Deviations from Covered Interest Rate Parity*

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Abstract

We find that deviations from the covered interest rate parity condition (CIP) imply large, persistent, and systematic arbitrage opportunities in one of the largest asset markets in the world. Contrary to the common view, these deviations for major currencies are not explained away by credit risk or transaction costs. They are particularly strong for forward contracts that appear on the banks' balance sheets at the end of the quarter, pointing to a causal effect of banking regulation on asset prices. The CIP deviations also appear significantly correlated with other fixed-income spreads and with nominal interest rates.

Keywords: exchange rates, currency swaps, dollar funding.

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The foreign exchange forward and swap market is one of the largest and most liquid derivative markets in the world with a total notional amount outstanding equal to $61 trillion and an average daily turnover equal to $3 trillion (Bank of International Settlements, 2013, 2014). The cornerstone of currency forward and swap pricing, presented in all economics and finance textbooks and taught in every class in international finance, is the covered interest rate parity (CIP) condition. In this paper, we document deviations from the CIP post crisis and investigate their causes.

We show that the CIP condition is systematically and persistently violated among G10 currencies, leading to significant arbitrage opportunities in currency and fixed income markets since the global financial crisis in 2008. Our findings are a puzzle for all no-arbitrage models in macroeconomics and finance. Since the arbitrage opportunities exist at very short horizon, such as overnight or one-week, our findings are also a puzzle for the classic limits-of-arbitrage models that rely on long-term market risk, as in Shleifer and Vishny (1997). The systematic patterns of the CIP violations point to the key interaction between costly financial intermediation and international imbalances in funding supply and investment demand across currencies in the new, post-crisis regulatory environment. In particular, we provide evidence of the impact of post-crisis regulatory reforms on CIP arbitrage.

The intuition for the CIP condition relies on a simple no-arbitrage condition. For example, an investor with U.S. dollars in hand today may deposit her dollars for one month, earning the dollar deposit rate. Alternatively, the investor may also exchange her U.S. dollars for some foreign currency, deposit the foreign currency and earn the foreign currency deposit rate for one month. At the same time, the investor can enter into a one-month currency forward contract today, which would convert the foreign currency earned at the end of the month into U.S. dollars. If both U.S. and foreign currency deposit rates are default-free and the forward contract has no counterparty risk, the two investment strategies are equivalent and should thus deliver the same payoffs. Therefore, the difference between U.S. dollar and foreign currency deposit rates should be exactly equal to the cost of entering the forward contract, i.e. the log difference between the forward and the spot exchange rates, with all rates observed at the same date.

The cross-currency basis measures the deviation from the CIP condition. It is the difference between the direct dollar interest rate from the cash market and the synthetic dollar interest rate obtained by swapping the foreign currency into U.S. dollars. A positive (negative) currency basis means that the direct dollar interest rate is higher (lower) than the synthetic dollar interest rate. When the basis is zero, CIP holds. Before the global financial crisis, the log difference between the forward and the spot rate was approximately equal to the difference in London interbank offered rates (Libor) across countries (Frenkel and Levich, 1975; Akram, Rime, and Sarno, 2008). In other words, the Libor cross-currency basis was very close to zero. As is by now well-known, large bases appeared during the height of the global financial crisis and the European debt crisis, as the interbank markets became impaired and arbitrage capital was limited.

We show that Libor bases persist after the global financial crisis among G10 currencies and remain large in magnitude. Our sample includes the most liquid currencies, with a total daily turnover above $2 trillion (Bank of International Settlements, 2013): the Australian dollar, the Canadian dollar, the Swiss franc, the Danish krone, the euro, the British pound, the Japanese yen, the Norwegian krone, the New Zealand dollar, and the Swedish krona. The average annualized absolute value of the basis is 24 basis points at the three-month horizon and 27 basis points at the five-year horizon over the 2010–2016 sample. These averages hide large variations both across currencies and across time. In the current economic environment, the cross-currency basis can be of the same order of magnitude as the interest rate differential. For example, the five-year basis for the Japanese yen was close to -90 basis points at the end of 2015, which was even greater in magnitude than the difference (of about -70 basis points) between the five-year Libor interest rate in Japan and in the United States.

We show that credit risk in the Libor market and the indicative nature of Libor cannot explain away the persistence of the cross-currency basis. A common explanation for CIP deviations is that interbank panels have different levels of credit worthiness (e.g., Tuckman and Porfirio, 2004). If, for example, interbank lending in yen entails a higher credit risk (due to the average lower credit quality of yen Libor banks) than interbank lending in U.S. dollars, the lender should be compensated for the credit risk differential between yen Libor and dollar Libor, and thus the cross-currency basis needs not be zero.[1] Studying the credit default spreads of banks on interbank panels in different currencies, we do not find much support for this explanation of the CIP deviations.

More crucially, we document that the currency basis exists even in the absence of any credit risk difference across countries and for actual interest rate quotes. To do so, we turn first to general collateral repurchase agreements (repo) and then to Kreditanstalt für Wiederaufbau (KfW) bonds issued in different currencies. Repo contracts are fully collateralized and thus do not exhibit any credit risk. KfW bonds are fully backed by the German government and thus exhibit very minimal credit risk, without differences in credit risk across currencies. Repo and forward contracts highlight the CIP deviations at the short-end of the yield curves, while KfW bonds and swaps focus on longer maturities. We find that the repo currency basis is persistently and significantly negative for the Japanese yen, the Swiss franc and the Danish krone, and that the KfW basis is also significantly different from zero for the euro, the Swiss Franc and the Japanese yen, even after taking into account transaction costs.

The CIP deviations thus lead to persistent arbitrage opportunities free from exchange rate and credit risks. A long-short arbitrageur may for example borrow at the U.S. dollar repo rate or short U.S. dollar-denominated KfW bonds and then earn risk-free positive profits by investing in repo rates or KfW bonds denominated in low interest rate currencies, such as the euro, the Swiss franc, the Danish krone or the yen, while hedging the foreign currency risk using foreign exchange forwards or swaps. The net arbitrage profits range from 10 to 20 basis points on average in annualized values. The conditional volatility of each investment opportunity is naturally zero and Sharpe ratios are thus infinite for the fixed investment horizon of the strategy.

After documenting the persistence of CIP deviations and formally establishing arbitrage opportunities, we turn to their potential explanations. We hypothesize that persistent CIP devi-

[1] "Libor" rates are supposed to measure the interest rates at which Libor panel banks borrow from each other. We use the term "Libor" loosely to refer to the benchmark unsecured interbank borrowing rate, which can be determined by local interbank panels rather than the British Banker Association (now Intercontinental Exchange) Libor panels.

ations can be explained by the combination of constraints on financial intermediaries post-crisis and persistent international imbalances in investment demand and funding supply across currencies. If financial intermediaries were unconstrained, the supply of currency hedging should be perfectly elastic, and any CIP deviations would be arbitraged away. Similarly, if the global funding and investment demand were balanced across currencies, there would be no client demand for FX swaps to transform funding liquidity or investment opportunities across currencies, and thus the cross-currency basis would also be zero regardless of the supply of currency hedging. Costly financial intermediation can explain why the basis is not arbitraged away post crisis. The imbalances in savings and investment across currencies can explain the systematic relationship between the basis and nominal interest rates.

Consistent with our two-factor hypothesis, we find that the CIP deviations exhibit four main characteristics. First, CIP deviations increase towards the quarter ends, as banks face tighter balance sheet constraints and renewed investors' attention due to quarterly regulatory filings. We find that the one-month CIP deviation increases exactly one month before the quarter ends, at the time when a one-month forward contract has to appear on the quarter-end balance sheet. Likewise, the one-week CIP deviation increases exactly one week before the quarter ends. This is the smoking gun. Meanwhile, a three-month CIP trade, which has to appear on a quarter-end report regardless of when it is executed, does not exhibit any particular dynamics. In this example, the one-month or the one-week forward contracts that cross the quarter ends are the "treated" assets, subject to higher balance sheet costs due to regulatory filings, while the three-month forward contract is the "non-treated" asset. Our simple difference-in-difference experiments exploits different lags before the quarter ends and different horizons of the forward contracts. The term structure of short-term CIP deviations suggests that banking regulation has a causal impact on asset prices.

Second, we find that a proxy for the shadow costs of banks' balance sheet accounts for about one third of the CIP deviations. Our proxy is the spread between the interest rates on excess reserves (IOER) paid by the Fed and the Fed Funds or the U.S. Libor rate. In the absence of balance sheet costs, banks should borrow at the Fed Funds/U.S. Libor rate and invest risk-free at the IOER, until the Fed Funds/Libor rate increases and both rates are equal. Yet, a significant spread persists, and we interpret it as a proxy for the shadow cost of leverage. Moreover, if banks invest at the foreign IOER, because foreign central bank reserves are more liquid than private money market instruments (as codified by the liquidity coverage ratio requirement under Basel III), the CIP deviations are further reduced by one third on average.

Third, in the cross-section and time series, the cross-currency basis is positively correlated with the level of nominal interest rates. In the cross section, high interest rate currencies tend to exhibit positive basis while low interest rate currencies tend to exhibit negative ones. An arbitrageur should thus borrow in high interest rate currencies and lend in low interest currencies while hedging the currency risk — this is the opposite allocation to the classic currency carry trade. In the time series, the cross-currency basis tends to increase with interest rate shocks, as measured in an event study of yield changes around monetary policy announcements of the European Central Bank.

Fourth, the cross-currency basis is correlated with other liquidity spreads, especially the KfW over German bund basis and the U.S. Libor tenor basis, the price of swapping the one-month in exchange of the three-month U.S. Libor rates. The co-movement in bases measured in different markets points to the role of financial intermediaries and correlated demand shocks for dollar funding and other forms of liquidity.

We now turn to a short review of the existing relevant work. A large literature show the CIP condition holds well before the global financial crisis.[2] A number of papers study the failure of the CIP condition during the global financial crisis and the European debt crisis (see, e.g., Baba, Packer, and Nagano, 2008; Baba, McCauley, and Ramaswamy, 2009; Coffey, Hrung, and Sarkar, 2009; Griffolli and Ranaldo, 2011; Bottazzi, Luque, Pascoa, and Sundaresan, 2012; and Ivashina, Scharfstein, and Stein, 2015). All these papers focus on CIP deviations based on short-term money market instruments. The large cross-currency basis during the crisis appears to be linked to a severe dollar funding shortage in the presence of limits to arbitrage. The estab-

[2]An early exposition of the CIP condition appears in Lotz (1889) and much more clearly in Keynes (1923). A large literature in the 70s and 80s tests the CIP condition, notably Frenkel and Levich (1975, 1977), Deardorff (1979), Dooley and Isard (1980), Callier (1981), Mohsen Bahmani-Oskooee (1985) and Clinton (1988).

lishment of the Fed swap lines with various foreign central banks, which alleviated the dollar shortage, significantly reduced the magnitude of the cross-currency basis (Baba and Packer, 2009; Goldberg, Kennedy, and Miu, 2011; and McGuire and von Peter, 2012).

Our work focuses on the post-crisis period and is closely related to a large literature that departs from the frictionless asset pricing benchmark.[3] On the theory side, Garleanu and Pedersen (2011) build a margin-based asset pricing model and use it to study the deviations from CIP during the crisis. Gabaix and Maggiori (2015) provide a tractable and elegant model of exchange rate determination in the presence of moral hazard. A variant of their model, presented in their Appendix, encompasses CIP deviations. Our evidence on the impact of banking regulation points towards models of intermediary-based asset pricing, as those of He and Krishnamurthy (2012, 2013) and Brunnermeier and Sannikov (2014) in the tradition of Bernanke and Gertler (1989) and Holmstrom and Tirole (1997). But many other friction-based models could potentially be relevant.[4] To the best of our knowledge, however, there is no model so far that can replicate our four main facts on CIP deviations. On the empirical side, Adrian, Etula and Muir (2014) and He, Kelly and Manela (2015) show that shocks to the equity capital ratio of financial intermediaries account for a large share of the cross-sectional variation in expected returns in different asset classes. Siriwardane (2016) shows that limited investment capital impacts pricing in the credit default swap market. Our work is also closely related to recent papers on the interaction between the new U.S. monetary policy implementation framework and banking regulations, as discussed in Duffie and Krishnamurthy (2016), Klee, Senyuz,

[3]Building on our work, CIP deviations after the crisis have become an area of active research. In on-going work, Advijev, Du, Koch and Shin (2016) study the relationship between the strength of the dollar spot exchange rate and CIP deviations. Amador, Bianchi, Bicola and Perri (2016) model exchange rate policy at the zero-lower bound and relate it to CIP deviations. Liao (2016) examines the implications of corporate funding cost arbitrage on CIP deviations. Rime, Schrimpf and Syrstad (2016) focus on the role of money market segmentation on CIP deviations. Sushko, Borio, McCauley and McGuire (2016) link the estimated dollar hedging demand (quantities) for major currencies to the variation in CIP deviations (prices).

[4]The large theoretical literature on limits-to-arbitrage, surveyed in Gromb and Vayanos (2011), provides useful frameworks, with the caveat that CIP arbitrages exist over very short time horizons over which market risk and collateral constraints are very limited. Focusing on the U.S. swap market, Jermann (2016) proposes a novel and attractive limits-to-arbitrage model based on the regulation-induced increased cost of holding Treasuries. Likewise, models of market and funding liquidity, as in Brunnermeier and Pedersen (2009), or models of preferred habitat, as in Vayanos and Vila (2009) and Greenwood or Vayanos (2014), are potential theoretical frameworks to account for the CIP deviations. Our findings are also related to models of the global imbalances in safe assets, as studied in the pioneer work of Caballero, Farhi, and Gourinchas (2008, 2016).

and Yoldas (2016), and Benegas and Tase (2016), and window dressing activities in repo markets on financial reporting dates (Munyan, 2015).

The paper is organized as follows. Section I defines and documents precisely the CIP condition and its deviations at the short- and long-end of the yield curves. Section II shows that the cross-currency basis exists in the absence of credit risk, for repo rates and KfW bonds, leading to clear arbitrage opportunities. Section III sketches a potential explanation of the CIP deviations centered on the capital constraints of financial intermediaries and global imbalances. Consistent with such potential explanation, Section IV presents four characteristics of the currency basis: its surge at the end of the quarters post-crisis, its high correlation with other liquidity-based strategies in different fixed-income markets, its relationship with the IOER, and finally its cross-sectional and time-series links with interest rates. Section V concludes.

I. CIP Condition and Cross-Currency Basis

In this section, we review the CIP condition and define the cross-currency basis as the deviation from the CIP condition. We then document the persistent failure of the textbook CIP condition based on Libor.

A. Covered Interest Rate Parity

Let $y^{\$}_{t,t+n}$ and $y_{t,t+n}$ denote the continuously compounded n-year risk-free interest rates quoted at date t in U.S. dollars and foreign currency, respectively. The spot exchange S_t rate is expressed in units of foreign currency per U.S. dollar: an increase in S_t thus denotes a depreciation of the foreign currency and an appreciation of the U.S. dollar. Likewise, $F_{t,t+n}$ denotes the n-year outright forward exchange rate in foreign currency per U.S. dollar at time t. The CIP condition states that the forward rate should satisfy

$$e^{ny^{\$}_{t,t+n}} = e^{ny_{t,t+n}} \frac{S_t}{F_{t,t+n}} \tag{1}$$

In logs, the continuously compounded forward premium, $\rho_{t,t+n}$, is equal to the interest rate difference

$$\rho_{t,t+n} \equiv \frac{1}{n}(f_{t,t+n} - s_t) = y_{t,t+n} - y^{\$}_{t,t+n}. \tag{2}$$

The intuition behind the CIP condition is simple: an investor with one U.S. dollar in hand today would own $e^{ny^{\$}_{t,t+n}}$ U.S. dollars n years from now by investing in U.S. dollars. But the investor may also exchange her U.S. dollar for S_t units of foreign currency and invest in foreign currency to receive $e^{ny_{t,t+n}}S_t$ units of foreign currency n years from now. A currency forward contract signed today would convert the foreign currency earned into $e^{ny_{t,t+n}}S_t/F_{t,t+n}$ U.S. dollars. If both domestic and foreign notes are risk-free aside from the currency risk and the forward contract has no counterparty risk, the two investment strategies are equivalent and should thus deliver the same payoffs. All contracts are signed today. The CIP condition is thus a simple no-arbitrage condition.[5]

B. Definition of the Cross-Currency Basis

We define the continuously compounded cross-currency basis, denoted $x_{t,t+n}$, as the deviation from the CIP condition:

$$e^{ny^{\$}_{t,t+n}} = e^{ny_{t,t+n}+nx_{t,t+n}}\frac{S_t}{F_{t,t+n}}. \tag{3}$$

Equivalently, in logs, the cross-currency basis is equal to:

$$x_{t,t+n} = y^{\$}_{t,t+n} - (y_{t,t+n} - \rho_{t,t+n}). \tag{4}$$

[5]In the presence of transaction costs, the absence of arbitrage is characterized by two inequalities: arbitrage must be impossible either by borrowing the domestic currency and lending the foreign currency, or doing the opposite, hedging the currency risk with the forward contract in both cases (see Bekaert and Hodrick, 2012, for a textbook exposition). As a result, the bid and ask forward rates satisfy

$$\frac{F^{ask}_{t,t+n}}{S^{bid}_t} \geq \frac{e^{ny^{bid}_{t,t+n}}}{e^{ny^{\$,ask}_{t,t+n}}} \text{ and } \frac{F^{bid}_{t,t+n}}{S^{ask}_t} \leq \frac{e^{ny^{ask}_{t,t+n}}}{e^{ny^{\$,bid}_{t,t+n}}}.$$

When CIP holds, the comparison of Equations (1) and (3) immediately implies that the currency basis is zero. The cross-currency basis measures the difference between the direct U.S. dollar interest rate, $y^{\$}_{t,t+n}$, and the synthetic dollar interest rate, $y_{t,t+n} - \rho_{t,t+n}$, obtained by converting the foreign currency interest rate in U.S. dollars using currency forward contracts. A negative currency basis suggests that the direct U.S. dollar interest rate is lower than the synthetic dollar interest rate.

As already noted, CIP holds in the absence of arbitrage. As soon as the basis is not zero, arbitrage opportunities theoretically appear. The cash flow diagram of this CIP arbitrage strategy is summarized in Figure 1. In the case of a negative basis, $x < 0$, the dollar arbitrageur can earn risk-free profits equal to an annualized $|x|$ percent of the trade notional by borrowing at the direct dollar risk-free rate, investing at the foreign currency risk-free rate and signing a forward contract to convert back the foreign currency into U.S dollars. In the case of a positive basis, the opposite arbitrage strategy of funding in the synthetic dollar risk-free rate and investing in the direct dollar risk-free rate would also yield an annualized risk-free profit equal to x percent of the trade notional. With these definitions in mind, we turn now to a preliminary look at the data.

C. *Failure of Textbook Libor-Based Covered Interest Parity*

Textbook tests of the CIP condition usually rely on Libor rates.[6] We document persistent failure of Libor-based CIP after 2007 for G10 currencies at short and long maturities. As we just saw, at short maturities less than one year, CIP violations can be computed using Libor rates and currency forward and spot rates. At the longer maturities (typically one year or greater), CIP violations based on Libor are directly quoted as spreads on Libor cross-currency basis swaps.

[6]Eurocurrency deposit rates based in London have long been used as benchmark interest rates to test the CIP condition, starting with the work of Frenkel and Levich (1975), because eurocurrency deposits are highly fungible and avoid many barriers to the free flow of capital, such as differential domestic interest rate regulations, tax treatments, and reserve regulations. Akram, Rime, and Sarno (2008) confirm the high-degree of validity of the CIP condition using bank deposit rates in the early 2000s sample.

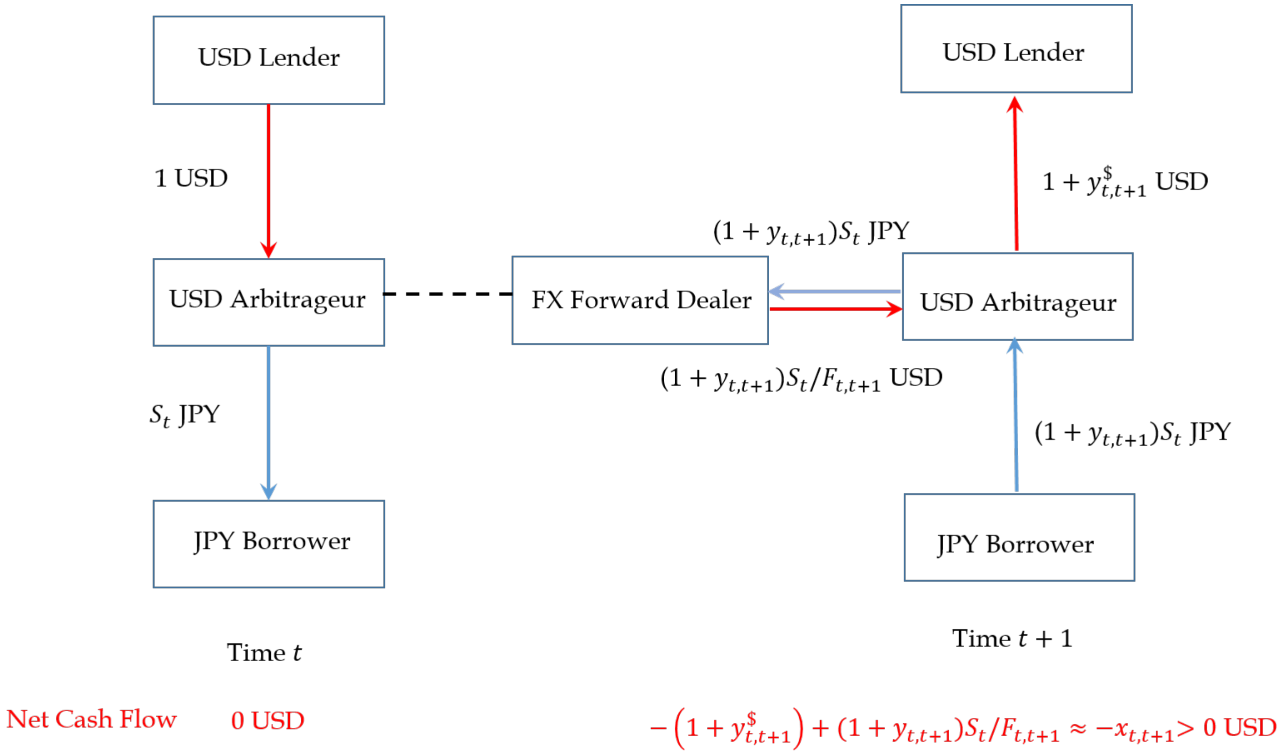

Figure 1. Cash Flow Diagram for CIP Arbitrage with a Negative Basis

This figure plots the cash flow exchanges of an arbitrageur profiting from a negative cross-currency basis ($x_{t,t+1} < 0$) between the yen and the U.S. dollar. To arbitrage the negative cross-currency basis, the U.S. dollar arbitrageur borrows 1 U.S. dollar at the interest rate $y^{\$}_{t,t+1}$, convert it into S_t yen, lends in yen at the interest rate $y_{t,t+1}$, and finally signs a forward contract at date t. There is no cash flow at date t. At date $t+1$, the arbitrageur receives $e^{y_{t,t+1}}S_t \simeq (1 + y_{t,t+1})S_t$ yen, and convert that into $e^{y_{t,t+1}}S_t/F_{t,t+1} \simeq (1 + y_{t,t+1})S_t/F_{t,t+1}$ U.S. dollars thanks to the forward contract. The arbitrageur reimburses her debt in U.S. dollars and is left with a profit equal to the negative of the cross-currency basis $x_{t,t+1}$. In essence, the arbitrageur is going long in the yen and short in the dollar, with the yen cash flow fully hedged by a forward contract.

C.1. Short-Term Libor Cross-Currency Basis

We define the Libor basis as equal to:

$$x^{Libor}_{t,t+n} \equiv y^{\$,Libor}_{t,t+n} - (y^{Libor}_{t,t+n} - \rho_{t,t+n}), \tag{5}$$

where the generic dollar and foreign currency interest rates of Equation (4) are replaced with Libor rates. We obtain daily spot exchange rates and forward points from Bloomberg using London closing rates for G10 currencies. Mid-rates (average of bid and ask rates) are used for benchmark basis calculations. Daily Libor/interbank fixing rates are also obtained from

Bloomberg and described in the Data Appendix. Figure 2 presents the three-month Libor basis for G10 currencies between January 2000 and September 2016.

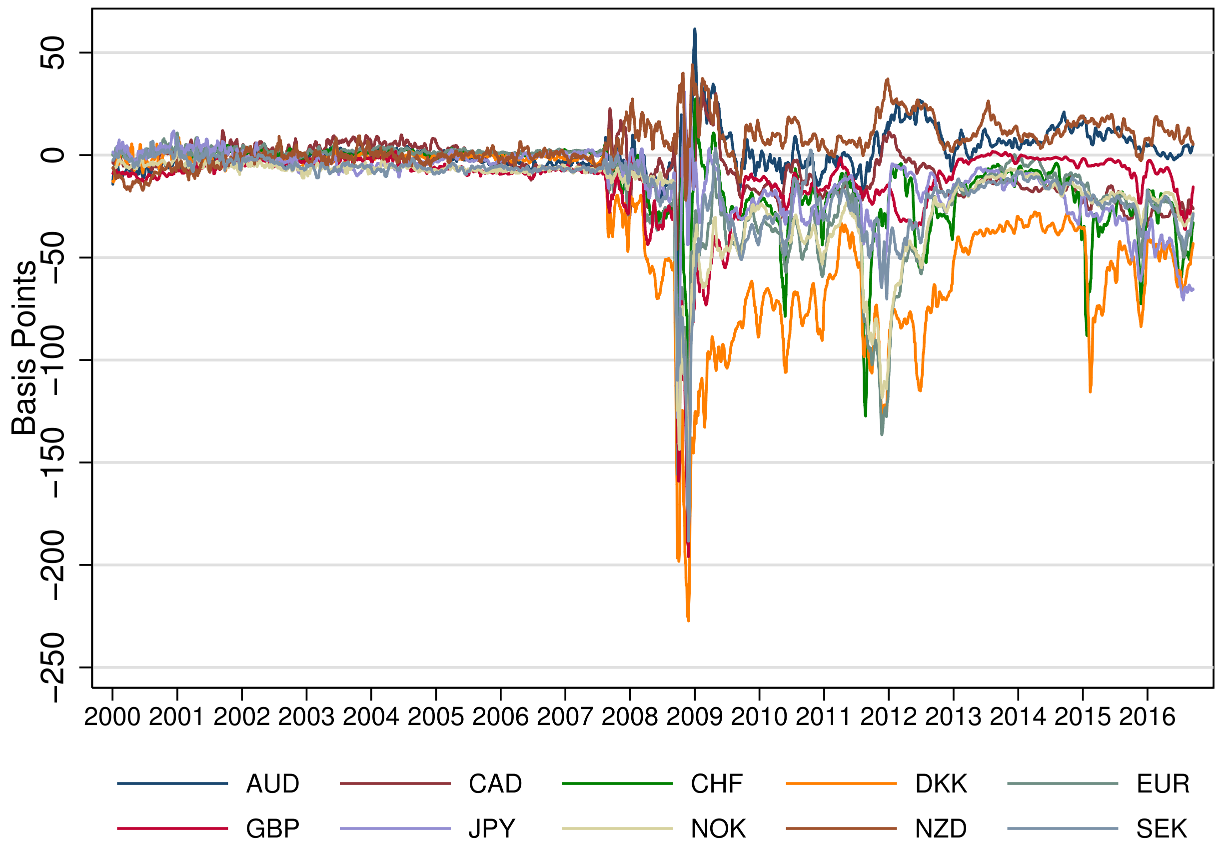

Figure 2. Short-Term Libor-Based Deviations from Covered Interest Rate Parity
This figure plots the 10-day moving averages of the three-month Libor cross-currency basis, measured in basis points, for G10 currencies. The covered interest rate parity implies that the basis should be zero. One-hundred basis points equal one percent. The Libor basis is equal to $y^{\$,Libor}_{t,t+n} - (y^{Libor}_{t,t+n} - \rho_{t,t+n})$, where n = three months, $y^{\$,Libor}_{t,t+n}$ and $y^{Libor}_{t,t+n}$ denote the U.S. and foreign three-month Libor rates, and $\rho_{t,t+n} \equiv \frac{1}{n}(f_{t,t+n} - s_t)$ denotes the forward premium obtained from the forward $f_{t,t+n}$ and spot s_t exchange rates.

The three-month Libor basis was very close to zero for all G10 currencies before 2007. As is well-known, during the global financial crisis (2007–2009), there were large deviations from Libor CIP, especially around the Lehman bankruptcy announcement, with some bases reaching -200 basis points. But the deviations from Libor CIP did not disappear when the crisis abated. In the aftermath of the crisis, since 2010, the three-month Libor basis has been persistently different from zero. Panel A of Table I summarizes the mean and standard deviation of the three-month Libor cross-currency basis across three different periods: 2000–2006, 2007–2009, and 2010–2016. Pre-crisis, the Libor basis was not significantly different from zero; post-crisis, it is. Moreover, a clear cross-sectional dispersion in the level of the basis appears among G10 currencies. The Australian dollar (AUD) and the New Zealand dollar (NZD) exhibit on average a positive basis of 5 and 12 basis points at the three-month horizon, while the Swiss franc (CHF), Danish krone (DKK), euro (EUR), Japanese yen (JPY), Norwegian krone (NOK), and Swedish krona (SEK) exhibit on average negative bases all below -20 basis points. Among the G10 currencies, the Danish krone has the most negative three-month Libor basis post crisis, with an average of -60 basis points, a stark contrast to its pre-crisis average of -2 basis point.[7]

C.2. Long-Term Libor Cross-Currency Basis

At long maturities, the long-term CIP deviation based on Libor is given by the spread on the cross-currency basis swap. A cross-currency basis swap involves an exchange of cash flows linked to floating interest rates referenced to interbank rates in two different currencies, as well as an exchange of principal in two different currencies at the inception and the maturity of the swap. Let us take a simple example. Figure 3 describes the cash flow diagram for the yen/U.S. dollar cross-currency swap on \$1 notional between Bank A and Bank B. At the inception of the swap, Bank A receives \$1 from Bank B in exchange of $¥S_t$. At the j-th coupon date, Bank A pays a dollar floating cash flow equal to $y_{t+j}^{Libor,\$}$ percent on the \$1 notional to Bank B, where $y_{t+j}^{Libor,\$}$ is the three-month U.S. dollar Libor at time $t+j$. In return, Bank A receives from Bank B a floating yen cash flow equal to $(y_{t+j}^{Libor,¥} + x_{t,t+n}^{xccy})$ on the $¥S_t$ notional, where $y_{t+j}^{Libor,¥}$ is the three-month yen Libor at time $t+j$, and $x_{t,t+n}^{xccy}$ is the cross-currency basis swap spread, which is pre-determined at date t at the inception of the swap transaction. When the swap contract matures, Bank B receives \$1 from Bank A in exchange of $¥S_t$, undoing the initial transaction.

The spread on the cross-currency basis swap, $x_{t,t+n}^{xccy}$, is the price at which swap counterparties are willing to exchange foreign currency floating cash flows against U.S. dollar cash flows.

[7] The Danish central bank maintains a peg of its currency to the euro. Yet, the CIP deviations are larger for the Danish krone than for the euro, in part reflecting the risk of a sudden break of the peg, similar to the Swiss franc experience in January 2015.

Table I
Summary Statistics for Libor-based Covered Interest Parity Deviations

This table reports the mean Libor basis for G10 currencies for three different periods in basis points. The periods are 1/1/2000–12/31/2006, 1/1/2007–12/31/2009, and 1/1/2010–09/15/2016. Standard deviations are shown in the parentheses. Panel A focuses on the three-month cross-currency basis, while Panel B focuses on the five-year cross-currency basis. The three-month Libor basis is equal to: $y^{\$,Libor}_{t,t+n} - (y^{Libor}_{t,t+n} - \rho_{t,t+n})$, where $y^{\$,Libor}_{t,t+n}$ and $y^{Libor}_{t,t+n}$ denote the U.S. and foreign three-month Libor rates and $\rho_{t,t+n} \equiv \frac{1}{n}(f_{t,t+n} - s_t)$ denotes the forward premium obtained from the forward $f_{t,t+n}$ and spot s_t exchange rates. The five-year currency basis is obtained from cross-currency basis swap contracts. The countries and currencies are denoted by their usual abbreviations: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), Danish krone (DKK), euro (EUR), British Pound (GBP), Japanese yen (JPY), Norwegian krone (NOK), New Zealand dollar (NZD) and Swedish krona (SEK). For each currency, the table reports the precise benchmark interest rates used to compute the basis. The full names of these benchmark interest rates are listed in the data appendix.

		Panel A: Three-month Horizon			Panel B: Five-year Horizon		
Currency	Benchmark	2000-06	2007-09	2010-16	2000-06	2007-09	2010-16
AUD	BBSW	-2.0	0.1	5.3	9.5	9.3	24.6
		(4.2)	(19.8)	(9.3)	(2.8)	(11.8)	(5.5)
CAD	CDOR	1.3	-3.9	-16.3	10.7	10.9	4.4
		(5.2)	(16.5)	(9.2)	(3.7)	(9.5)	(6.2)
CHF	LIBOR	1.0	-16.9	-25.4	-2.2	-12.9	-39.8
		(3.0)	(27.2)	(19.7)	(0.9)	(12.8)	(12.0)
DKK	CIBOR	-1.5	-63.1	-59.7	-2.6	-30.2	-46.7
		(4.0)	(54.4)	(23.2)	(2.4)	(30.2)	(14.1)
EUR	EURIBOR	2.0	-27.7	-31.2	0.1	-15.0	-28.6
		(2.9)	(32.3)	(25.2)	(2.0)	(16.2)	(13.5)
GBP	LIBOR	-5.8	-34.1	-10.9	-0.9	-17.2	-6.6
		(3.8)	(36.7)	(9.7)	(2.3)	(18.1)	(6.6)
JPY	LIBOR	-1.3	-13.8	-24.6	-5.3	-13.5	-62.0
		(5.3)	(22.9)	(15.5)	(4.2)	(20.1)	(17.3)
NOK	NIBOR	-5.9	-30.6	-30.3	-4.7	-14.8	-15.1
		(3.7)	(33.5)	(21.5)	(1.9)	(12.3)	(9.0)
NZD	BKBM	-2.2	9.0	12.1	3.6	7.9	31.0
		(6.8)	(14.8)	(7.6)	(2.9)	(8.6)	(8.2)
SEK	STIBOR	-4.4	-26.6	-23.9	-1.8	-7.2	-2.7
		(4.4)	(33.3)	(12.1)	(1.0)	(7.9)	(8.2)
Average		-1.9	-20.8	-20.4	0.6	-8.3	-14.1
		(5.2)	(36.7)	(25.2)	(6.0)	(20.5)	(30.7)

In the case of the yen/U.S dollar cross-currency swap over the recent period, $x^{xccy}_{t,t+n}$ is often negative. Let us assume for simplicity that Bank B is able to lend risk-free in yen at the three-month yen Libor rate, $y^{Libor,¥}_{t+j}$. Then, according to the cross-currency basis swap contract, Bank B has

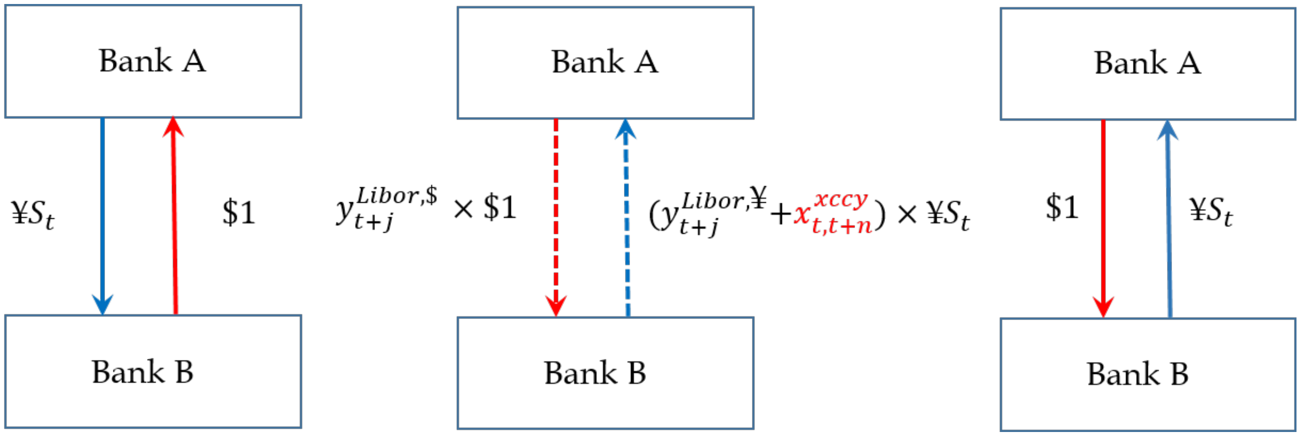

Figure 3. Cash Flow Diagram for JPY/USD Cross-Currency Basis Swap

This figure shows the cash flow exchanges of a standard yen/dollar cross-currency basis swap. At the inception of the swap, Bank A receives \$1 from Bank B in exchange of $¥S_t$. At the j-th coupon date, Bank A pays a dollar floating cash flow equal to $y_{t+j}^{Libor,\$}$ percent on the \$1 notional to Bank B, where $y_{t+j}^{Libor,\$}$ is the three-month U.S. dollar Libor at time $t+j$. In return, Bank A receives from Bank B a floating yen cash flow equal to $(y_{t+j}^{Libor,¥} + x_{t,t+n}^{xccy})$ on the $¥S_t$ notional, where $y_{t+j}^{Libor,¥}$ is the three-month yen Libor at time $t+j$, and $x_{t,t+n}^{xccy}$ is the cross-currency basis swap spread, which is pre-determined at date t at the inception of the swap transaction. When the swap contract matures, Bank B receives \$1 from Bank A in exchange of $¥S_t$, undoing the initial transaction.

to pay to Bank A the yen cash flows $(y_{t+j}^{Libor,¥} + x_{t,t+n}^{xccy})$, which is clearly less than the yen Libor rate $y_{t+j}^{Libor,¥}$ that Bank B collects by investing the yen it received originally from Bank A. In this example, Bank B pockets a sure profit by lending U.S. dollars to Bank A. In other words, if both banks can borrow and lend risk-free at Libor rates, then the cross-currency basis should be zero. As soon as the cross-currency basis swap is not zero, one counterparty seems to benefit from the swap, hinting at potential deviations from the CIP condition at the long end of the yield curve.

More formally, to see how the cross-currency basis swap directly translates into deviations from the long-term Libor-based CIP condition, let us focus on the case of zero-coupon fixed-for-fixed cross-currency swap contracts. Such contracts are similar to the swap contract described above and in Figure 3, but no coupon payments are exchanged at the intermediary dates. Intuitively, an investor can take three steps to swap fixed foreign currency cash flows into fixed U.S. dollar cash flows. First, she pays the foreign currency interest rate swap, $y_{t,t+n}^{IRS}$, to swap fixed foreign currency cash flows into floating foreign currency Libor cash flows. Second, she pays the cross-currency basis swap, $x_{t,t+n}^{xccy}$, to swap floating foreign currency Libor into U.S. dollar Libor cash flows. Third, she receives the U.S. interest rate swap, $y_{t,t+n}^{\$,IRS}$, to swap floating dollar

U.S. Libor cash flows into fixed U.S. dollar cash flows. The combination of the three steps eliminate all floating cash flows, and only exchanges of fixed cash flows in two different currencies at the inception and maturity of the swap remain.[8]

In this synthetic agreement, an investors pays \$1 in exchange of S_t yen at the start of the swap period, receives $e^{ny^{\$,IRS}_{t,t+n}}$ U.S. dollars at the maturity of the contract and pays $e^{ny^{IRS}_{t,t+n}+nx^{xccy}_{t,t+n}}S_t$ yen at the end of the contract, worth $e^{ny^{IRS}_{t,t+n}+nx^{xccy}_{t,t+n}}S_t/F_{t,t+n}$ U.S. dollars at that time. The cross-currency basis swap rates are priced such that:

$$e^{ny^{\$,IRS}_{t,t+n}} = e^{ny^{IRS}_{t,t+n}+nx^{xccy}_{t,t+n}}\frac{S_t}{F_{t,t+n}}.$$

Equivalently, the long-term forward premium to hedge a foreign currency against the U.S. dollar is implicitly given by:

$$\rho_{t,t+n} \equiv \frac{1}{n}(f_{t,t+n} - s_t) = y^{IRS}_{t,t+n} + x^{xccy}_{t,t+n} - y^{\$,IRS}_{t,t+n}. \tag{6}$$

The cross-currency basis swap rate, $x^{xccy}_{t,t+n}$, thus measures deviations from the CIP condition where interest rates are Libor interest rate swap rates.

Data on cross-currency basis swaps come from Bloomberg. Figure 4 shows the five-year Libor basis for G10 currencies between January 2001 and September 2016, while the Panel B of Table I reports averages and standard deviations by sub-periods. Before 2007, the five-year Libor basis was slightly positive for Australian, Canadian, and New Zealand dollars and negative for all the other currencies, but all bases were very close to zero. The five-year Libor bases started diverging away from zero in 2008, and reached their sample peak during the European debt crisis in 2012. The Libor bases narrowed in 2013 and early 2014, but started widening again in the second half of 2014. In the post-crisis sample, the Australian dollar and the New Zealand dollar exhibit the most positive bases, equal to 25 and 31 basis points on average, respectively, while the Japanese yen and the Danish krone exhibit the most negative bases, equal to -62 and

[8] A detailed cash flow diagram of these transactions can be found in the Online Appendix.

−47 basis points on average, respectively. The Swiss franc and the euro also experience very negative bases.

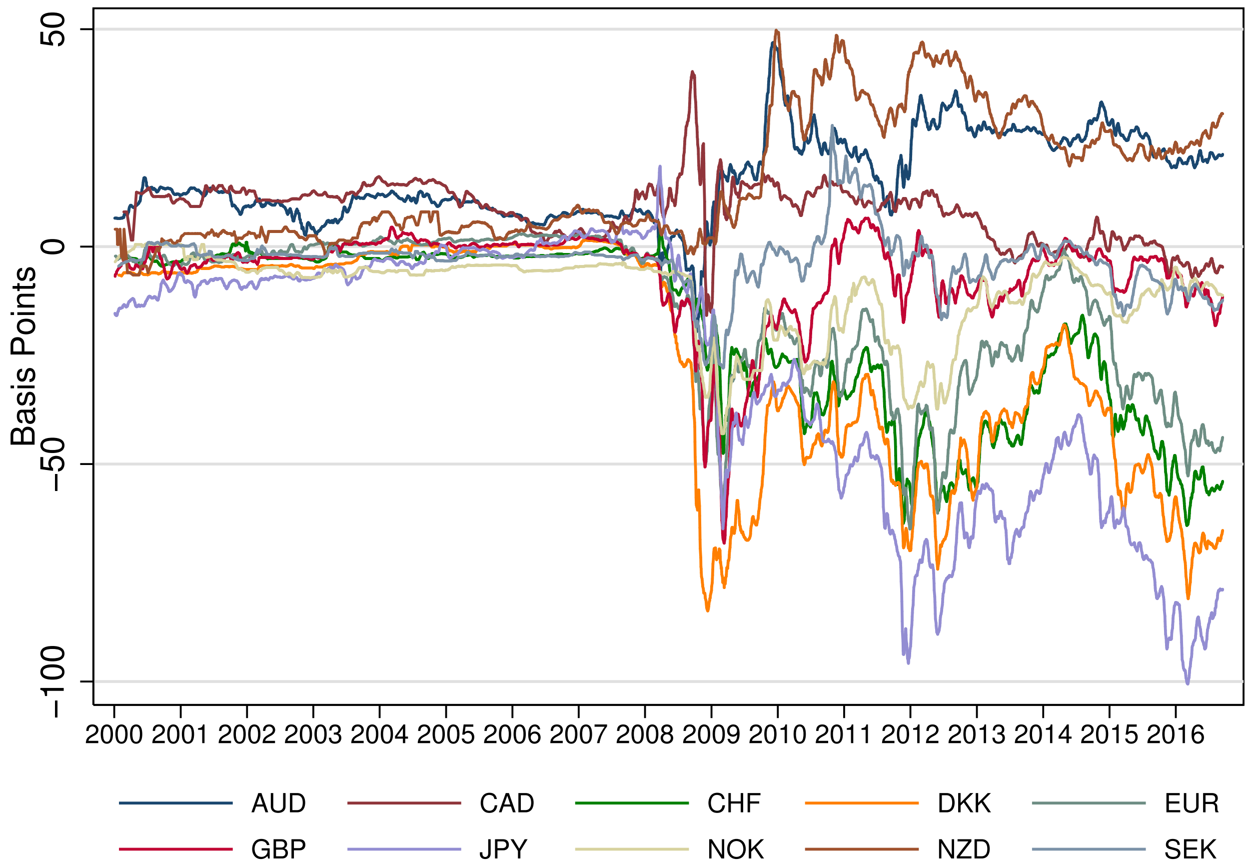

Figure 4. Long-Term Libor-Based Deviations from Covered Interest Rate Parity
This figure plots the 10-day moving averages of the five-year Libor cross-currency basis, measured in basis points, for G10 currencies. The covered interest rate parity implies that the basis should be zero.

At short and long horizons, CIP deviations abound post-crisis. But the textbook treatment of these deviations point to potential transaction costs and default risk, not necessarily to arbitrage opportunities.

II. CIP-Based Arbitrage Opportunities

In this section, we start with a short description of the main issues of a Libor-based investment strategy and then address those issues using repo contracts and bonds issued by KfW and other multi-currency issuers. We demonstrate that the existence of the repo and KfW basis implies CIP arbitrage opportunities free from currency and credit risk, even after taking into account transaction costs.

A. *Credit Risk in the Libor CIP Arbitrage*

A potential arbitrageur, noticing for example a negative Libor CIP basis on the yen/dollar market, would need to borrow in U.S. dollars at the dollar Libor rate, invest in yen at the yen Libor rate and enter a forward contract to convert back yen into U.S dollars at the end of her investment period. The investment strategy raises immediately three questions. First, can the arbitrageur really borrow and lend at the Libor rates? Libor rates are only indicative and do not correspond to actual transactions. The actual borrowing rate in U.S. dollars of the arbitrageur may thus be higher than the indicative Libor rate, even in the absence of any manipulation. More generally, transaction costs exist for both spot and derivative contracts and may lower the actual returns. Second, is the arbitrageur taking on credit risk when lending at the yen Libor rate? Libor rates are unsecured: if the arbitrageur faces a risk of default on her loan, she should be compensated by a default risk premium, which may then account for the CIP deviations. Third, is the arbitrageur taking on counterparty risk when entering an exchange rate forward contract? This last concern seem second-order, as the impact of counterparty risk on the pricing of forwards and swaps is negligible due to the high degree of collateralization. As specified in the Credit Support Annex of the International Swap and Derivative Association, the common market practice is to post variation margins in cash with the amount equal to the mark-to-market value of the swap. Initial margins are also posted to cover the gap risk not covered by the variation margins. In the event of a counterparty default, the collateral is seized by the other counterparty to cover the default cost.[9]

[9]Direct empirical estimates for the magnitude of counterparty risk is available for the credit default swap (CDS) market, where counterparty risk is a more serious concern due to the possibility of losing the full notional of the trade. Consistent with high degree of collateralization, Arora, Gandhi, and Longstaff (2011) find that a 645 basis point increase in the seller's CDS spreads translates only to a one basis point reduction in the quoted CDS premium using actionable quote data. Using real CDS transaction data, Du, Gadgil, Gordy, and Vega (2016) obtain estimates of similar magnitude.

The indicative nature of Libor and the potential default risk are valid concerns. Default risk appears indeed as the recent leading explanation of the CIP deviations in the literature (e.g., Tuckman and Porfirio, 2004). Formally, the default risk explanation of CIP deviations relies on cross-country differences in credit worthiness of different Libor panel banks. Let us assume that the mean credit spread for the yen Libor panel is given by sp_t^{JPY} and the mean credit spread for the U.S. dollar Libor panel is given by sp_t^{USD}. Let y_t^{*JPY} and y_t^{*USD} be the true risk-free rates in yen and U.S. dollars and assume that CIP holds for risk-free rates. Starting from the definition of the basis in Equation (4) and replacing each interest by the sum of the risk-free rate and the credit spread leads to:

$$\begin{aligned} x_t^{JPY/USD,Libor} &= (y_t^{*USD} + sp_t^{USD}) - (y_t^{*JPY} + sp_t^{JPY} - \rho_t^{JPY/USD}), \\ &= [y_t^{*USD} - (y_t^{*JPY} - \rho_t^{JPY/USD})] + (sp_t^{USD} - sp_t^{JPY}). \end{aligned} \tag{7}$$

In the absence of CIP deviations for risk-free rates, the term inside brackets is zero. In this case, the Libor-based currency basis of the yen/dollar is given by the difference between credit risk in dollar and yen Libor panels:

$$x_t^{JPY/USD,Libor} = sp_t^{USD} - sp_t^{JPY}. \tag{8}$$

Therefore, the yen basis can be negative if the yen Libor panel is riskier than the U.S. Libor panel. We test this hypothesis by regressing changes in the Libor basis $\Delta x_t^{i,Libor}$ for currency i on changes in the mean credit default swap spreads (CDS) between banks on the interbank panel of currency i and the dollar panel:

$$\Delta x_t^{i,Libor} = \alpha^i + \beta \Delta (cds_t^i - cds_t^{USD}) + \epsilon_t^i. \tag{9}$$

We use weekly changes in five-year Libor cross-currency basis swaps and five-year CDS of banks since 2007. The list of banks on the interbank panels included in our study and detailed regression results are reported in the Online Appendix. If CDS measure credit spreads perfectly, Equation (8) suggests a slope coefficient of -1 and an R^2 of 1. All the slope coefficients are statistically different from -1, most of them positive, and all R^2 are tiny. In a nutshell, we do not find much evidence in favor of credit risk. To rule it out, we turn to repo contracts.

B. *Repo Basis*

At short maturities, one way to eliminate the credit risk associated with Libor-based CIP is to use secured borrowing and lending rates from the repo markets. We thus use general collateral (GC) repo rates in U.S. dollars and foreign currencies to construct an alternative currency basis measure.

A GC repo is a repurchase agreement in which the cash lender is willing to accept a variety of Treasury and agency securities as collateral. Since GC assets are of high quality and very liquid, GC repo rates are driven by the supply and demand of cash, as opposed to the supply and demand of individual collateral assets. Given the U.S. dollar GC repo rate $y^{\$,Repo}_{t,t+n}$ and the foreign currency GC repo rate $y^{Repo}_{t,t+n}$, the general definition of the basis in Equation (4) leads to the following repo basis:

$$x^{Repo}_{t,t+n} = y^{\$,Repo}_{t,t+n} - (y^{Repo}_{t,t+n} - \rho_{t,t+n}). \tag{10}$$

Since the bulk of repo transactions are concentrated at very short maturities, we focus on the repo basis at the one-week horizon.

Our data cover the Swiss, Danish, Euro, Japanese, and U.S. repo markets. The first two columns of Table II report the annualized mean and standard deviation of Libor- and repo-based bases during the January 2009 to September 2016 period. The two bases are indistinguishable from each other for most of the sample period. The Danish krone exhibits the most negative mean repo basis, equal to -41 basis points if Libor-based and -35 basis points if repo-based. The euro exhibits the least negative mean repo basis equal to -20 basis points with Libor rates and -15 with repo rates. For the Swiss franc and the yen, the CIP deviation is larger in magnitude for repo than for Libor rates. Clearly, CIP deviations exist even for interest rates that are free of credit risk.

Table II
One-week Libor- and Repo-based Basis and Repo CIP Arbitrage

Columns 1 and 2 report the annualized mean and standard deviation for the one-week Libor and GC repo basis for the Swiss franc (CHF), the euro (EUR), the Danish Krone (DKK) and the Japanese yen (JPY) during the 01/01/2009 to 09/15/2016 period. Column 3 reports the mean and standard deviation for the one-week arbitrage profits of funding at the U.S. dollar GC repo rate and investing at the foreign currency GC repo rate provided that the arbitrage profits are positive. The last column reports the mean and standard deviation for the one-week arbitrage profits of funding at the U.S. Libor and investing at the foreign currency GC repo rate provided that the arbitrage profits are positive. In the last two columns, we also report the percentage of the sample with positive arbitrage profits in the third row for each currency. All arbitrage profits take into account the transaction costs on the forward and spot exchange rates, and the U.S. and Danish krone repo rates, but not for the Swiss franc, euro, and yen repo rates.

		(1) Libor Basis	(2) Repo Basis	(3) Repo-Repo Arb. Profits	(4) Repo-Libor Arb. Profits
CHF	Mean	-20.8	-24.4	15.6	16.9
	S.D.	(28.1)	(31.2)	(26.6)	(28.2)
	% sample with profits > 0			83%	83%
DKK	Mean	-41.0	-34.9	18.5	20.4
	S.D.	(21.6)	(26.9)	(22.2)	(23.2)
	% sample with profits > 0			70%	62%
EUR	Mean	-19.7	-15.4	11.2	12.1
	S.D.	(16.3)	(14.3)	(13.1)	(13.9)
	% sample with profits > 0			80%	84%
JPY	Mean	-21.6	-25.9	17.1	17.7
	S.D.	(27.7)	(27.6)	(21.8)	(22.9)
	% sample with profits > 0			93%	96%

A negative basis entices the arbitrageur to borrow at the U.S. dollar GC repo rate and invest in the foreign currency GC repo rate, while paying the forward premium to hedge the foreign currency exposure. A positive basis suggests the opposite strategy, borrowing at the foreign currency rate, receiving the forward premium, and investing in the U.S. dollar rate. The arbitrage profits under the negative and positive arbitrage strategies, denoted by $\pi^{Repo-}$and π^{Repo+}, are thus:

$$\pi_{t,t+n}^{Repo-} \equiv [y_{t,t+n,Bid}^{Repo} - \rho_{t,t+n,Ask}] - y_{t,t+n,Ask}^{\$,Repo}, \tag{11}$$

$$\pi_{t,t+n}^{Repo+} \equiv y_{t,t+n,Bid}^{\$,Repo} - [y_{t,Ask}^{Repo} - \rho_{t,t+n,Bid}]. \tag{12}$$

We assume that the transaction cost for each step of the arbitrage strategy is equal to one half of the posted bid-ask spread. We take into account bid-ask spreads on all forward and spot contracts and a conservative bid-ask spread for the U.S. dollar repo. The average bid-ask spread for U.S. repo used in our calculation is about 9 basis points, which is significantly higher than the 4 basis points bid-ask spread quoted on Tullett Prebon. Transaction costs for Danish repos are also taken into account with significantly wider average bid-ask spreads equal to 19 basis points. The Bloomberg series used in our repo basis calculations do not contain bid-ask spreads for the euro, Swiss franc and yen. In the case of euro repos, data from Thomson Reuters Eikon suggest that the average bid-ask spread is about 6 basis points. We do not have bid-ask spreads information available for the Swiss franc and the yen.

The third column of Table II reports the net profits obtained from the negative basis arbitrage strategy, which is implemented provided that the ex-ante profits are positive. The average annualized profits range from 11 to 19 basis points after taking into transaction costs. The profits vary over time, with standard deviations ranging from 13 basis points to 27 basis points. The arbitrage profits are positive for the majority of the sample window. The conditional volatility of each arbitrage strategy is again naturally zero, and the conditional Sharpe ratio is infinite.

One potential consideration with the arbitrage above is that borrowing in the U.S. GC repo market would require posting a U.S. Treasury bond as collateral and investing in the foreign GC repo market would entail receiving a foreign Treasury bond as collateral. Therefore, the scarcity of the U.S. Treasury as collateral or the difference in collateral value between U.S. and foreign Treasury bonds could in theory be a source of CIP deviations for repo rates. To address this concern, in the last column of Table II, we show the arbitrage profits for borrowing in the U.S. Libor market and investing in the respective foreign GC repo market. Since this arbitrage uses unsecured dollar funding, the arbitrageur does not need to post the U.S. Treasury as collateral, but receives the foreign Treasury bonds as collateral, nevertheless. The arbitrage profits in Column 4 are very similar to the profits in Column 3 based on U.S. repo funding. This suggests that the collateral valuation cannot be a main driver for CIP deviations.

C. KfW Basis

We turn now to CIP deviations at the long end of the yield curves. GC repo contracts do not exist for long maturities, but we can construct an alternative long-term cross–currency basis free from credit risk by comparing direct dollar yields on dollar denominated debt and synthetic dollar yields on debt denominated in other currencies for the same risk-free issuer and the same maturity in years. To do so, we focus on bonds issued by the KfW, an AAA-rated German government-owned development bank, with all its liabilities fully backed by the German government. The KfW is a very large multi-currency issuer, with an annual issuance of around \$70 billion and \$370 billion of bonds outstanding. Schwartz (2015) provides more details on the KfW bonds, comparing them to German government bonds to study their liquidity premium. Instead, we compare KfW bonds of similar maturity issued in different currencies.

For the simplicity of exposition, we consider a world with zero-coupon yield curves and swap rates. Detailed calculations involving coupon bearing bonds and additional data are reported in the Online Appendix.

The first column of Table III reports summary statistics on the KfW basis during the January 2009 to August 2016 period. The mean post-crisis KfW basis is zero for the Australian dollar but is significantly negative for the other three currencies: -24 basis points for the Swiss franc, -14 basis points for the euro, and -30 basis points for the yen. The second column of Table III reports similar summary statistics for the basis conditional on a positive basis for the Australian dollar and a negative basis for the other three currencies: while the Australian dollar basis is only positive 56% of the time, the other bases are negative at least 94% of the sample. As a result, the average conditional basis is 7 basis points for the Australian dollar, and close to their unconditional values for the other currencies: -24 basis points for the Swiss franc, -15 basis points for the euro, and -31 basis points for the yen. These bases point to potential arbitrage strategies.

When the KfW basis is negative, a potential arbitrage strategy would be to invest in the KfW bond denominated in foreign currency, pay the cross-currency swap to swap foreign currency

Table III
KfW Basis and KfW CIP Arbitrage

Following the general definition of the basis in Equation (2), the KfW cross-currency basis is the difference between the direct borrowing cost of KfW in U.S. dollars and the synthetic borrowing cost of KfW in a foreign currency j:

$$x_{t,t+n}^{KfW} = y_{t,t+n}^{\$,KfW} - \left(y_{t,t+n}^{j,KfW} - \rho_{t,t+n}^{j} \right),$$

where $y_{t,t+n}^{\$,KfW}$ and $y_{t,t+n}^{j,KfW}$ denote the zero-coupon yields on KfW bonds denominated in U.S. dollars and foreign currency j. The first column reports the annualized mean and annualized standard deviation for the KfW basis by currency during the 1/1/2009 to 08/31/2016 period. The second column reports similar statistics, conditional on observing a positive KfW basis for the Australian Dollar (AUD) and a negative KfW basis for the Swiss franc (CHF), the euro (EUR), and the Japanese yen (JPY). The third column reports summary statistics for the arbitrage profits. The arbitrages (a positive basis arbitrage strategy for the Australian Dollar and a negative basis arbitrage strategy for Swiss franc, the euro, and the Japanese yen) are implemented provided that the profits remain positive after taking into account the bid-ask spreads of bonds and swaps. The last two columns report similar profits taking also into account the cost of shorting KfW bonds. The fourth (fifth) column assumes that the costs are equal to the 25th (50th) percentile of the shorting costs for KfW bonds of the corresponding currency on the same trading date.

		(1) Basis full sample	(2) Basis conditional	(3) Pos. Profits ex. shorting fee	(4) Pos. Profits 25 pct fee	(5) Pos. Profits median fee
AUD	Mean	0.0	7.0	4.3	4.5	3.5
	S.D.	(11.6)	(6.1)	(4.2)	(2.8)	(2.8)
	% sample		56%	10%	9%	3%
CHF	Mean	-23.5	-24.3	15.0	11.8	10.1
	S.D.	(15.7)	(15.0)	(10.7)	(9.0)	(9.4)
	% sample		97%	72%	50%	33%
EUR	Mean	-13.6	-14.7	9.3	6.7	6.1
	S.D.	(9.7)	(8.8)	(6.7)	(5.4)	(5.0)
	% sample		94%	68%	34%	23%
JPY	Mean	-30.2	-30.8	21.6	17.7	16.3
	S.D.	(15.2)	(14.6)	(13.5)	(12.0)	(11.7)
	% sample		98%	90%	75%	63%

cash flows into U.S. dollars, and short-sell the KfW bond denominated in U.S. dollars, paying the shorting fee. When the KfW basis is positive, the arbitrage strategy would be the opposite.[10]

The last three columns of Table III describe the profits net of transaction costs for the positive Australian dollar arbitrage and the negative Swiss franc, euro, and Japanese yen arbitrages. The

[10]Since shorting contracts expire before KfW bonds mature, the strategy embeds a small rollover fee risk.

third column takes into account bid-ask spreads on swaps and bonds, but not the bond short selling costs. The negative basis arbitrage strategy yields positive profits for Swiss franc, euro, and Japanese yen for the majority of the sample, with averages ranging from 9 to 22 basis points. The positive arbitrage strategy of the Australian dollar yields positive profits only 10% of the sample. The fourth and fifth columns report similar profits taking also into account the cost of shorting KfW bonds. The fourth (fifth) column assumes that the costs are equal to the 25th (50th) percentile of the shorting costs for KfW bonds of the corresponding currency on the same trading date. The negative basis arbitrage strategy yields positive profits between 30% and 50% of the sample for the Swiss franc and the euro, and around 75% of the sample for the Japanese yen. The positive basis arbitrage only yields profits in less than 5% of the sample for the Australian dollar. While the Australian dollar does not exhibit significant arbitrage opportunities net of transaction costs, the Swiss franc, euro, and Japanese yen clearly do. Assuming that arbitrageurs incur the median shorting fees prevalent on the day of their transaction, average profits range from 6 to 16 basis points, with standard deviations ranging from 5 to 12 basis points. Again, the conditional volatility of such strategies is zero and the conditional Sharpe ratio is infinite for the fixed investment horizon of the bonds.

Can cross-country differences in the liquidity of KfW bonds explain the CIP deviations? The answer depends on the currency pairs. For the euro and the Australian dollar, differences in liquidity vis-a-vis the U.S. dollar cannot explain CIP deviations; for the yen and the Swiss franc, they may.[11]

Finally, neither credit risk nor the covariance between credit risk and currency risk seem to explain CIP deviations for KfW yields. Even if there is small amount of credit risk embedded in KfW bonds, it should be similar across currencies, and thus should not have a first-order

[11] On the one hand, the liquidity of euro-denominated KfW bonds is at least comparable to, if not better than, the liquidity of dollar-denominated bonds. Therefore, liquidity differences cannot explain the positive arbitrage profits of going long in the euro bonds and shorting the U.S. dollar bonds. Likewise, the Australian dollar market, with the amount outstanding around $21 billion, is significantly less liquid than the U.S. dollar market. Thus, the lower liquidity in the KfW Australian market works against finding positive CIP arbitrage opportunities of going long in U.S. dollar-denominated KfW bonds and shorting Australian-dollar denominated KfW bonds. On the other hand, the Swiss franc and the Japanese yen markets are comparatively small with total amounts outstanding of less than $5 billion. As a result, liquidity differential can be a potential factor in explaining the positive profits of going long in the more illiquid yen and Swiss franc KfW bonds and shorting the more liquid dollar KfW bonds.

impact on CIP deviations for KfW yields.[12] In theory, combining credit risk and exchange rate risk may explain the CIP deviations if the credit risk and the exchange rate risk are correlated. This is the case for the euro basis, as the investors are likely to expect the euro to depreciate against the dollar upon the KfW default. However, as explained in Du and Schreger (2016), such a covariance adjustment should be very small in magnitude because the credit spread of the KfW is small and directionally at odds with a negative cross-currency basis for the euro.

Overall, deviations from CIP are present in many currency and fixed income markets, often leading to significant arbitrage opportunities. In the next section, we review the potential causes of such arbitrage opportunities.

III. Potential Explanations

Deviations from CIP are at odds with frictionless financial markets. In this section, we hypothesize that the persistent and systematic CIP deviations can be explained by a combination of two factors: (1) balance sheet constraints facing financial intermediaries, which limit the size of exposure that can be taken to narrow the CIP deviations, and (2) international imbalances in investment demand and funding supply across currencies, which affect the demand for exchange rate forwards and swaps and open up CIP deviations.

A. Balance Sheet Constraints of Financial Intermediaries

Before the global financial crisis, global banks actively arbitraged funding costs in the interbank markets across currencies and enforced the CIP condition. Since the crisis, a wide range of regulatory reforms has significantly increased the banks' balance sheet costs associated with arbitrage and market making activities. Bank regulations likely affect other non-regulated entities, such as hedge funds, increasing the cost of leverage for the overall financial market. We consider more specifically how the following banking regulations affect the CIP arbitrages: (i)

[12]Since we are using debt of the same seniority, the pari passu clause should guarantee the same recovery rate.

non-risk weighted capital requirements, or the leverage ratio, (ii) risk-weighted capital requirements, and (iii) other banking regulations, such as the restrictions on proprietary trading and the liquidity coverage ratio. Finally, we also discuss limits to arbitrage facing other players, such as hedge funds, money market funds, foreign currency reserve managers and corporate issuers.

A.1. Non-risk-weighted Capital Requirements

First, non risk-weighted capital requirements are particularly relevant for short-term CIP arbitrage. The leverage ratio requires banks to maintain a minimum amount of capital against all on-balance-sheet assets and off-balance-sheet exposure, regardless of their risk. Short-term CIP arbitrage trades have very little market risk, but still expand bank balance sheets when levered since it involves borrowing and lending in the cash markets and therefore makes the leverage ratio requirement more binding.[13]

For foreign banks, the leverage ratio did not exist before the crisis; it is now equal to 3% under Basel III.[14] For U.S. banks, even though the leverage ratio existed before the crisis, the ratio became more stringent after the crisis with the introduction of the supplementary leverage ratio, equals to 5 to 6% for systematically important financial institutions. The leverage ratio requirement is likely to be acting as the constraint on the bank balance sheet (Duffie, 2016). If the leverage ratio is equal to 3% and binds, a simple back of the envelope approximation illustrates its impact: if we assume that banks need to maintain 3% of their capital against the CIP arbitrage trades and that their overall objective in terms of rates of return on capital is around 10%, then banks need at least a 3% $\times$ 10% = 30 basis point cross-currency basis to engage

[13] Banks may arbitrage the CIP deviations as real money investors, selling dollar Treasury bills and purchasing an equivalent value of yen Treasury bills. Such trades change the composition of the assets without affecting the total size of the balance sheet, and thus have no effects on the leverage ratio.

[14] As noted by the Basel Committee on Banking Supervision (2014), "Implementation of the leverage ratio requirements has begun with bank-level reporting to national supervisors of the leverage ratio and its components from 1 January 2013, and will proceed with public disclosure starting 1 January 2015. The Committee will continue monitoring the impact of these disclosure requirements. The final calibration, and any further adjustments to the definition, will be completed by 2017, with a view to migrating to a Pillar 1 (minimum capital requirement) treatment on 1 January 2018." Even though there is no formal penalty during the observation period before the rule finally kicks in on January 1, 2018, the leverage ratio has been a concern for European banks due to the close monitoring by the regulatory authority and public disclosure requirements.

in the trade.[15] In a nutshell, many of the arbitrage opportunities that are balance sheet intensive may not be attractive enough for banks: as balance sheet expansion becomes expensive due to the leverage ratio requirement, banks may limit or even shy away from CIP arbitrage.

The Basel Committee recommends the leverage ratio to be disclosed at minimum at the quarter end. The actual calculation method of the leverage ratio differs across jurisdictions. For European banks, effective in January 2015, the European Leverage Ratio Delegated Act switches the definition of this ratio from the average of the month-ends over a quarter to the point-in-time quarter-end ratio. For U.S. banks, the supplementary leverage ratio is calculated based on the daily average balances of the quarter. Furthermore, mandatory public disclosure of the Leverage Ratio for European banks began in January 2015. Since European banks play an important role intermediating U.S. dollars offshore, we expect the quarter-end dynamics to be particularly pronounced since January 2015.

A.2. Risk-weighted Capital Requirements

Second, from the perspective of risk-weighted capital, global banks face significantly higher capital requirements since the global financial crisis. For example, for the eight U.S. globally systematically important banks (G-SIBs), the Tier 1 capital ratio increased from 4% pre-crisis to the 9.5%–13% range under Basel III, and the total capital ratio increased from 8% to the 11.5%–15% range. In addition to higher capital ratios against the risk-weighted assets (RWA), the estimation of the RWA itself also increased significantly due to more stringent capital rules and the higher volatility of the cross-currency basis.

The central component of the RWA calculation for a CIP trade is the 99% Value-at-Risk (VaR) measure based on the 10-business-day holding period returns, typically calculated over a sample window that corresponds to the past calendar year. Since one-week arbitrage opportunities exhibit zero VaR, constraints about RWA only matter for long-term CIP arbitrages. Basel II.5 (effective January 2013 in the United States) introduced an additional "stress-VaR" (SVaR) cal-

[15] Even if the leverage ratio requirement does not bind, banks might prefer to maintain some buffer over the minimum leverage ratio requirement, so the leverage ratio would still matter. For an alternative approach that takes into the debt overhang effect, see Duffie (2017).

ibrated for the stress period. As Figure 4 shows, the cross-currency basis became significantly more volatile after the crisis, thus increasing the VaR on the CIP trade. In the Online Appendix, focusing on a specific five-year Libor CIP arbitrage trade, we show that its capital charge theoretically increases 10 times after the crisis. Capital charges are in practice more difficult to estimate as they depend on the whole portfolio, not just a single trade. But this simple example shows that risk-weighted requirements very likely increased the costs of long-term CIP arbitrage strategies.

A.3. Other Banking Regulations

Third, a host of other financial regulations have also reduced banks' willingness to engage in CIP arbitrage. For example, the Volcker Rule (a part of the Dodd-Frank Act) forbids banks to actively engage in proprietary trading activities. Proprietary trading in spot exchange rates is allowed, but not in exchange rate forwards and swaps. As a result, banks can only engage in market making or facilitate arbitrage activities of their clients in the exchange rate derivative markets. In practice, however, the distinction between arbitrage and market making may be difficult to draw. In addition, the over-the-counter derivatives market reform sets higher capital and minimum margin requirements for cross-currency swaps, which are generally uncleared by central counterparties, further increasing the capital necessary to implement the CIP trade.

In addition to the new risk-weighted capital rules and the leverage ratio, the Basel III agreement also introduces the liquidity coverage ratio, which requires banks to hold High Quality Liquidity Assets (HQLA) against potential net cash outflows during a 30-day stress period, where the expected inflows are at most equal to 75% of the expected outflows. The impact of the CIP trade is complex. When the 75% cap is binding, the CIP trade can deteriorate the liquidity coverage ratio. Investing in HQLAs, e.g. central bank reserves, could, however, improve the liquidity coverage ratio.

A.4. Limits to arbitrage facing other potential arbitrageurs

We turn now to the other potential arbitrageurs, i.e., hedge funds, money market funds, reserve managers, and corporate issuers. For each category, we review briefly their ability to profit from, and thus attenuate, the CIP deviations, along with their potential constraints. The persistence of CIP deviations suggests that these potential arbitrageurs take only limited positions.

The regulatory reforms on banks certainly have some spillover effects on the cost of leverage faced by non-regulated entities, such as hedge funds. This is because hedge funds need to obtain funding from their prime brokers, which are regulated entities. In order to sell the CIP arbitrage strategy to their clients, hedge funds would need to lever up the arbitrage strategy ten or twenty times to make it attractive. When borrowing large amounts, their borrowing costs may increase significantly as their positions show up in their prime brokers' balance sheets (making prime brokers' capital requirements more binding).

U.S. prime money market funds (MMFs) hold large amounts of commercial paper (CP) and certificates of deposits (CD) issued by foreign banks and act as an important alternative source of dollar funding to foreign banks. The recent MMF reform has significant impact on the intermediation capacity of the prime MMFs. The reform requires a floating Net Asset Value for prime MMFs and allows gates and fees to limit redemptions for prime funds, which led to large outflows of funds from prime MMFs to government MMFs. Government MMFs do not hold bank CDs or CPs. In the run-up to the MMF reform implementation (October 14, 2016), as dollar funding from U.S. prime MMFs became scarcer and more expensive, the cross-currency basis also widened notably.

In addition to MMFs, FX reserve managers with large dollar-denominated holdings may arbitrage CIP deviations. For example, the People's Bank of China reportedly increased their holdings of Japanese Treasury bills, which, on the swapped basis, quadrupled yields on U.S. Treasury bills (Bloomberg, August 21, 2016). In addition, as of June 30, 2016, more than half of the foreign currency assets at the Reserve Bank of Australia are denominated in the Japanese yen, with more than 90% of the yen-denominated assets swapped into other currencies (Reserve Bank of Australia, 2016).

Last but not the least, corporate issuers and bank treasuries can also arbitrage long-term CIP deviations by issuing long-term debt in different currencies and then swapping into their desired currency. In the Online Appendix, we report additional evidence on the CIP condition for bond yields of the same risky issuer denominated in different currencies. Using a panel including global banks, multinational non-financial firms and supranational institutions, we show that the issuer-specific basis was close to zero pre-crisis but has been persistently different from zero post-crisis. Large differences in CIP bases appear post-crisis across issuers due to the differences in funding costs over respective Libor benchmarks. Relative to the synthetic dollar rate obtained by swapping foreign currency interest rates, foreign banks generally borrow in U.S. dollars directly at higher costs, whereas U.S. banks and supranational institutions generally borrow in U.S. dollars directly at lower costs. As a result, the U.S. banks and supranational institutions are in the best position to arbitrage the negative cross-currency basis, especially during periods of financial distress.

A.5. Testable hypothesis

In summary, the rules and the behavior of banks have changed since the crisis, offering a potential explanation of the CIP deviations and suggesting some simple predictions:

Prediction #1: (i) CIP deviations are wider when the banks' balance sheet costs are higher, particularly towards quarter-end financial reporting dates; (ii) CIP deviations should be of similar magnitude as the balance sheet costs associated with wholesale dollar funding; and (iii) CIP deviations should be correlated with other near-risk-free fixed-income spreads.

Constraints on financial intermediaries are a likely driver of the overall increase in CIP deviations post-crisis. In the absence of currency-specific trading costs though, frictions to financial intermediation would likely affect all currencies similarly. Yet, large cross-currency differences exist in the data, pointing to hedging demand arising from international imbalances in funding and investment opportunities across currencies.

B. *International Imbalances*

The second element of our two-factor hypothesis works as follows. Search-for-yield motives create a large customer demand for investments in high-interest-rate currencies, such as the Australian and New Zealand dollars, and a large supply of savings in low-interest-rate currencies, such as the Japanese yen and the Swiss franc. Japanese life insurance companies, for example, may look for high yields in the U.S. Treasury markets (instead of investing in the low yield, yen-based Treasuries). Part of such investments is certainly currency-hedged: e.g., Japanese life insurers sell dollars and buy yen forward to hedge their U.S. Treasury bond portfolios. Financial intermediaries, such as foreign exchange swap market makers, supply currency hedging, but do not want to bear the currency risk. To that effect, the financial intermediaries hedge the currency exposure of their forward and swap positions in the cash market by going long in low interest rate currencies and short in high interest rate currencies. The profit per unit of notional is equal to the absolute value of the cross-currency basis, compensating the intermediary for the cost of capital associated with the trade. This hypothesis leads to the following prediction:

Prediction #2: The cross-currency basis is increasing in the nominal interest rate differential between the foreign currency and the dollar.

The intuition behind the prediction is that the lower the foreign currency interest rate compared to the U.S. interest rate, the higher the demand for U.S. dollar-denominated investment opportunity, which generates a greater currency hedging demand to sell U.S. dollars and buy foreign currencies in the forward or the swap market. Since providing these currency hedging contracts is costly for financial intermediaries, the cross-currency basis has to become more negative to justify the higher balance sheet costs associated with larger positions.

With the two-factor hypotheses in mind, we turn now to additional empirical evidence on CIP deviations.

IV. Characteristics of the Basis

In this section, we characterize the systematic nature of the basis and test the two predictions outlined in the previous section, looking at (i) CIP deviations at quarter ends, (ii) a proxy for the cost of wholesale dollar funding, (iii) the correlation of the CIP deviations with other liquidity spreads, (iv) and the correlation with nominal interest rates.

A. Quarter-End Dynamics

We find that, since the 2007–2008 global financial crisis, one-week and one-month CIP deviations tend to increase at the quarter ends for contracts that would cross quarter-end reporting dates. The quarter-end anomalies become more exacerbated since January 2015, which coincides with the change in the leverage ratio calculation method and the beginning of the public disclosure of the leverage ratio for European banks. These findings are consistent with the view that tightened balance sheet constraints at quarter ends, due to banking regulation, translate into wider CIP deviations in the post-crisis period.

A.1. Quarter-end Effects on the Level of CIP Deviations

To build intuition, Figure 5 focuses on the yen starting in 2015. Banks may experience some specific demands on the last day of each quarter, but our identification strategy relies on what happens either one week or one month before the quarter ends. The blue shaded area denotes the dates for which one-week contracts cross quarter-end reporting dates. The grey area denotes the dates for which the one-month contract crosses quarter-end reporting dates, but one-week contracts stay within the quarter. The figure plots the one-week, one-month and three-month CIP deviations in levels. It is clear that once the one-month contract crosses the quarter end, the one-month CIP deviation increases in absolute value. Likewise, once the one-week contract crosses the quarter end, the one-week CIP deviation increases in absolute value. There is no similar pattern for the three-month CIP deviations. With this pattern in mind, we turn to a formal causality test.

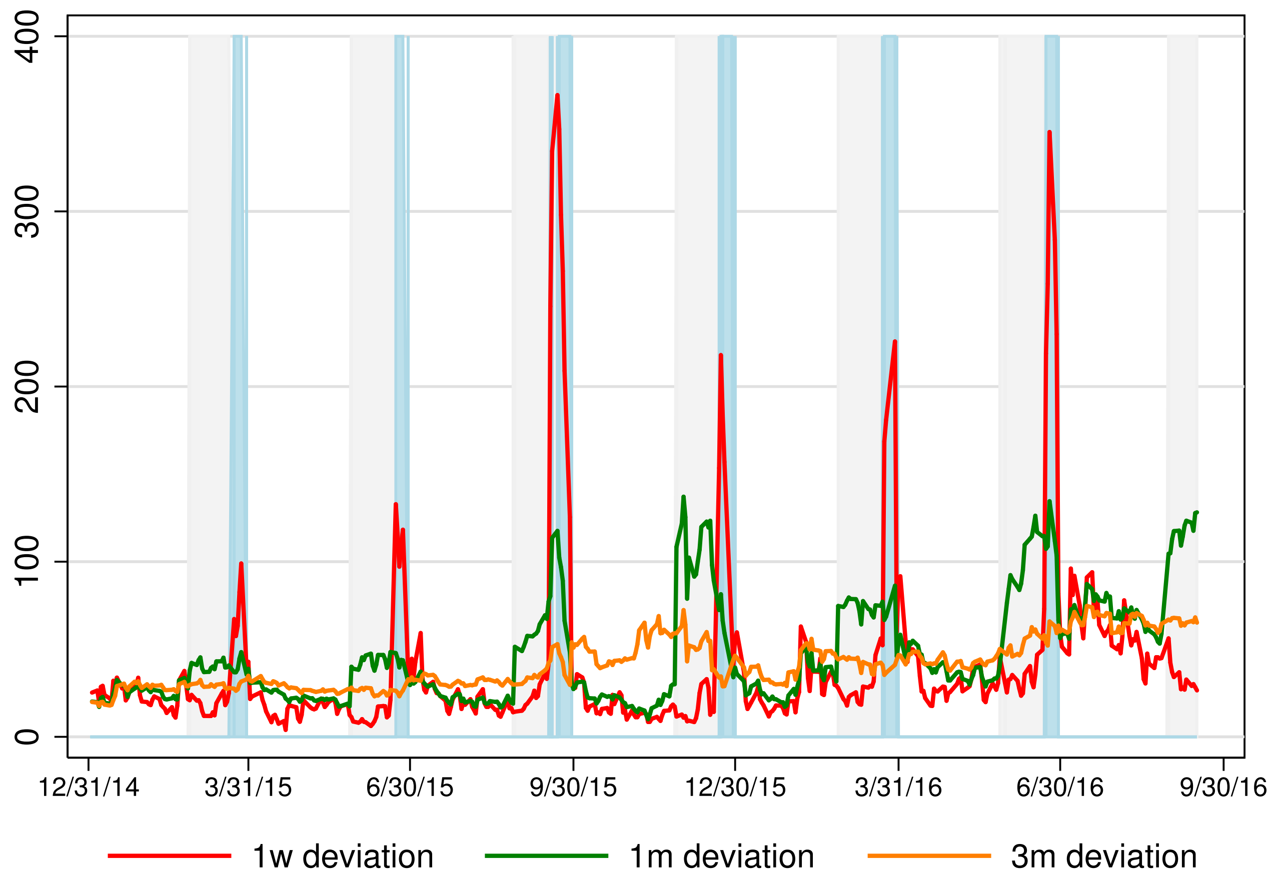

Figure 5. Illustration of Quarter-End Dynamics of CIP Deviations
The blue shaded area denotes the dates for which the settlement and maturity of a one-week contract spans two quarters. The grey shaded area denotes the dates for which the settlement and maturity dates of a one-month contract spans two quarters, and excludes the dates in the blue shaded area. The figure plots the one-week, one-month and three-month Libor CIP deviations for the yen (in absolute values) in red, green and orange, respectively.

We test whether CIP deviations are more pronounced at the end of the quarters vs. any other point in time, and especially so since the global financial crisis and since 2015. Our simple difference-in-difference test for the one-week contract takes the following form:

$$
\begin{aligned}
-x_{1w,it} &= \alpha_i + \beta_1 QendW_t + \beta_2 QendW_t \times Post07_t + \beta_3 QendW_t \times Post15_t \\
&+ \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it},
\end{aligned} \tag{13}
$$

where $x_{1w,it}$ is the one-week basis for currency i at time t, α_i is a currency fixed effect. $POST07_t$ is an indicator variable equal to one after January 1, 2007 and zero otherwise, and $POST15_t$ is an indicator variable equal to one after January 1, 2015 and zero otherwise.[16] The variable $QendW_t$ is an indicator variable that equals one if the settlement date for the contract traded at t is within the last week of the current quarter and the maturity date is within the following quarter.[17] These one-week contracts crossing the quarter ends would show up on the bank balance sheet on quarter-end reporting dates. The regression is estimated on the daily sample from 01/01/2000 to 09/15/2016 on one-week Libor, overnight interest rate swap (OIS) and repo bases.[18] Similarly, we also test the quarter-end effect for the monthly CIP deviation as follows:

$$
\begin{aligned}
-x_{1m,it} &= \alpha_i + \beta_1 QendM_t + \beta_2 QendM_t \times Post07_t + \beta_3 QendM_t \times Post15_t \\
&+ \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it},
\end{aligned} \tag{14}
$$

where $QendM_t$ is a binary variable indicating if the settlement date and maturity date of the monthly contract spans two quarters.

Table IV reports the regression results. Columns 1 to 3 pertain to the one-week CIP deviations based on Libor, OIS, and repos. The slope coefficients β_2 and β_3 are positive and sta-

[16]Since most currencies have a negative basis, we obtain almost identical results using the absolute value of the basis.

[17]FX forwards follow the $T+2$ settlement convention.

[18]Banks can borrow without collateral at the daily Fed Funds rate, swap these daily rates for a weekly rate to avoid any interest rate risk over one week. By doing so, banks effectively borrow at the OIS rate for one week. As long as banks can borrow at the effective daily fed funds rate, no matter how high or low this rate is, the banks are not subject to any interest rate risk. Recent data by the Federal Reserve Bank of New York suggest that banks do indeed borrow at rates very close to the effective daily Fed Funds rate. From March 2016 to May 2017, the 75th percentile of the spread between the actual borrowing rate and the effective borrowing rate is only 0.7bp on average; the 99th percentile is 13bp on average. As a result, only banks in distress would bear some interest rate risk.

tistically significant across all three instruments. The quarter-end CIP deviation relative to the mean deviation in the rest of the quarter is on average 9 to 31 basis points higher in the post-2007 sample than over the pre-2007 sample for the one-week contracts.[19] Furthermore, compared to the post-2007 sample, the quarter-end weekly CIP deviation increases by another 30-40 basis points on average since January 2015. Columns 4 to 6 pertain to the one-month CIP deviations. Again, we find that β_2 and β_3 are all significantly positive except in one case. For CIP deviation based on Libor and OIS rates, the month-end deviation relative to the rest of the quarter is on average 3 to 5 basis point higher post-crisis than the level pre-crisis and increases by another 8 basis point in the post-2015 sample. For one-month repo, even though β_3 is not significant, β_2 is highly significant and equals 14 basis points. Furthermore, we note that coefficients on $QendW_t$ and $QendM_t$ are very small and largely insignificant, suggesting that there is very little quarter end effect before 2007.[20]

A.2. Quarter-end Effects on the Term Structure of CIP Deviations

Since a three-month forward contract always shows up in a quarterly report regardless of when it is executed within the quarter, we should not expect discrete price movement one week or one month prior to the quarter end. Therefore, the quarter-end balance sheet constraint has implications for the term structure of the basis. In particular, we expect the difference between three-month and one-month CIP deviation ($ts_{t,3M-1M} \equiv x_{t,3M} - x_{t,1M}$) to drop significantly once the one-month contract crosses the quarter-end. Meanwhile, the difference between one-month and one-week CIP deviation ($ts_{t,1M-1W} \equiv x_{t,1M} - x_{t,1W}$) should first increase significantly as the one-month contract crosses the quarter end and then decreases significantly once the one-week contract crosses the quarter end.

Table V confirms these observations in panel regressions. Columns 1 to 3 report regression

[19] The large result for the repo basis is largely due to a smaller sample, which only includes the Danish krone, the euro, the Swiss franc, and the yen.

[20] The magnitude of the quarter-end effect varies across currencies. The effect is strongest for the Japanese yen, likely reflecting the importance of the continental European banks subject to the quarter-end regulatory reporting in intermediating dollars to Japan.

Table IV
Quarter-End Effects on the Level of CIP Deviations

This table reports regression results for (the negative of) the daily one-week and one-month Libor, OIS and GC repo bases. $QendM_t$ is an indicator variable that equals 1 if the one-month contract traded at t crosses quarter ends and equals 0 if otherwise. $QendW_t$ is an indicator variable that equals 1 if the one-week contract traded at t crosses quarter ends and equals 0 if otherwise. $Post07$ is an indicator variable that equals 1 if the trading date t is on or after 01/01/2007 and equals 0 if other wise. $Post15$ is an indicator variable that equals 1 if the trading date t is on or after 01/01/2015 and equals 0 if other wise. All regressions include currency fixed effects. Columns 1-2 and 4-5 use all sample currencies. Columns 3 and 6 only include the Danish krone, the euro, the Japanese yen, and the Swiss franc due to the lack of good term repo data for other currencies. Newey-West standard errors are used with 90-day lags and one, two, and three stars denote significance levels at 10, 5, and 1 percent confidence levels. The sample period is 1/1/2000 to 09/15/2016.

	(1) 1w Libor	(2) 1w OIS	(3) 1w Repo	(4) 1m Libor	(5) 1m OIS	(6) 1m Repo
$QendW_t$	1.0	3.7	5.5*			
	(1.0)	(2.9)	(3.2)			
$QendW_t \times Post07_t$	9.7***	9.3***	31.0***			
	(1.3)	(3.2)	(4.5)			
$QendW_t \times Post15_t$	42.9***	36.7***	43.4***			
	(2.2)	(3.4)	(8.0)			
$QendM_t$				-0.1	1.4	1.5
				(0.6)	(1.4)	(2.2)
$QendM_t \times Post07_t$				4.6***	3.0*	13.7***
				(0.8)	(1.7)	(3.1)
$QendM_t \times Post15_t$				7.9***	8.3***	3.5
				(1.3)	(2.4)	(6.2)
$Post07_t$	15.4***	19.3***	27.8***	17.1***	17.6***	29.1***
	(1.0)	(2.8)	(2.6)	(1.1)	(2.1)	(2.9)
$Post15_t$	5.1***	2.7	-9.2**	3.8**	2.7	1.8
	(1.6)	(2.6)	(4.5)	(1.8)	(2.9)	(6.0)
Observations	32,102	22,664	7,868	41,577	31,765	7,333
R-squared	0.256	0.140	0.150	0.276	0.191	0.198

results using $ts_{t,3M-1M}$ based on Libor, OIS and repo as follows, similar to Equation (14):

$$\begin{aligned} -ts_{t,3M-1M} &= \alpha_i + \beta_1 QendM_t + \beta_2 QendM_t \times Post07_t + \beta_3 QendM_t \times Post15_t \\ &+ \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it}. \end{aligned} \tag{15}$$

We find that β_1 is small and insignificant, and β_2 and β_3 are both significantly negative. Compared to the pre-crisis sample, $-ts_{t,3M-1M}$ is 2.3 basis point lower relative to its mean in the rest of the quarter when the one-month contract crosses the quarter ends in the post-crisis sample. In the post-2015 sample, the quarter-end effect corresponds to another 10 basis point reduction in $-ts_{t,3M-1M}$ compared to its post-crisis mean. Columns 4 to 6 report similar tests for $ts_{s,1M-1W}$:

$$\begin{aligned} -ts_{t,1M-1W} &= \alpha_i + \beta_1 \mathbb{I}_{QendM_t=1,QendW_t=0} + \beta_2 \mathbb{I}_{QendM_t=1,QendW_t=0} \times Post07_t \\ &\quad + \beta_3 \mathbb{I}_{QendM_t=1,QendW_t=0} \times Post15_t + \beta_4 QendW_t + \beta_5 QendW_t \times Post07_t \\ &\quad + \beta_6 QendW_t \times Post15_t + \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it}, \end{aligned}$$

where $\mathbb{I}_{QendM_t=1,QendW_t=0}$ is an indicator variable that equals 1 if a one-month contract traded at t crosses the quarter end, but the one-week contract traded at t does not cross the quarter end. As expected, we find significantly positive β_2 and β_3 coefficients and significantly negative β_5 and β_6 coefficients, which suggests that the difference between one-month and one-week CIP deviation first increases as the once-month contract crosses the quarter end, but the one-week contract does not, and then decreases as the one-week contract crosses the quarter end. These quarter-end effects are again larger in the post-crisis period and especially since 2015.

In summary, consistent with the key role of banks' balance sheets on quarter-end reporting dates, we find that CIP deviations are systematically larger for contracts that cross quarter-end reporting dates post the crisis. We do not pin down which part of the regulation matters most, but we show that banking regulation affects asset prices. The quarter-end anomalies in the cross-currency markets, driven by "window dressing" for better regulatory capital ratios, are consistent with the quarter-end sharp decline in the U.S. Triparty repo volume (Munyan, 2015) and the quarter-end increase in the spread between repo rates in the GFC market and the tri-party markets.[21]

[21]More details on the GFC-Triparty repo spread can be found in the Online Appendix.

Table V
Quarter-End Effects on the Term Structure of CIP Deviations

This table reports regression results on (the negative of) the daily one-week and one-month Libor, OIS and GC repo bases. $QendM_t$ is an indicator variable that equals 1 if the one-month contract traded at t crosses quarter ends and equals 0 if otherwise. $QendW_t$ is an indicator variable that equals 1 if the one-week contract traded at t crosses quarter ends and equals 0 if otherwise. $\mathbb{I}_{QendM_t=1,QendW_t=0}$ is an indicator variable that equals 1 if $QendM_t = 1$ and $QendW_t = 0$ and equals 0 if otherwise. $Post07$ is an indicator variable that equals 1 if the trading date t is on or after 01/01/2007 and equals 0 if other wise. $Post15$ is an indicator variable that equals 1 if the trading date t is on or after 01/01/2015 and equals 0 if other wise. All regressions include currency fixed effects. Columns 1-2 and 4-5 use all sample currencies. Columns 3 and 6 only include the Danish krone, the euro, the Japanese yen, and the Swiss franc due to the lack of good term repo data for other currencies. Newey-West standard errors are used with 90-day lags and one, two, and three stars denote significance levels at 10, 5, and 1 percent confidence levels. The sample period is 1/1/2000 to 09/15/2016.

	(1)	(2)	(3)	(4)	(5)	(6)
	ts^{Libor}_{3M-1M}	ts^{OIS}_{3M-1M}	ts^{Repo}_{3M-1M}	ts^{Libor}_{1M-1W}	ts^{OIS}_{1M-1W}	ts^{Repo}_{1M-1W}
$QendM_t$	0.3	-1.1**	-1.4			
	(0.4)	(0.6)	(0.9)			
$QendM_t \times Post07_t$	-2.3***	-2.0***	-6.5***			
	(0.5)	(0.7)	(1.3)			
$QendM_t \times Post15_t$	-10.2***	-8.3***	-23.7***			
	(0.9)	(1.0)	(3.5)			
$\mathbb{I}_{QendM_t=1,QendW_t=0}$				-0.5	1.4	2.2*
				(0.6)	(1.3)	(1.2)
$\mathbb{I}_{QendM_t=1,QendW_t=0} \times Post07_t$				5.7***	3.0**	10.6***
				(0.7)	(1.4)	(1.8)
$\mathbb{I}_{QendM_t=1,QendW_t=0} \times Post15_t$				13.2***	11.2***	23.9***
				(1.2)	(1.4)	(4.2)
$QendW_t$				-0.6	-2.8*	-3.3*
				(0.8)	(1.6)	(1.8)
$QendW_t \times Post07_t$				-2.6**	-5.7***	-14.2***
				(1.0)	(1.8)	(2.7)
$QendW_t \times Post15_t$				-36.4***	-27.3***	-82.0***
				(1.7)	(1.9)	(6.8)
$Post07_t$	0.4	0.5	3.5***	1.9***	1.5	1.1
	(0.6)	(0.5)	(0.8)	(0.7)	(1.1)	(1.0)
$Post15_t$	-0.2	2.4***	2.0	-2.9***	0.6	3.8
	(0.9)	(0.7)	(2.3)	(1.1)	(1.0)	(2.4)
Observations	41,553	31,502	5,671	32,045	22,491	5,799
R-squared	0.096	0.056	0.071	0.098	0.106	0.136

B. CIP Arbitrage Based on Excess Reserves at Central Banks

We now compare a proxy for the banks balance sheet costs to the CIP deviations. Under unconventional monetary policies implemented by major central banks since the global financial crisis, global depositary institutions have held large amounts of excess reserves at major central banks (e.g., $2.4 trillion at the Fed and $0.5 trillion at the ECB in 2016). Excess reserves are remunerated at a rate set by the central bank, referred to as the interest rate on excess reserves (IOER).

The IOER at the Fed is often above interest rates paid on private money market instruments (for example, the Fed Funds rate) because government-sponsored enterprises (GSEs), such as the Federal Home Loan Banks, do not have access to the IOER deposit facility and are net lenders. This creates the well-known IOER-Fed funds arbitrage for depositary institutions with access to the IOER deposit facility: banks borrow in the Fed fund market from the GSEs and deposit the proceeds in the forms of excess reserves at the Fed, earning the IOER-Fed Funds spread. The trade is risk-free, and central bank reserve balances dominates private money market instruments in terms of liquidity and fungibility.

Figure 6 shows the IOER, one-week OIS, Libor and repo rates for the U.S. dollar since 2009. The IOER is always greater than the one-week OIS rate over the entire sample and is also greater than the one-week Libor and repo rates for most of the sample. If borrowing funds did not carry additional costs, banks would demand more reserves at the Fed in order to profit from this arbitrage opportunity, and the interest rate gap between IOER and private money instruments would disappear. The spread earned on the IOER-private money market instrument arbitrage thus gives us a concrete measure of the cost of balance sheet expansion for depository institutions that engage in risk-free arbitrage opportunities.[22]

[22] This cost includes at least two components. For U.S. and foreign banks, the cost of leverage, summarized in leverage ratios, is likely to be the most important factor since the trade is risk-free, but still expands the size of banks' balance sheet. For U.S. banks, an additional cost matters: the deposit insurance fees paid on wholesale funding, which mattered after the Federal Deposit Insurance Corporation (FDIC) widened the assessment base for deposit insurance fees to include wholesale funding in April 2011. In other words, the IOER is the opportunity cost of wholesale dollar funding for depository institutions, and the synthetic dollar interest rates by swapping foreign currency investments have to be higher than the IOER to attract banks to engage in CIP trades, instead of parking the dollars as excess reserves at the Fed. Consistent with our CIP evidence, the gap between the IOER and the Fed

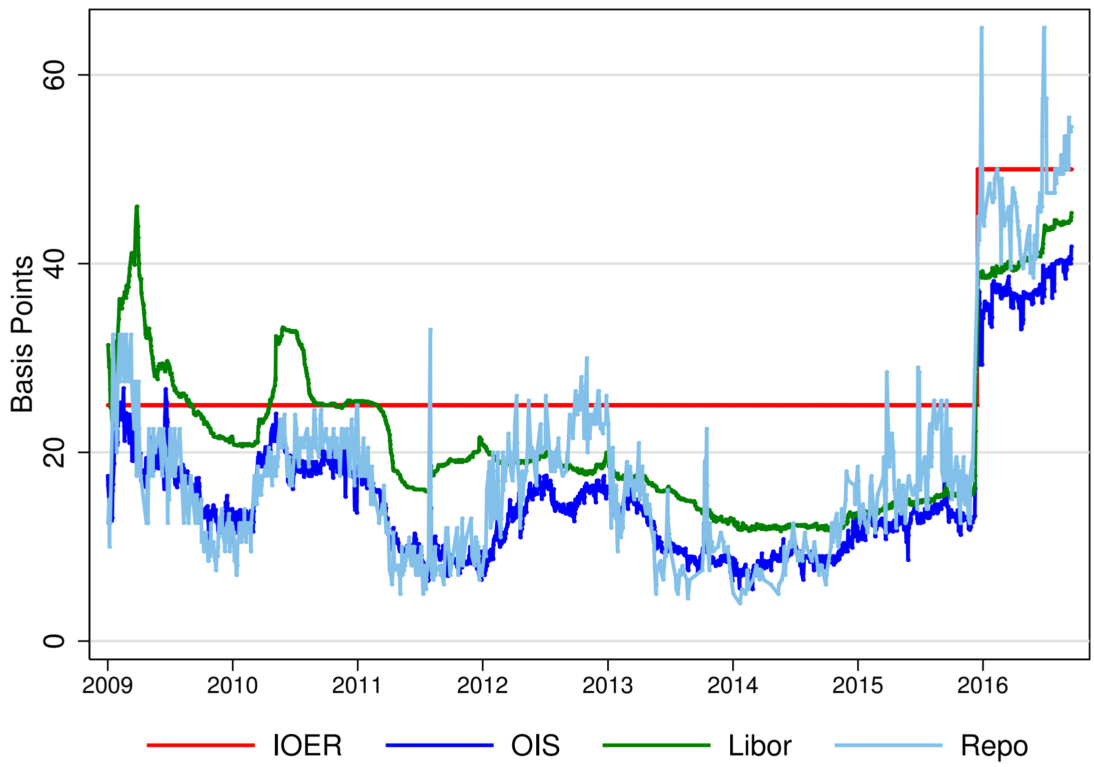

Figure 6. IOER, OIS, Repo, and Libor rates for the U.S. Dollar
This figure plots the one-week interest on excess reserves (IOER), overnight interest swap (OIS), GC Repo and Libor rates for the U.S. dollar from 1/1/2009 to 09/15/2016.

Therefore, instead of using the Libor (OIS or repo) rates as the direct U.S. dollar funding costs when computing the cross-currency basis, we use the IOER as the dollar funding costs. This is equivalent to assuming, for example, that banks borrow at the Libor (OIS or repo) rates and that the difference between the IOER minus the Libor (OIS or repo) rate proxies for the banks' balance sheet costs. Table VI shows the results for this alternative basis calculation. Compared to the standard Libor basis reported in the first column, "funding" at the IOER reduces the magnitude of the Libor basis by 6 basis points on average, as shown in the second column. Similarly, compared to the standard OIS basis reported in the third column, the basis is 12 basis point narrower when using the IOER instead of the OIS as the direct dollar funding cost, as shown in the fourth column. Compared to the standard repo basis, the basis is 8 basis point

Funds rate widens at quarter ends if we use the overnight Fed Fund rate, instead of the one-week OIS rate. This is because the IOER-Fed Fund arbitrage is typically done at the overnight horizon.

narrower when using the IOER as the funding cost, as shown in the sixth column. Therefore, the gap between the IOER and OIS/Libor/repo in the U.S. can explain about one-third of the one-week CIP deviations.

Table VI
One-Week Deviations from CIP and Interest Rates on Excess Reserves

This table shows the means and standard deviations of the one-week cross-currency basis for the Swiss franc (CHF), the Danish Krone (DKK), the euro (EUR), and the Japanese yen (JPY). Column 1, denoted x_t^{Libor}, refers to the Libor cross-currency basis. Column 2, denoted "IOER-Libor," refers to the basis obtained by borrowing at the U.S. dollar interest rate on excess reserves (IOER) and investing at the foreign currency Libor rate and hedging the exchange rate risk. Column 3, denoted x_t^{OIS}, refers to the overnight interest rate swap (OIS) cross-currency basis. Column 4, denoted "IOER-OIS," refers to the basis obtained by borrowing in U.S. dollars at the IOER and investing in foreign currency at the OIS rate. Column 5, denoted x_t^{Repo}, refers to the repo cross-currency basis. Column 6, denoted "IOER-repo," refers to the basis obtained by borrowing in U.S. dollars at the IOER and investing in foreign currency at the repo rate. The seventh column, denoted x_t^{IOER}, refers to the IOER cross-currency basis. The sample starts in 01/01/2009 and ends in 09/15/2016.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Currency	x_t^{Libor}	IOER-Libor	x_t^{OIS}	IOER-OIS	x_t^{Repo}	IOER-Repo	x_t^{IOER}
CHF	-20.8	-14.9	-36.1	-24.1	-24.4	-15.7	-12.6
	(28.1)	(29.1)	(36.3)	(36.8)	(31.2)	(33.2)	(29.8)
DKK	-41.0	-35.1	-28.5	-15.5	-34.9	-25.3	-11.8
	(21.6)	(24.9)	(22.3)	(23.1)	(26.9)	(27.9)	(25.3)
EUR	-19.7	-13.8	-22.8	-11.0	-15.4	-6.9	8.9
	(16.3)	(18.8)	(15.4)	(16.8)	(14.3)	(16.9)	(23.2)
JPY	-21.6	-15.8	-25.8	-13.6	-25.9	-17.5	-14.9
	(27.7)	(28.2)	(29.7)	(29.9)	(27.6)	(29.5)	(28.4)
Total	-25.7	-19.8	-27.8	-15.6	-24.4	-15.7	-7.5
	(25.5)	(27.0)	(27.0)	(27.6)	(26.4)	(28.1)	(28.5)

The CIP arbitrage based on Libor, OIS and repo rates have neutral impact on the liquidity coverage ratio at best, but the IOER-Fed fund arbitrage can potentially improve the liquidity coverage ratio.[23] Also, more generally, central bank balances are considered safer and more liquid than any private market alternatives even before being codified as the Level-1 HQLA by the Basel liquidity coverage ratio requirement. To take into account the better liquidity of

[23]The IOER-Fed Funds arbitrage can improve the liquidity coverage ratio in two potential ways. First, the IOER-Fed Funds arbitrage increases the numerator and the denominator by the same amount, which leads to a mechanical increase in the ratio, especially for large positions. Second, if the bank were to be subject to the composition cap for eligible Level-2 HQLA (40% of total HQLAs), adding reserve balances (Level-1 HQLA) may permit the inclusion of additional eligible Level-2 assets in the LCR numerator.

central bank balances, we assume that banks funds themselves at the U.S. IOER (as above) and invest at the foreign IOER. Summary statistics for the IOER basis are reported in the last column. The average IOER basis is -8 basis points, much closer to zero than the Libor and OIS basis at -26 and -28 basis points, respectively.[24]

Using the IOER–Libor spread as proxy for the banks' balance sheet costs and investing at the foreign central bank deposit facility significantly reduces the size of the CIP deviations, but it does not eliminate them. For the Danish krone, the Swiss franc, and the Japanese yen, the CIP deviations still range from -12 to -15 basis points on average.[25] Such CIP deviations imply risk-free arbitrage opportunity for global depository institutions that can borrow U.S. dollars in wholesale cash funding market, and deposit at the foreign central bank deposit facility while hedging currency risk, even after proxying for their balance sheet costs. Banks are either factoring in higher shadow costs, or they are willing to forego some extra yields to hold Fed balances over swapped balances at the Bank of Japan, the Swiss National Bank or the Danish National Bank, even though these central bank reserve balances are all risk-free HQLAs. One potential explanation is that Fed balances are more desirable to fulfill banks' dollar liquidity needs compared to swapped foreign central bank balances, even though there is no hardwired Liquidity Coverage Ratio imposed at the individual currency level.

In summary, by assuming that banks borrow and invest at the IOER, we proxy for the banks' balance sheet costs associated with the leverage ratio and take into account the liquidity advantage of central bank reserve balances over private money market instruments. These adjustments correspond approximately to two-thirds of the average CIP deviations.

[24]The Online Appendix reports the time-series of the IOER basis, together with the Libor basis and the modified Libor basis obtained by "funding" at the IOER. The bases based on the IOER can be positive, while the Libor basis is always negative. A positive IOER basis would lead U.S. banks to park excess reserves at the Fed, as opposed to lending out in U.S. dollars as suggested by a negative Libor basis. Increasing reserves at the Fed further reduces the bank flows to arbitrage the Libor basis.

[25]In the euro area, since the EONIA is significantly higher than the ECB deposit rate (unlike in the U.S.), the CIP arbitrage involving euro borrowing and Fed deposits is rarely profitable despite the 8 basis point average IOER basis for the euro.

C. Correlated Spreads in Other Markets

Intermediary constraints, if present, would likely affect other asset classes beyond exchange rates. We thus compare the dynamics of the currency bases to other types of near-arbitrage fixed-income strategies, focusing on (1) the KfW-German Bund basis, (2) the one-versus three-month U.S. Libor tenor swap basis, (3) the CDS-CDX basis, and (4) the CDS and corporate bond (CDS-bond) basis, all detailed in the Online Appendix. Figure 7 plots the average of the absolute value of the five-year Libor currency basis for G10 currencies and the four other types of bases in four different panels.

The currency basis appears highly correlated with the two liquidity-based bases, the KfW-German bund basis and the Libor tenor basis. They all increased during the recent global financial crisis and during the European debt crisis. Although there is no mechanical link between the CIP deviations and the KfW-bund and Libor tenor swap bases, their co-movement is striking.

The currency basis appears less correlated with the two credit bases, the CDS-CDX basis and the bond-CDS basis. The credit bases both increased significantly during the recent global financial crisis, together with the cross-currency basis, but they narrowed significantly after the crisis between 2010 and 2014, whereas the currency basis did not. In the past two years again, the credit and currency bases appear to move in sync.

We test the link across asset classes with a simple regression of the G10 average changes in the cross-currency bases on changes in the four other liquidity and credit bases for the 2005–2016 and the 2010–2016 samples. The results are reported in the Online Appendix. In the full sample that includes the global financial crisis, CIP deviations co-move significantly with the four other spreads. In the post-crisis sample, CIP deviations still co-move significantly with the two liquidity spreads. The correlation with the two credit spreads remains positive but is no longer significant. Overall, the correlation between the CIP deviations and other near-arbitrage strategies, especially the KfW-German bund basis and the Libor tenor basis, is consistent with a key role for liquidity-providing intermediaries.

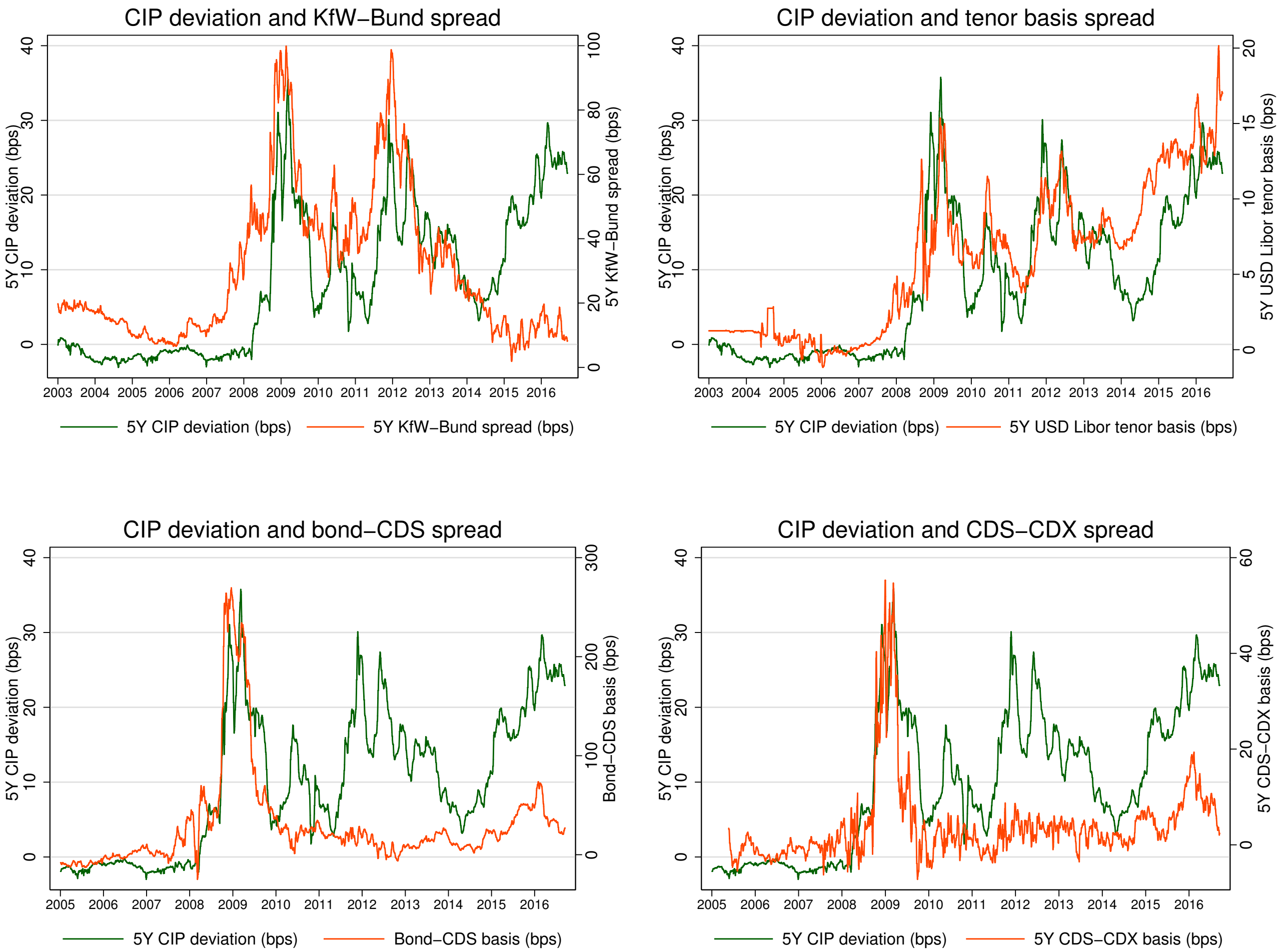

Figure 7. The Cross-Currency Basis and Other Near-Risk-free Arbitrages
Each panel compares the time-series of the average currency basis to the time-series of other fixed-income spreads. The average currency basis corresponds to the average of the five-year Libor cross-currency bases of G10 currencies; its scale in basis points is reported on the left-hand side. The scale of the other fixed-income spreads, also expressed in basis points, is reported on the right-hand side of each panel. The other fixed-income spreads include: (1) the KfW-Bund spread, defined as the spread of a five-year euro-denominated KfW bonds over a five-year German Bund, obtained from Bloomberg, (2) the U.S. dollar Libor tenor basis spread, defined as the five-year spread of exchanging one-month U.S. dollar Libor against three-month U.S. dollar Libor, obtained from Bloomberg, (3) the bond-CDS spread for investment grade firms, obtained from Morgan Markets, and (4) the CDS-CDX spread, defined as difference between the average five-year CDS spreads on the 125 constituents of the NA.IG.CDX index and the spread on the NA.IG.CDX index, obtained from Markit.

D. Cross-Currency Basis and Nominal Interest Rates

Consistent with Prediction #2, we find that CIP deviations are highly correlated with nominal interest rates in the cross section and in the time series.

D.1. Cross Section of CIP Deviations and Interest Rates

We first document a robust cross-sectional relationship between nominal interest rates and various types of cross-currency basis. We find that low interest rate currencies tend to have most negative bases and high interest rate currencies tend to have less negative bases or positive bases.

Figure 8 reports the mean cross-currency basis on the vertical axis as a function of the average nominal interest rates between 2010 and 2015 on the horizontal axis. The Libor cross-currency basis is positively correlated with Libor rates at short and long maturities. The relationship is particularly strong at long maturities, with the correlation between five-year Libor bases and Libor rates equal to 90 percent for G10 currencies.[26]

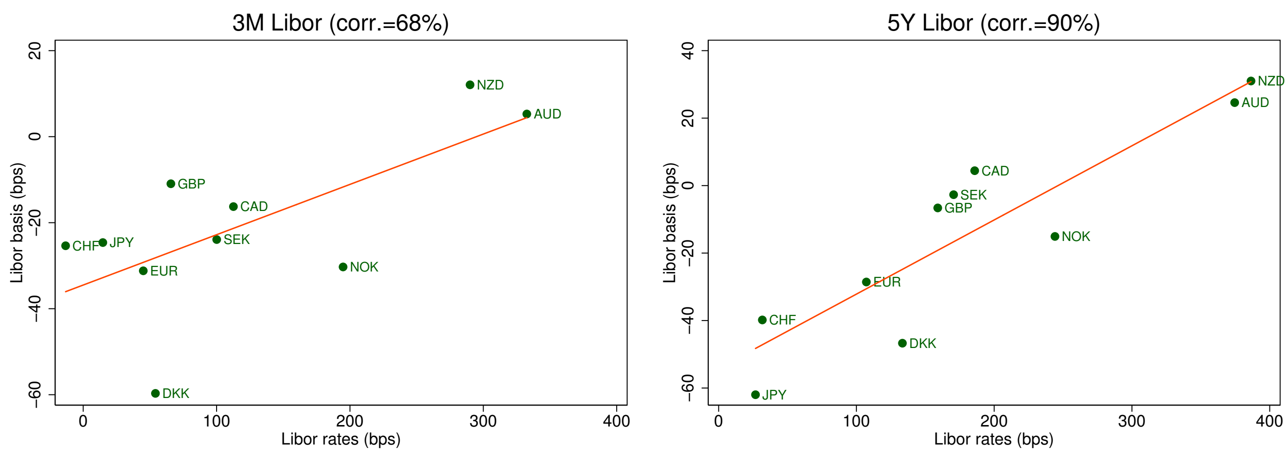

Figure 8. Cross-Sectional Variations in Currency Basis (2010-2016)
This figure shows the cross-currency relationship between various cross-currency bases on the y-axis and nominal interest rates on the x-axis. The left figure plots the relationship for 3-month Libor and the right figure plots the relationship for five-year Libor.

Therefore, for a long-short arbitrageur, there exist arbitrage opportunities for going long in low interest rate currencies, short in high interest rate currencies with the currency risk hedged using exchange rate swaps. The direction of the arbitrage trade is exactly the opposite of the conventional unhedged carry trade of going long in high interest rate currencies and short in

[26]Similarly, as shown in the Online Appendix, we obtain a very high correlation between the average level of interest rates and the CIP deviations measured on bonds issued by KfW and other multinationals. By contrast, the mean CDS spread of the interbank panel exhibits a correlation of -33 percent with the five-year Libor basis.

low interest rate currencies.[27] This finding has clear implications for carry trade investors and multinational issuers.

For carry trade investors, the CIP deviations make the carry trade more profitable on the forward than on the cash markets. The unhedged currency excess return is:

$$\begin{aligned} f_t - s_{t+1} &= f_t - s_t + s_t - s_{t+1} \\ &= y_t - y_t^{\$} - \Delta s_{t+1} + x_t \end{aligned} \tag{16}$$

For any investor who borrows in U.S. dollars (or yen) and invest in Australian (or New Zealand) dollar, the CIP basis is positive ($x_t > 0$). As a result, the carry trade excess return obtained through forward contracts, equal to $f_t - s_{t+1}$, is larger than the excess return obtained on the cash markets, equal to $y_t - y_t^{\$} - \Delta s_{t+1}$.

For multinational issuers with diversified clienteles, the cross-sectional pattern has a simple funding cost implication: if they want to obtain U.S. dollars, they are better off borrowing in high than in low interest rate currencies, and then swap their debt into U.S. dollars. Consistent with this finding, we present some evidence in the Online Appendix that diversified supranational issuers do issue disproportionately more in high interest rate currencies than in low interest rate currencies.

D.2. Time Series of CIP Deviations and Interest Rates

As in the cross-section, the nominal interest rate differential between two currencies is also a significant driver of the cross-currency basis in the time series. Assuming that the monetary policy is exogenous to the basis, an event study of a narrow window around the ECB monetary policy announcements shows the effect of unexpected shocks to the interest rate differential on the cross-currency basis.

Our event study focuses on changes in the dollar/euro basis and changes in the yield differ-

[27] Note that the average CIP deviations and average carry trade excess returns differ by an order of magnitude: less than 50 basis points for the CIP deviations, and more than 500 basis points for average carry trade excess returns.

ential between German Bunds and U.S. Treasuries. The event window starts five minutes before the release of the monetary decision, usually at 1:45 pm Central European Time (CET), and ends 105 minutes after the release of the statement, thus including the one-hour press conference that usually takes place between 2:30 pm CET and 3:30 pm CET. By choosing such a narrow event window, the movements in the currency basis and government yields can be attributed to monetary policy shocks from the ECB. Intraday data come from the Thomson Reuters Tick History database. The currency basis corresponds to OTC quotes, from a major European bank, for an Euribor/U.S. Libor one-year maturity basis contract.[28] The event-study focuses on the ECB announcements because quotes on the currency basis are available at high frequency for the euro.

We regress the changes in the currency basis around the i-th monetary policy announcement (Δx_i) on the changes in the German bund and U.S. Treasury two-year benchmark yield differentials around the same event window ($\Delta y_i^{GE} - \Delta y_i^{US}$):

$$\Delta x_i = \alpha + \beta(\Delta y_i^{GE} - \Delta y_i^{US}) + \epsilon_i. \tag{17}$$

In the cross-section, as we saw, the currency basis tends to increase with the interest rate differential. A similar behavior would imply a positive slope coefficient, $\beta > 0$. As Figure 9 shows, this is clearly the case: in the time-series too, the currency basis tends to increase with the interest rate differential. The slope coefficient on the interest rate differential in Equation (17) is equal to 0.15 with a t-statistic equal to 5.88. Therefore, a 10 basis point reduction in the German/U.S. Treasury two-year yield differential due to an accommodative ECB monetary policy shock leads to 1.5 basis point reduction in the one-year euro/dollar Libor CIP deviations. A more accommodative-than-expected monetary policy by the ECB thus results in a more negative cross-currency-basis for the euro, implying that the synthetic dollar rate increases compared to the direct dollar rate, making the indirect dollar funding of European banks more expensive

[28] Cross-currency bases at tenors longer than one year are not quoted frequently enough for our event study. The three-month cross-currency basis was not actively traded as a separate derivative product until 2012. Our results, however, are robust to using the three-month basis since it became separately quoted.

than before the announcement.

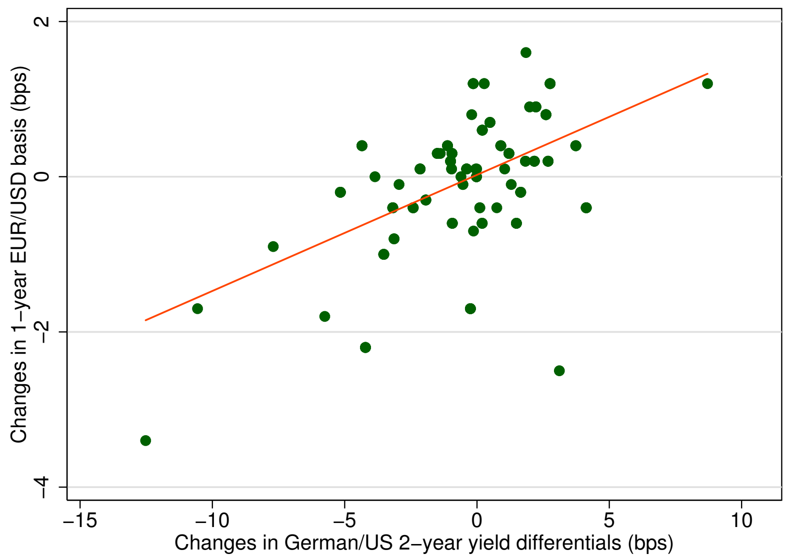

Figure 9. Monetary Policy Shocks and Deviations from CIP
This figure plots intraday changes in the two-year German bund and U.S. Treasury yield differential around the ECB monetary policy announcements on the horizontal axis and intraday changes in the one-year euro/dollar cross-currency basis around the same time on the vertical axis. All intraday data are from Thomson Reuters Tick History. The sample period is from 1/1/2010 to 10/30/2015.

V. Conclusion

In this paper, we examine the persistent and systematic failures of the CIP condition in the post crisis period. After formally establishing CIP arbitrage opportunities based on repo rates and KfW bonds, we argue that these arbitrage opportunities can be rationalized by the interaction between costly financial intermediation and international imbalances in funding supply and investment demand across currencies. Consistent with this two-factor hypothesis, we report four empirical characteristics of the CIP deviations. First, CIP deviations increase at the quarter ends post crisis, especially for contracts that appear on banks' quarter-end balance sheets. Second, proxies for the banks' balance sheet costs account for two-thirds of the CIP deviations. Third, CIP deviations co-move with other near-risk-free fixed income spreads. Fourth, CIP deviations are highly correlated with nominal interest rates in the cross section and time series.

Looking beyond our paper, we expect a large literature to investigate further the CIP deviations. The deviations occur in one of the largest and most liquid markets in the world after the crisis in the absence of financial distress, suggesting that other arbitrage opportunities exist elsewhere. While trading in exchange rate derivatives is a zero-sum game, the CIP deviations may have large welfare implications because of the implied deadweight cost borne by firms seeking to hedge their cash flows. Furthermore, the existence of CIP deviation introduces wedges between the interest rates in the cash and swap markets, which affects the external transmission of monetary policy. The welfare cost of the CIP deviation is beyond the scope of this paper; it would necessitate a general equilibrium model. Yet, even without such model, the CIP condition is a clean laboratory to test the impact of financial frictions in a very general framework. In this spirit, we present the first international evidence on the causal impact of recent banking regulations on asset prices. We expect more research in this direction in the future.

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REFERENCES

Adrian, Tobias, Erkko Etula, and Tyler Muir, 2014, Financial intermediaries and the cross-section of asset returns, *Journal of Finance* 69, 2557–2596.

Akram, Q. Farooq, Dagfinn Rime, and Lucio Sarno, 2008, Arbitrage in the foreign exchange market: Turning on the microscope, *Journal of International Economics* 76, 237–253.

Amador, Manuel, Javier Bianchi, Luigi Bocola, and Fabrizio Perri, 2016, Exchange rate policies at the zero lower bound, Working Paper.

Arora, Navneet, Priyank Gandhi, and Francis A. Longstaff, 2011, Counterparty credit risk and the credit default swap market, *Journal of Financial Economics* 103.

Avdjiev, Stefan, Wenxin Du, Catherine Koch, and Hyun Song Shin, 2016, The dollar, bank leverage and the deviation from covered interest parity, BIS Working Paper No. 592.

Baba, Naohiko, Robert N McCauley, and Srichander Ramaswamy, 2009, US dollar money market funds and non-US banks, *BIS Quarterly Review* 65–81.

Baba, Naohiko, and Frank Packer, 2009, Interpreting deviations from covered interest parity during the financial market turmoil of 2007-08, *Journal of Banking and Finance* 33, 1953–1962.

Baba, Naohiko, Frank Packer, and Teppei Nagano, 2008, The spillover of money market turbulence to FX swap and cross-currency swap markets, *BIS Quarterly Review* 73–86.

Baklanova, Viktoria, Adam Copeland, and Rebecca McCaughrin, 2015, Reference guide to u.s. repo and securities lending markets, Federal Reserve Bank of New York Staff Report No. 740.

Banegas, Ayelen, and Manjola Tase, 2016, Reserve balances, the federal funds market and arbitrage in the new regulatory framework, Finance and Economics Discussion Series 2016-079, Federal Reserve Board.

Basel Committee on Banking Supervision, 2014, Basel III leverage ratio framework and disclosure requirements, Technical report, Bank for International Settlements.

Bekaert, Geert, and Robert J Hodrick, 2012, *International financial management* (Pearson Prentice Hall Upper Saddle River, New Jersey, NJ).

Bernanke, Ben, and Mark Gertler, 1989, Agency costs, net worth, and business fluctuations, *American Economic Review* 14–31.

BIS, 2013, Triennial central bank survey of foreign exchange and derivatives market activity in 2013, Technical report, Bank for International Settlements.

BIS, 2014, Detailed tables on semiannual otc derivatives statistics at end-december 2014, Technical report, Bank for International Settlements.

Bloomberg, August 21, 2016, World's biggest bond traders undeterred by negative yields.

Bottazzi, Jean-Marc, Jaime Luque, Mario Pascoa, and Suresh M. Sundaresan, 2012, Dollar shortage, central bank actions, and the cross currency basis, Working Paper.

Brunnermeier, Markus K, and Lasse Heje Pedersen, 2009, Market liquidity and funding liquidity, *Review of Financial studies* 22, 2201–2238.

Brunnermeier, Markus K, and Yuliy Sannikov, 2014, A macroeconomic model with a financial sector, *American Economic Review* 104, 379–421.

Buraschi, Andrea, Murat Menguturk, and Emrah Sener, 2015, The geography of risk capital, *Review of Financial Studies* 28, 1103–1152.

Caballero, Ricardo J, Emmanuel Farhi, and Pierre-Olivier Gourinchas, 2008, An equilibrium model of "global imbalances" and low interest rates, *The American Economic Review* 98, 358–393.

Caballero, Ricardo J, Emmanuel Farhi, and Pierre-Olivier Gourinchas, 2016, Global imbalances and currency wars at the zlb, *Working Paper, Harvard University* .

Callier, Philippe, 1981, One way arbitrage, foreign exchange and securities markets: A note, *The Journal of Finance* 36, 1177–1186.

Clinton, Kevin, 1988, Transactions costs and covered interest arbitrage: Theory and evidence, *Journal of Political Economy* 96, 358–370.

Coffey, Niall, Warren B. Hrung, and Asani Sarkar, 2009, Capital constraints, counterparty risk, and deviations from covered interest rate parity, *Federal Reserve Bank of New York Staff Report 393* .

Deardorff, Alan V., 1979, One-way arbitrage and its implications for the foreign exchange markets, *Journal of Political Economy* 87, 351–364.

Dooley, Michael P, and Peter Isard, 1980, Capital controls, political risk, and deviations from interest-rate parity, *Journal of Political Economy* 370–384.

Du, Wenxin, Salil Gadgil, Michael B. Gordy, and Clara Vega, 2016, Counterparty risk and counterparty choice in the credit default swap market, Working Paper, Federal Reserve Board.

Du, Wenxin, and Jesse Schreger, 2016, Local currency sovereign risk, *Journal of Finance* 71, 1027–1070.

Duffie, Darrell, 2016, Why are big banks offering less liquidity to bond markets?, Forbes, March.

Duffie, Darrell, 2017, The covered interest parity conundrum, *Risk.net* .

Duffie, Darrell, and Arvind Krishnamurthy, 2016, Passthrough efficiency in the fed's new monetary policy setting, *Jackson Hole Symposium of the Federal Reserve Bank of Kansas City* .

Frenkel, Jacob A, and Richard M Levich, 1975, Covered interest arbitrage: Unexploited profits?, *Journal of Political Economy* 83, 325–338.

Gabaix, Xavier, and Matteo Maggiori, 2015, International liquidity and exchange rate dynamics, *Quarterly Journal of Economics* 130, 1369–1420.

Garleanu, Nicolae, and Lasse Pedersen, 2011, Margin-based asset pricing and deviations from the law of one price, *Review of Financial Studies* 24, 1980–2022.

Goldberg, Linda S., Craig Kennedy, and Jason Miu, 2011, Central bank dollar swap lines and overseas dollar funding costs, Federal Reserve Bank of New York Economic Policy Review, May.

Greenwood, Robin, and Dimitri Vayanos, 2014, Bond supply and excess bond returns, *Review of Financial Studies* 27, 663–713.

Griffolli, Mancini Tommaso, and Angelo Ranaldo, 2011, Limits to arbitrage during the crisis: Funding liquidity constraints and covered interest parity, Working Paper.

Gromb, Denis, and Dimitri Vayanos, 2010, Limits of arbitrage, *Annual Review of Financial Economics* 2, 251–275.

He, Zhigu, and Arvind Krishnamurthy, 2012, A model of capital and crises, *The Review of Economic Studies* 79, 735–777.

He, Zhiguo, Bryan Kelly, and Asaf Manela, 2017, Intermediary asset pricing: New evidence from many asset classes, *Journal of Financial Economics* 126, 1–35.

He, Zhiguo, and Arvind Krishnamurthy, 2013, Intermediary asset pricing, *American Economic Review* 103, 732–770.

Holmstrom, Bengt, and Jean Tirole, 1997, Financial intermediation, loanable funds, and the real sector, *Quarterly Journal of economics* 663–691.

ICMA, 2016, European repo market survey number 30, International Capital Market Association.

Ivashina, Victoria, David S Scharfstein, and Jeremy C Stein., 2015, Dollar funding and the lending behavior of global banks, *Quarterly Journal of Economics* 130, 1241–1281.

Jacob A. Frenkel, Richard M. Levich, 1977, Transaction costs and interest arbitrage: Tranquil versus turbulent periods, *Journal of Political Economy* 85, 1209–1226.

Jermann, Urban J, 2016, Negative swap spreads and limited arbitrage, Working paper, available at SSRN.

Keynes, John Maynard, 1923, *A Tract on Monetary Reform* (Macmillan).

Klee, Elizabeth, Zeynep Senyuz, and Emre Yoldas, 2016, Effects of changing monetary and regulatory policy on overnight money markets, Finance and Economics Discussion Series 2016-084, Federal Reserve Board.

Liao, Gordon Y., 2016, Credit migration and covered interest rate parity, Working Paper, Harvard Business School.

Lotz, Walther, 1889, *Die Währungsfrage in Österreich-Ungarn und ihre wirtschaftliche und politische Bedeutung* (Duncker & Humblot).

McGuire, Patrick, and Goetz von Peter, 2012, The dollar shortage in global banking and the international policy response, *International Finance* 15, 155–178.

Mohsen Bahmani-Oskooee, Satya P. Das, 1985, Transaction costs and the interest parity theorem, *Journal of Political Economy* 93, 793–799.

Munyan, Benjamin, 2015, Regulatory arbitrage in repo markets, Working Paper.

Nelson, Bill, 2016, Money market developments and bank regulation, `https://www.theclearinghouse.org/eighteen53-blog/2016/october/21-money-market-regulation/`.

Reserve Bank of Australia, 2016, Operations in financial markets, Reserve Bank of Australia Annual Report 2016.

Rime, Dagfinn, Andreas Schrimpf, and Olav Syrstad, 2016, Segmented money markets and covered interest parity arbitrage, Working Paper.

Sato, Takehiro, 2015, Toward further development of the tokyo financial market: Issues on repo market reform, Keynote Speech at the Futures Industry Association Japan Financial Market Conference 2015 in Tokyo.

Schwartz, Krista, 2015, Mind the gap: Disentangling credit and liquidity in risk spreads, Working Paper.

Shleifer, Andrei, and Robert W. Vishny, 1997, The limits of arbitrage, *Journal of Finance* 52, 35–55.

Siriwardane, Emil N., 2016, Concentrated capital losses and the pricing of corporate credit risk, Working paper, Harvard Business School.

Tuckman, Bruce, and Pedro Porfirio, 2004, Interest rate parity, money market basis swaps, and cross-currency basis swaps, Lehman Brothers Fixed Income Liquid Markets Research.

Vayanos, Dimitri, and Jean-Luc Vila, 2009, A preferred-habitat model of the term structure of interest rates, Working paper, London School of Economics.

Vladyslav Sushko, Robert Neil McCauley, Claudio Borio, and Patrick McGuire, 2016, The failure of covered interest parity: Fx hedging demand and costly balance sheets, BIS Working Papers No 590.

DATA APPENDIX

We provide a brief overview of the data sources used in the paper. Detailed Bloomberg or Reuters tickers of the data series can be found in the spreadsheet online.

Exchange Rates: Daily spot exchange rates and forward points come from Bloomberg using London closing rates for G10 currencies. Mid-rates (average of bid and ask rates) are used for benchmark basis calculations. Daily Libor/interbank fixing rates are also obtained from Bloomberg.

Benchmark Interbank Rates We use the following benchmark interest rates from Bloomberg for our sample currencies: Australian dollar (AUD): Bank Bill Swap Rate (BBSW); Canadian dollar (CAD): Canadian Dollar Offered Rate (CDOR); Swiss franc (CHF): London Interbank Offered Rate (LIBOR); Danish krone (DKK): Copenhagen Interbank Offered Rate (CIBOR); Euro (EUR): Euro Interbank Offered Rate (EURIBOR); British pound (GBP): LIBOR; Japanese yen (JPY): LIBOR; Norwegian krone (NOK): Norwegian Interbank Offered Rate (NIBOR); New Zealand dollar (NZD): Bank Bill Market Rate (BKBM); Swedish Krona (SEK): Stockholm Interbank Offered Rate (STIBOR). We follow the market day count conventions for these interest rates: 365/ACT for the commonwealth currencies (AUD/CAD/GBP/NZD), and 360/ACT for the other currencies.

GC Repo rates U.S. bid and ask repo rates come from the Thomson Reuters Tick History database. The mid rates are very close to the daily GC repo quotes from JP Morgan (obtained from Morgan Markets), one of the only two clearing banks to settle tri-party U.S. repo markets.

The euro mid repo data are based on German bunds as collateral and are obtained from Bloomberg. Similar series from JP Morgan are very close the Bloomberg series, but shorter. Bid and ask rates on euro repos are available from Thomson Reuters Eikon. We do not use the Thomson Reuters Eikon GC euro rates in our baseline calculation because eligible collateral also includes sovereign bonds in other European countries besides the German bunds. Thomson Reuters Eikon euro GC repo rates are persistently higher than the Bloomberg rates, and thus imply larger arbitrage profits than the reported results.

Swiss franc mid repo and Danish krone bid and ask repo rates also come from Bloomberg. The Japanese repo rates come from the Bank of Japan and the Japan Securities and Dealer Association. More details on the GC repo markets in our sample countries can be found in the Online Appendix.

Other fixed-income spreads We compare the cross-currency basis with four types of near-riskfree fixed-income spreads. First, the KfW-German bund basis is the spread of a five-year euro-denominated bond issued by KfW over the five-year German Bund yield. The five-year KfW bond yield is estimated by the Nelson-Siegel methodology on individual KfW bond prices obtained from Bloomberg.

Second, the one-month vs. three-month Libor tenor swap basis measures the premium that one party has to pay in order to receive the one-month floating U.S. Libor in exchange of the three-month floating U.S. Libor for the five-year duration of the contract. The tenor swap basis reflects a premium for more frequent payments or a higher desirability of short-term liquidity. The tenor swap basis data are downloaded from Bloomberg.

Third, the CDS-CDX basis measures the difference between the average five-year CDS spreads on the 125 constituent names of the North America investment grade credit default swap index (NA.IG.CDX) and the spread on the corresponding aggregate NA.IG.CDX index. All data on CDS and CDX spreads are obtained from Markit.

Fourth, the CDS-bond basis measures the difference between the asset swap spread on a corporate bond over the CDS spread on the same reference entity. We use the CDS-bond basis provided by Morgan Markets for investment-grade bonds. Both the CDS-CDX basis and CDS-bond basis lead to popular credit arbitrage strategies.