the transactions with cash leg in US dollar are usually conducted against non-US dollar collateral and can hence be regarded as CCY repos.

dummy variable regression:²²

$$\begin{aligned}
y_t = & \beta_1 \cdot \text{Pre-crisis ex. } Q\text{-end}_t + \beta_2 \cdot \text{GFC ex. } Q\text{-end}_t + \beta_3 \cdot \text{Debt crisis ex. } Q\text{-end}_t \\
& + \beta_4 \cdot \text{Post-crisis ex. } Q\text{-end}_t + \beta_5 \cdot \text{Pre-crisis } Q\text{-end}_t + \beta_6 \cdot \text{GFC } Q\text{-end}_t \\
& + \beta_7 \cdot \text{Debt crisis } Q\text{-end}_t + \beta_8 \cdot \text{Post-crisis } Q\text{-end}_t + \epsilon_t. \quad (4)
\end{aligned}$$

The coefficients β_1 to β_4 capture within-quarter, while the coefficients β_5 to β_8 capture quarter-end CIP deviations during the respective subperiods.

Running regressions instead of simply calculating average CIP deviations allows us to compute Newey-West heteroscedasticity and autocorrelation consistent standard errors in a straightforward manner (see Newey and West (1987)). We have chosen a lag length of eight to account for autocorrelation due to the time overlap, which arises because CIP deviations are calculated by taking 1W interest rates on a daily basis.²³

7.2. Results

Table 4 shows CIP deviations between July 31, 2013 and December 31, 2017 based on CCY Repo (Column 1), IBOR (Column 2) and OIS (Column 3) interest rates. The upper panel displays the results for USDCHF and the lower panel for EURUSD.

CIP deviations are small and hardly of economic importance when calculated based on CCY repo rates. An arbitrageur would have made a mere 11.4 bp per annum on average by conducting CIP arbitrage between the US dollar and the Swiss franc based on SIX Repo rates. CIP deviations between the US dollar and the euro are almost inexistent (2.1 bp) based on GCP Repo rates. However, deviations are considerably larger when based on OIS rates, irrespective of whether we look at the USDCHF or the EURUSD. IBOR-based deviations are relatively small, but still significantly larger than deviations based on CCY repo rates. A paired t -test rejects the null hypothesis that average CIP deviations are equal in size across the three interest rate specifications (see Table 8 in the Appendix C.2).

Table 5 displays the results of the second regression specification. CIP deviations tend to be much larger for contracts running over quarter-ends as opposed to those with only within-quarter observations. This holds for the USDCHF and the EURUSD and across all interest rates. However, CCY repo rates seem to capture quarter-end dynamics better

²²The regression outlined in Equation 4 is based on 1,337 observations. See Table 7 in the Appendix C.1 for the number of observations per dummy variable.

²³The results are robust with respect to the lag length definition as proposed by Greene (2003) which is to set the number of lags to the rounded up integer to the fourth root of the number of observations.

Table 4: Average CIP deviations

	(1)	(2)	(3)
	CCY repo	IBOR	OIS
USDCHF analysis			
Entire sample	11.40*** (4.08)	16.00*** (4.38)	41.50*** (10.38)
Observations	452	452	452
EURUSD analysis			
Entire sample	2.10*** (2.84)	14.80*** (6.53)	16.10*** (6.53)
Observations	496	496	496

Table 4 shows average CIP deviations between July 31, 2013 and December 31, 2017 in bp per annum. The upper panel displays USDCHF CIP deviations, while the lower panel shows EURUSD CIP deviations. (***), (**), and (*) denote statistical significance (one-tailed) at the 1%, 5%, and 10% significance level. t -statistics are in parentheses below the coefficients. While CCY repo and OIS calculations include all transactions costs, IBOR calculations only take account of bid-ask spreads in FX transactions.

than calculations based on IBOR or OIS rates. While average deviations over quarter-ends are 85.9 and 110.5 bp for IBOR- and OIS-based calculations in USDCHF, they amount to 64.8 bp for CCY repos. In the EURUSD panel, CCY repos render 16.4 bp over quarter-ends compared to 45.9 and 48.7 bp for IBOR and OIS. A paired t -test rejects the null that average CIP deviations are equal in size across the three different interest rate specifications (see Table 9 in the Appendix C.2).

We now turn to the results of the third regression specification, which focuses on USDCHF CIP deviations. Table 6 shows that CIP deviations are zero or even slightly negative during the precrisis period. This supports the well-established finding that CIP deviations were nonexistent before the GFC. For all other periods, CIP deviations are positive and mostly statistically significant. At quarter-ends, CIP deviations are considerably larger compared to nonquarter-ends. Comparing our estimates across interest rates shows that deviations are again generally largest when calculated based on OIS rates, irrespective of the period under consideration and irrespective of whether we are investigating within-quarter data or data running over quarter-ends. In contrast, IBOR and especially CCY repo-based CIP deviations are much smaller. CCY repo-based arbitrage profits of economic and statistical significance can only be observed for transactions running over quarter-ends during the postcrisis period (71 bp).

The paired t -test generally rejects the null hypothesis that average CIP deviations are equal in size across the three different interest rates analyzed. More specifically, with the exception of the precrisis period, CIP deviations between CCY repo and IBOR rates on one

Table 5: Average CIP deviations – quarter-end analysis

	(1)	(2)	(3)
	CCY repo	IBOR	OIS
USDCHF analysis			
Non Q-end (β_1)	6.10*** (3.13)	9.00*** (3.72)	34.60*** (12.43)
Q-end (β_2)	64.80*** (3.50)	85.90*** (3.53)	110.50*** (4.24)
Non Q-end Obs.	411	411	411
Q-end Obs.	41	41	41
EURUSD analysis			
Non Q-end (β_1)	1.10*** (3.09)	12.80*** (8.82)	13.90*** (8.81)
Q-end (β_2)	16.40* (1.72)	45.90** (2.16)	48.70** (2.16)
Non Q-end Obs.	465	465	465
Q-end Obs.	31	31	31

Table 5 shows average CIP deviations between July 31, 2013 and December 31, 2017 in bp per annum. The upper panel displays USDCHF CIP deviations, while the lower panel shows EURUSD CIP deviations. (***) , (**) and (*) denote statistical significance (one-tailed) at the 1%, 5%, and 10% significance levels. t -statistics are in parentheses below the CIP coefficients. While CCY repo and OIS calculations include all transactions costs, IBOR calculations only take account of bid-ask spreads in FX transactions.

side and OIS rates on the other differ significantly from each other. The test results are slightly less unambiguous for CIP deviations calculated on the basis of CCY SIX Repo as opposed to IBOR rates where the paired t -test fails to reject the null that CIP deviations are equal in size during the GFC and the postcrisis quarter-end period (see Table 10 in the Appendix C.2).

8. Discussion of results

The empirical analysis shows that CIP deviations are much smaller when calculated on the basis of CCY repo rates as opposed to IBOR and in particular as opposed to OIS rates. This holds for the USDCHF analysis based on CCY repo data from the SIX Repo market and even more so for the EURUSD analysis based on CCY repo data from the GCP Repo market. CIP deviations are generally larger on quarter-ends than on nonquarter-ends, but these quarter-end disruptions are again tightest for CCY repo-based calculations. The

Table 6: Average USDCHF CIP deviations – long sample

Period	(1) CCY SIX repo	(2) IBOR	(3) OIS
Pre-crisis ex. Q-end (β_1)	-5.80*** (-5.32)	-1.50* (-1.81)	-1.30 (-1.52)
GFC ex. Q-end (β_2)	1.30 (0.21)	1.70 (0.35)	27.80*** (3.03)
Debt crisis ex. Q-end (β_3)	3.20 (1.24)	12.90*** (6.41)	15.80*** (7.88)
Post-crisis ex. Q-end (β_4)	6.00*** (2.96)	9.00*** (3.60)	35.40*** (12.50)
Pre-crisis Q-end (β_5)	-1.80 (-1.12)	-0.20 (-0.14)	-1.60 (-1.17)
GFC Q-end (β_6)	57.50 (1.43)	45.40* (1.70)	88.10* (1.82)
Debt crisis Q-end (β_7)	12.30*** (2.67)	26.30*** (4.50)	30.30*** (4.88)
Post-crisis Q-end (β_8)	71.00*** (3.58)	94.30*** (3.64)	121.10*** (4.44)
Observations	1337	1337	1337

Table 6 shows the estimates for USDCHF CIP deviations in bp per annum. The precrisis period covers data from January 2006 to June 2007, the GFC from July 2007 to December 2009, the sovereign debt crisis from January 2010 to December 2013, and the postcrisis period from January 2014 to July 31, 2017. The *Q-end*-dummies take on a value of one in the period from nine days to one day before the turn of a quarter. The coefficient estimates are shown in bp per annum. (***) , (**) and (*) denote statistical significance (one-tailed) at the 1%, 5%, and 10% significance levels. *t*-statistics are in parentheses below the coefficients. While CCY repo and OIS calculations include all transactions costs, IBOR calculations only take account of bid-ask spreads in FX transactions.

empirical findings are in line with our arbitrage and risk premium discussion where we argued that CCY repo interest rate differentials and FX swaps are subject to the same risk dynamics: both are almost devoid of counterparty credit risk but incorporate a relative funding liquidity risk premium. Consequently, only CCY repo rates allow us to truly arbitrage CIP deviations. In what follows, we discuss policy implications of our findings.

8.1. Regulation

Numerous studies report large CIP deviations over quarter-ends (see, for instance, Du et al. (2018)). Such deviations are usually attributed to new regulatory standards such as the Basel III Leverage Ratio (see Basel Committee on Banking Supervision (2014)). Our analysis also reveals economically and statistically significant CIP deviations over quarter-ends, even when using CCY repo rates. This finding can only be reconciled with our risk premium considerations if we assume the existence of a quarter-end premium affecting FX swaps and CCY repo rate differentials differently.

Although FX swaps and CCY repos are very similar from an economic point of view, regulators treat the two instruments differently with regard to Leverage Ratio requirements. Borrowing cash via CCY repos lengthens a bank's balance sheet due to the new cash position booked on the asset side and a payable on the liability side. Lending cash via CCY repos does not affect the length of the balance sheet as the cash position is merely exchanged for a receivable position. Combining both a borrowing and a lending transaction leads to a lengthening of the balance sheet equal in size to the borrowed amount.²⁴ In contrast, an FX swap leaves the balance sheet unchanged. The spot component of the swap transaction merely leads to an exchange of currencies on the asset side while the forward component of the transaction is booked off-balance sheet. This difference in treatment and the fact that European and Swiss banks are required to report the Leverage Ratio on quarter-ends only could potentially explain CIP violations towards quarter-ends.

Other regulatory and nonregulatory measures such as risk management standards might also play a role in regard to quarter-end CIP dislocations. Various such measures have been introduced in recent years and disentangling their pricing impact is difficult. However, to have an impact on CIP, they need to affect FX swaps and CCY repos differently.

8.2. Central bank swap lines

Our findings provide an interesting perspective on central bank swap lines, which were installed among major central banks during the GFC to alleviate US dollar funding tensions. central bank swap lines allow non-US banks to get hold of US dollar liquidity through their home central bank via repo transactions against collateral eligible at the respective central bank. Because most central banks only accept collateral denominated in domestic currency,

²⁴Haircuts leading to a cash and collateral value mismatch during the term of the repo transaction are captured by the Leverage Ratio calculation, too. However, they can be neglected for our argumentation because of the small size of haircuts usually applied in GC repos compared to the Leverage Ratio impact of the notional volume. As mentioned previously, in repos against the GCP ECB basket, haircuts are small. Moreover, SIX Repo has a zero-haircut standard in repos against the SNB GC basket.

US dollar funding via these swap lines actually amounts to a CCY repo transaction. We conjecture that the effectiveness in calming US dollar funding tensions stems from the CCY repo nature of the swap lines. The CCY repo setup puts a ceiling to the relative funding liquidity premium of the US dollar vis-à-vis the collateral currency.²⁵

8.3. *The impact of the FX basis on CCY repos and collateral markets*

Relative funding liquidity risk or the FX basis enters FX swap prices. It should also enter CCY repo rates and the pricing of collateral when collateral in one currency is exchanged against collateral or cash in another. To substantiate this claim, we subsequently provide theoretical and empirical evidence.

The FX basis enters CCY repo rates: Take an investor borrowing US dollars in the CCY repo market collateralized by securities denominated in Swiss francs. He could arrive at the very same exposure by borrowing Swiss francs in a conventional repo transaction, i.e., against collateral denominated in Swiss francs and by exchanging the proceeds in a buy and sell USDCHF FX swap transaction. The two strategies must come at the same cost because in both cases the investor has initiated the transactions with Swiss franc collateral while he ends up with US dollars in cash. The FX basis, which is inherent in USDCHF FX swap prices, must hence show up in US dollar CCY repo rates as well.

The FX basis drives a wedge between CCY and conventional repo rates: Figure 1 shows overnight US dollar repo rates for conventional repo transactions against US Treasuries as collateral (gray line). These rates represent volume weighted median interest rates for transactions conducted on the triparty repo platform of the Bank of New York Mellon (BNYM). The black line represents overnight US dollar CCY repo rates from the SIX Repo market.²⁶ The CCY repo rate is higher than the conventional repo rate, which is what we would expect because conventional repos (as opposed to CCY repos) do not incorporate the FX basis.²⁷ Moreover, US dollar CCY repo rates exhibit spikes towards quarter-ends since 2016, similar to the FX basis. By contrast, conventional repo rates remain little changed on

²⁵The interest rate for accessing US dollars via central bank swap lines corresponds to the US dollar OIS rate plus 50 bp.

²⁶For the subsequent graphical analysis we ideally had US dollar conventional repo rates with a maturity of 1W at our disposal to be in line with our previous analysis. Unfortunately and to the best of our knowledge, such a benchmark repo rate does not exist. We thus focus on overnight US dollar repo rates here.

²⁷We argue that this interest rate differential is somewhat related to the premium paid for special repos compared to regular GC repos. While GC repos are driven by acquiring cash, special repos are driven by acquiring specific securities for the length of the repo contract that comes at a cost (see Duffie (1996) for an overview).

quarter-ends.

Fig. 1. US dollar CCY SIX Repo and US dollar conventional repo rates

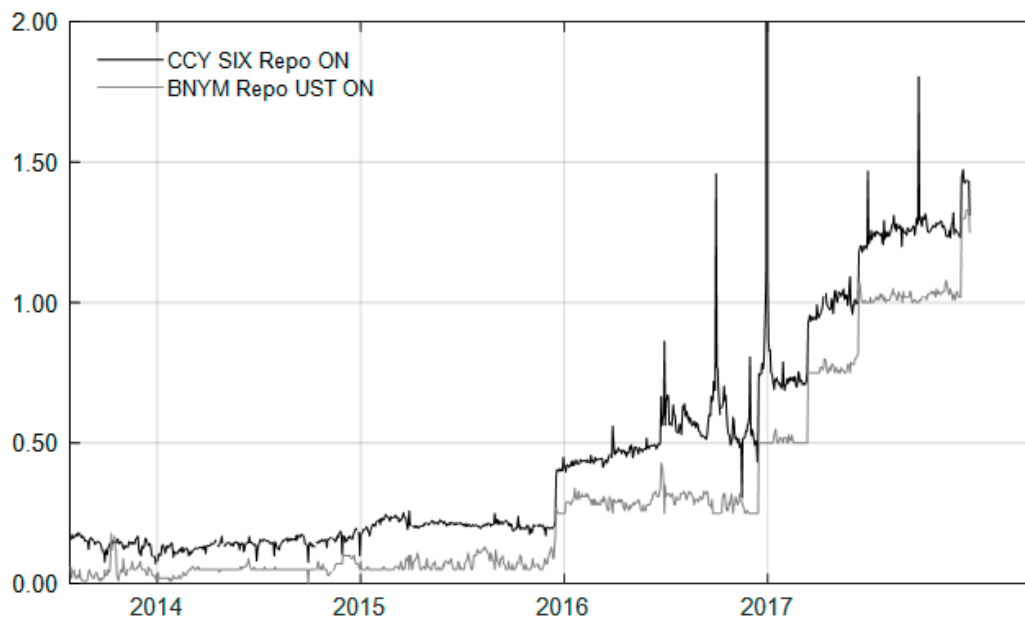


Figure 1 shows overnight US dollar CCY SIX Repo (black line) and overnight US dollar conventional repo rates (gray line). The conventional repo rate represents the volume weighted median interest rate for transactions conducted on the triparty repo platform of the Bank of New York Mellon.

The FX basis and the pricing of collateral: Both repo contracts in Figure 1 have a US dollar cash leg and are collateralized with high-quality liquid securities. The difference in the interest rates, which we attribute to the FX basis, is thus due to the different currency denominations of the underlying collateral. We thus assume that the FX basis does not only enter transactions where cash is exchanged against cash similar to in FX swaps but also transactions where cash is exchanged against collateral in another currency such as in CCY repos or transactions where collateral in one currency is exchanged against collateral in another currency.

Empirical and anecdotal evidence corroborates this claim. According to the argumentation above, the borrower in a CCY repo transaction will most likely deliver non-US dollar collateral because US dollar collateral is more valuable than collateral in other currencies. In fact, as documented in Section 5, US dollar CCY repos conducted on the SIX CCY Repo platform are indeed collateralized with securities denominated in Swiss francs (40%), Danish kroner (38%), and euros (16%). The FX basis between the US dollar on one side and the Swiss franc, the Danish kroner and the euro on the other has been large historically, which

renders collateral in these currencies cheapest-to-deliver.²⁸

Pozsar (2017) moreover provides anecdotal evidence in support of our argument. Japanese banks apparently swap Japanese government bonds for US Treasuries with the Japanese Ministry of Finance at negligible cost. Subsequently, Japanese banks acquire US dollars in the repo market against US Treasuries. Pozsar (2017) argues that due to this scheme, the FX basis between the US dollar and Japanese yen remained relatively stable in 2017, which also suggests that there is indeed a link between the collateral and the cash market as described above.

9. Conclusion

Arbitrageurs might run into practical difficulties when trying to exploit deviations from CIP. The crux is choosing the right money market rate when evaluating arbitrage opportunities. While CCY repo rates incorporate hardly any counterparty credit risk, they account for relative funding liquidity risk, which arises due to a preference for liquidity in a certain currency. We argue that the risk characteristics of a CCY repo are essentially the same as those of an FX swap. This is not the case for IBOR, OIS or conventional repo interest rates. Although IBOR differentials correctly reflect relative funding liquidity risk, they are unsuitable when putting CIP to the test because they feature (relative) counterparty credit risk. OIS rates incorporate hardly any funding liquidity risk, and conventional repos fail to reflect funding conditions properly, which renders these rates unsuitable as well. Thus, CIP should hold tightly when calculated based on CCY repo rates, while it should fail IBOR-, OIS- and conventional repo-based calculations.

In the empirical part, we show that the parity relationship holds indeed much better when running CIP based on CCY repos as opposed to IBOR or OIS rates. We investigate CIP deviations between the US dollar on the one hand and the Swiss franc and the euro on the other and focus on nonquarter-end as well as quarter-end data. The CCY repo rates are from two different venues – the SIX Repo and the GCP Repo multicurrency platforms which both produce similar results. We conclude that the CIP puzzle is much smaller than previously thought if only the right money market rate is applied.

Several policy implications can be derived from our findings. First, regulators should treat FX swaps and CCY repos equally because an FX swap can be replicated with two CCY repo transactions. Both strategies are subject to the same risk dynamics and produce

²⁸Other arguments such as a possible home bias in the banks' collateral pool, internal risk-management considerations or regulatory requirements might also play a role in collateral selection.

the very same cash flow. Second, we argue that central bank swap lines, which were installed among major central banks in response to the GFC, are effective in alleviating US dollar funding tensions because they are designed as CCY repos. That is, non-US banks are able to access US dollar funding at their home central bank against non-US dollar collateral. Third, our findings suggest that the FX basis should not only affect cash markets but also collateral markets where market participants exchange collateral in one currency against collateral in another currency (cross-currency securities lending and borrowing transactions). Finally, neither our study nor related papers can pinpoint the exact sources of the FX basis and in particular of relative funding liquidity risk. We can only speculate that the preference for US dollar liquidity arises due to its dominant role as funding and settlement currency. Highly developed and liquid US financial markets probably contribute to the Greenback's importance. It is left for future research to investigate why US dollar funding tends to be so costly compared to funding in most other currencies.

Appendix A. Description of money market rates

A.1. *Overnight-index swap rates*

An OIS agreement is an interest rate swap where one party agrees to pay a fixed interest rate on a certain principal amount in exchange for a floating interest rate on the same principal amount during the term of the contract. The floating leg of the agreement is usually tied to an overnight rate. There are no cash flows until the contract matures when the net difference between the realized overnight interest rate, averaged over the term of the contract, and the predefined fixed interest rate, is settled.

The net profit or replacement cost is usually subject to frequent margin calls, which is why the OIS agreement on its own involves no counterparty credit risk. Nevertheless, OIS interest rates are not entirely devoid of counterparty credit risk due to the floating leg, which is an unsecured interbank transaction and thus incorporates counterparty credit risk. A similar argument applies in regard to the funding liquidity premium. Except for potential margin calls and the net settlement payment at the end, an OIS agreement ties up no liquidity. In particular, unlike an FX swap, it does not involve an exchange of notional amounts at the beginning of the contract. OIS interest rates are nevertheless potentially affected by a small funding liquidity premium through the floating leg.

It is often overlooked that the exploitation of CIP deviations based on OIS rates involves rollover risk. A CIP arbitrageur can only log in the fixed leg interest rate if capable of borrowing and lending at the overnight interest rate underlying the OIS agreement for the entire length of the contract. If an investor is unable to tap the overnight market at these rates, for instance, due to a deterioration in his credit quality during the term of the contract, he will fail to reap (all) arbitrage profits. Note that the longer the contract, the higher this risk is. In other words, the rollover risk should increase with the maturity of the OIS contract implying that the mismatch in risk exposure between the left- and the right-hand side of Equation (1) should rise with longer maturities and thus CIP deviations should, in principle, increase.²⁹

A.2. *IBOR*

Numerous studies analyze the CIP relationship on the basis of IBOR. The IBOR reflects the interest at which prime banks are able to borrow on an unsecured basis for different

²⁹Rime et al. (2017) outline the sequence of transactions when striving to secure a CIP arbitrage profit on the basis of OIS rates. They also discuss associated rollover risks.

maturities.³⁰ It is therefore not an ideal interest rate for CIP testing purposes, because the IBOR incorporates a counterparty credit risk premium component while an FX swap is exempt from such risks. This difference could result in a residuum when putting Equation (1) to test. Proponents of the IBOR might argue that the counterparty credit risk premium is likely to affect domestic as well as foreign interest rates and thus cancels out on the right-hand side of Equation (1). However, the composition of the IBOR panel differs from currency to currency so that the counterparty credit risk component in the two currencies underlying the FX swap is usually not equal in size.³¹

The IBOR does a better job in regard to capturing the funding liquidity risk component. Lending in the IBOR market results in liquidity being tied up until the contract matures. Therefore, differences in the funding liquidity premium across currencies are fully reflected in IBOR interest rate differentials.

Although widely used as a reference rate in financial contracts, the representative content of the IBOR to reflect overall interbank funding conditions is questionable. This is because IBOR is based on quotes of the submitting prime banks and because of a general decline in the underlying market of unsecured interbank transactions during and after the GFC. Reports of manipulative behavior add to reservations.³² In other words, it cannot be taken for granted that a CIP arbitrage can effectively be set up based on IBOR interest rates.

A.3. Conventional repo rates

While the collateral provider remains entitled to coupon and interest payments on the securities provided, legal ownership is usually transferred to the cash lender, which puts him in a position to liquidate the securities received if confronted with a sudden liquidity need. The optionality to sell or to reuse the collateral, for instance in another repo transaction, combined with the fact that the collateral is denominated in the same currency as the cash loan results in a relatively low funding liquidity premium.³³ Note that the resulting funding

³⁰Strictly speaking, IBOR represents an indicative ask interest rate, i.e., the rate at which a prime bank could borrow unsecured. When calculating CIP deviations based on IBOR, the rate is also used for the rate at which the currency received in the FX swap can be invested, i.e., the bid interest rate. In the paper, we use IBOR as a proxy for general unsecured funding conditions.

³¹There is a cross-sectional difference between IBOR-OIS spreads for different currencies, which is evidence that the relative counterparty credit risk premium is nonzero.

³²During the GFC some contributors resorted to understating their borrowing costs in order to avoid the perception that their default risk had deteriorated. Others manipulated contributions with the goal of making a profit on derivative positions referencing to the IBOR (see, for instance, Duffie and Stein (2015)).

³³Exercising the reuse option exposes the investor to market risk. After all, at the expiration date of the contract, he needs to return securities of similar quality to his repo counterpart. However, a short-position in highly rated (government) bonds is much less risky than an open currency position due to the former's lower price volatility. The collateral receiver could moreover avoid risks related to unfavorable price movements by reusing the collateral received in an offsetting reverse repo transaction. Unlike the pricing of FX swaps,

liquidity premium is somewhat different from the relative funding liquidity premium inherent in an FX swap transaction because the latter involves an exchange of assets (cash) in two currencies while the former represents an exchange of assets (cash and collateral) in one currency. We are of the opinion that the funding liquidity premium should be relatively small if cash and collateral are denominated in the same currency. Collateral of high quality should be convertible into cash with relative ease, even in times of stress, not least due to the central bank discount window or emergency liquidity facilities where such collateral could be pledged against liquidity should the need arise.

Appendix B. Institutional details of the CCY Repo markets

B.1. SIX Repo market

The SIX Repo market is the representative secured money market in Switzerland. The major segment is the Swiss franc market, i.e., repos where the cash leg is denominated in Swiss francs. However, other currencies and in particular US dollars can be traded on the platform, as well.³⁴ The SIX Repo market is a triparty repo market. Trades are concluded on an electronic trading platform with a direct link to the central securities depository (CSD) and to the real-time gross settlement payment (RTGS) system for trades with cash leg in Swiss francs. Trades with non-Swiss franc cash legs are settled via a correspondent bank. SIX SIS Ltd. acts as the third party in the transaction managing the collateral selection, the settlement, the ongoing valuation of the collateral and the initiation of margin calls. Participants are mostly banks domiciled in Switzerland and abroad, some with global reach while others are more focused on domestic markets. Moreover, insurance companies as well as Swiss federal agencies participate in the market.

The SIX Repo market is regarded as a GC repo market. In other words, the main focus of the repo trade is not to acquire specific securities, which would be the case in special repos, but to acquire funding. These types of repo transactions are called GC repos because

which exhibit large price swings in response to changing liquidity scarcity levels, repo rates should respond in a more lethargic manner to a liquidity squeeze. Moreover, as long as there is a lender of last resort offering cash against collateral, market participants with central bank access should always be willing to provide liquidity against such collateral. Consequently, even in times of stress, it should not become prohibitively expensive to enter an offsetting reverse repo position to cover sudden liquidity needs. See Fuhrer et al. (2016) for an empirical analysis of the reuse of collateral.

³⁴Other currencies include the euro, Canadian dollar, Japanese yen, Australian dollar, New Zealand dollar, Swedish krona, Norwegian krone, Danish krone, Hungarian forint, Czech koruna and Polish zloty. These currencies are summarized as other currencies because they are traded very rarely in comparison to transactions in Swiss francs, US dollars and euros.

the collateral exchanged is of second-order relevance as long as it fulfills certain requirements with respect to credit and liquidity qualities. Securities that fulfill these requirements are summarized in so-called collateral baskets and GC repos are conducted against these collateral baskets whereby the collateral receiver lacks knowledge of the specific securities delivered when accepting a trade.

In the case of the SIX Repo market, the collateral standard used in interbank repo transactions is the same standard that the SNB uses in its monetary policy operations. Securities that fulfill the SNB eligibility criteria are summarized in the so-called SNB GC basket. Note that this basket is used as the standard, irrespective of the currency of the cash leg.

B.2. GCP Repo market

The GCP market is one of the leading euro repo markets in terms of trading volume and participation (see European Central Bank (2012) and Mancini et al. (2016) for a description of the GCP market). In contrast to the SIX Repo market, which is a triparty repo market, the GCP market is a central counterparty cleared market. While the euro market represents the major market segment, the GCP also allows for trading in US dollars, Swiss francs and pounds sterling. Trades in the GCP market are concluded on an electronic trading platform operated by Eurex Repo Ltd. To execute a trade in the GCP market, banks accept a quote on the platform and with the conclusion of the trade, Eurex Clearing becomes the legal counterparty of the banks involved in the trade. In this role, Eurex Clearing sends the settlement instruction to Clearstream, which triggers the reallocation of cash and collateral to the respective accounts on the settlement date.³⁵ Participants are almost exclusively banks domiciled in Europe, some with global reach while others are more focused on domestic markets.

The GCP market is also regarded as a GC repo market and trades are concluded against the following four collateral baskets: the GCP ECB Basket, the GCP ECB Extended Basket, the GCP INT MXQ Basket, and the GCP Equity Basket. The GCP ECB Basket and the GCP ECB Extended Basket are subsets of the collateral which is eligible in the ECB's monetary policy operations and the GCP ECB Basket is regarded as the standard collateral basket, irrespective of the currency.

³⁵Note that cash and collateral exposures are only reallocated after a process called multilateral netting. That is, Eurex Clearing adds up all borrowing and lending exposures of each bank for each currency, secured by the same collateral basket and for the same settlement date, and reallocates only net cash and collateral exposures in the delivery-versus-payment process (overnight trades are settled nonnetted and in real-time). Note that netting also takes place at the repurchase date of the repo transaction (including overnight transactions). The same conditions with regard to the currency and collateral apply.

The GCP ECB Basket consists of securities denominated in euros, issued by central banks, central, regional or local governments, supranational institutions and covered bonds. The potential volume of securities eligible for the GCP ECB Basket stood at 5,868 billion euros as of September 4, 2017. Since 2015, collateral in the GCP ECB Basket is exclusively denominated in euros. Before 2015, a selection of noneuro denominated securities including few US dollar-denominated securities were eligible, too. After 2015, we know that we are dealing with CCY repos in the case of repo transactions with cash-leg in US dollars and against the GCP ECB Basket. Before, we have to rely on anecdotal evidence suggesting that US dollar-denominated collateral was very rarely used.

For the GCP ECB Basket, ECB haircuts are used and, depending on the risk assessment by Eurex Clearing, an additional margin can be applied. Only securities in the GCP ECB Basket can be reused in ECB open market operations as well as within the GCP market and for Eurex Clearing margin obligations, while all other collateral baskets only qualify for reuse in the latter two.

Appendix C. Empirical analysis

C.1. Number of Observations

Regression 4 is based on the number of observations outlined in Table 7 below:

Table 7: Number of observations

Period	CCY SIX Repo	LIBOR	OIS	Dataset
Overall sample	1337	2694	2694	1337
Pre-crisis ex. Q-end	42	323	323	42
GFC ex. Q-end	242	529	529	242
Debt crisis ex. Q-end	542	788	788	542
Post-crisis ex. Q-end	396	809	809	396
Pre-crisis x Q-end	3	34	34	3
GFC x Q-end	18	50	50	18
Debt crisis x Q-end	57	80	80	57
Post-crisis x Q-end	37	81	81	37

Table 7 displays the number of observations used to calculate arbitrage profits based on 1W CCY SIX Repo, IBOR, and OIS rates. The precrisis period covers data from January 2006 to June 2007, the GFC from July 2007 to December 2009, the sovereign debt crisis from January 2010 to December 2013, and the postcrisis period from January 2014 to July 31, 2017. The interaction between the various periods and quarter-ends denotes the number of observations where the contract runs over a quarter-end. To avoid a sample selection bias affecting our regression analysis, only days where interest rate information for every interest rate type is available are considered (see column five, dataset).

C.2. *P-values of paired t-tests across regressions*

Table 8: *P-values of a paired t-test for average CIP deviations across regressions*

Period	(1) CCY repo vs. IBOR	(2) CCY repo vs. OIS	(3) IBOR vs. OIS
USDCHF analysis			
Avg. CIP deviation	0.00***	0.00***	0.00***
EURUSD analysis			
Avg. CIP deviation	0.00***	0.00***	0.00***

Table 8 shows p -values from a paired t -test with unknown variance. According to the null hypothesis, average CIP deviations (estimate for the intercept) are equal in size for the regressions shown in the respective columns of the table. The sample period analyzed runs from July 31, 2013 to December 31, 2017. (***) (***) and (*) denote statistical significance (one-tailed) at the 1%, 5%, and 10% significance level.

Table 9: *P-values of a paired t-test for average CIP deviations across regressions*

Period	(1) CCY repo vs. IBOR	(2) CCY repo vs. OIS	(3) IBOR vs. OIS
USDCHF analysis			
Q-end	0.00***	0.00***	0.00***
Non Q-end	0.00***	0.00***	0.00***
EURUSD analysis			
Q-end	0.00***	0.00***	0.00***
Non Q-end	0.00***	0.00***	0.01***

Table 9 shows p -values from a paired t -test with unknown variance. According to the null hypothesis, average CIP deviations (estimate for the intercept) are equal in size for the regressions shown in the respective columns of the table. The sample period analyzed runs from July 31, 2013 to December 31, 2017. (***) (***) and (*) denote statistical significance (one-tailed) at the 1%, 5%, and 10% significance level.

Table 10: P -values of a paired t -test for β -estimates across regressions

Period	(1) CCY repo vs. IBOR	(2) CCY repo vs. OIS	(3) IBOR vs. OIS
Pre-crisis ex. Q-end (β_1)	0.00***	0.00***	40.55
GFC ex. Q-end (β_2)	71.37	0.00***	0.00***
Debt crisis ex. Q-end (β_3)	0.00***	0.00***	0.00***
Post-crisis ex. Q-end (β_4)	0.00***	0.00***	0.00***
Pre-crisis Q-end (β_5)	47.68	90.27	21.93
GFC Q-end (β_6)	19.77	0.03**	0.83*
Debt crisis Q-end (β_7)	0.00***	0.00***	0.00***
Post-crisis Q-end (β_8)	0.15	0.00***	0.00***

Table 10 shows p -values from a paired t -test with unknown variance. According to the null hypothesis, the β -estimates are equal in size for the regressions shown in the respective columns of the table. The precrisis period covers data from January 2006 to June 2007, the GFC from July 2007 to December 2009, the sovereign debt crisis from January 2010 to December 2013, and the postcrisis period from January 2014 to July 31, 2017. The Q -end-dummies take on a value of one in the period from nine days to one day before the turn of a quarter. (***) (** and *) denote statistical significance (one-tailed) at the 1%, 5%, and 10% significance level.

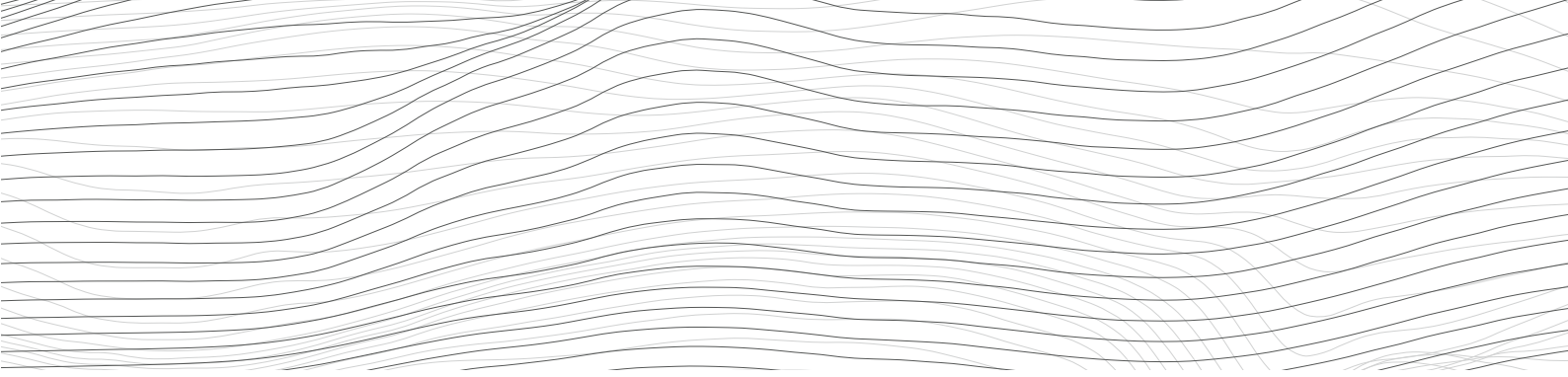
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