Deviations from Covered Interest Rate Parity *

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Abstract

Currently, taking into account transaction costs, there are large and persistent arbitrage opportunities in one of the largest asset markets in the world. Contrary to a common view, we show that the deviations from the covered interest parity condition are not explained away by credit risk or transaction costs. We find that these deviations imply large, persistent, and systematic arbitrage opportunities for major currencies, which points to key frictions in financial intermediation and their interactions with global imbalances during the post-crisis period. These arbitrage opportunities are highly correlated with nominal interest rates in the cross-section and in the time series; they increase at quarter ends post-crisis; they are highly correlated with other fixed-income spreads; and are much lower after proxying for banks' balance sheet costs.

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1 Introduction

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 CIP 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 funding markets since the global financial crisis. Furthermore, we argue that the systemic pattern of the CIP violations point to the key interaction between costly financial intermediation and global imbalances in funding supply and investment demand across currencies.

According to the CIP condition, the log difference between the currency forward rate and the spot rate of two currencies, both measured at the same date, should be equal to the interest rate difference between the two currencies over the horizon of the forward contract. 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 the 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. In addition, 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 ex-ante payoffs. Therefore, from the investor's perspective, the CIP condition indicates that the yield on a dollar asset should be exactly equal to the yield on a foreign currency asset after hedging currency risk, provided that the two assets have the same risk characteristics except different currency denomination. Similarly, from the

borrower's perspective, the cost of funding directly in dollars should be exactly equal to the combined cost of funding in a foreign currency and swapping the funds into dollars.

The cross-currency basis measures the deviation from the CIP condition. We define the cross-currency basis as difference between the direct dollar interest rate 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. Before the global financial crisis, the log difference between the forward and the spot rate was approximately equal to the difference in London interbank offer rates (Libor) across countries (Frenkel and Levich, 1975; Akram, Rime, and Sarno, 2008). In other words, the Libor cross-currency basis was very close 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: 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 (Bank of International Settlements, 2013). The average annualized absolute value of the basis is 24 basis points at the three-month horizon and 26 basis points at the five-year horizon over the 2010–2015 sample. These averages hide large variation 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 U.S.

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 Libor 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 can persist. Using credit spreads of banks on interbank panels in different currencies, however, we do not find any economically significant link between the Libor cross-currency basis and the average credit default swap differential between interbank panels.

Furthermore, 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 6 to 19 basis points on average in annualized values. The averages may appear small, but again they hide large time variations: the standard deviation of the net arbitrage profits range from

4 to 23 basis points. Moreover, the conditional volatility of each investment opportunity is naturally zero and Sharpe ratios are thus infinite for the fixed investment horizon of the strategy. For funding cost arbitrageurs, the potential savings by borrowing in the cheapest currencies on the swap basis are even larger because of significantly lower transaction costs. Since the global financial crisis, there are large and persistent arbitrage opportunities in one of the largest asset markets in the world because the CIP condition does not hold any more.

In addition, we study 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 also been persistently different from zero post-crisis. A large cross-sectional dispersion in the issuer-specific bases appears post-crisis across different types of issuers. 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. dollar 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.

After documenting the persistence of CIP deviations across a constellation of interest rates, we turn to their potential explanations. We hypothesize that persistent CIP deviations can be explained by the combination of increased cost of financial intermediation post-crisis and persistent global 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 the why the basis is not

arbitraged away post the 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, 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 carry trade. In time-series, the 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. Second, the magnitude of the CIP deviation is larger at quarter ends, when the cost of balance sheet may be higher due to quarterly regulatory reporting. The quarter-end anomaly is featured in the post-2007 sample, but is absent from the pre-2007 sample, suggesting more binding bank balance sheet constraints towards quarter ends since the global financial crisis. Third, the cross-currency basis is correlated with other liquidity risk premia, 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 supports the role of financial intermediaries and likely correlated demand shocks for dollar funding and other forms of liquidity. Fourth, the spread between the interest rates on excess reserves (IOER) and the Fed fund or U.S. Libor interest rates is a proxy for the U.S. banks' balance sheet costs. We show that CIP arbitrage profits based on IOER differentials at major central banks are often closer to zero than arbitrage profits based on private money market instruments.

Our work is closely related to two main strands of the literature.[1] First, an extensive literature studies 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 establishment 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). We contribute to this literature by uncovering arbitrage opportunities and their systematic cross-sectional and time-series dynamics post the crisis, often under normal financial conditions. In addition, we study the significant differences in the relative premium or discount in the dollar funding across currencies and across issuer types, and the role of excess reserves at central banks.

Second, another large literature studies the role of financial intermediaries in international finance, and could thus provide convincing explanations of the characteristics of the cross-currency basis. Gabaix and Maggiori (2015) provide a tractable and elegant model of exchange rate determination in the presence of moral hazard. 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), suggest a key role for financial intermediaries' wealth. Likewise, models of margin-based asset pricing, as in Garleanu and Pedersen (2011) and 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. In

[1] An early exposition of the CIP condition appears 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). Up to the recent global financial crisis, the consensus was that the CIP condition holds in the data.

on-going work, Liao (2016) models the impact of corporate issuance decisions on CIP deviations. Our findings are also related to global imbalances in safe assets, as studied in the pioneer models of Caballero, Farhi, and Gourinchas (2008, 2016). Empirically, the cross-sectional dispersion in the currency basis may be related to the geography of risk capital as documented in Buraschi, Menguturk, and Sener (2015), the geography of global liquidity and the role of global banks in the transmission of funding shocks across countries (e.g., Cetorelli and Goldberg, 2011, 2012; Correa, Sapriza, and Zlate, 2012; Shin, 2012; and Bruno and Shin, 2015). 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.

The paper is organized as follows. Section 2 defines and documents precisely the CIP condition and its deviations at the short- and long-end of the yield curves. Section 3 shows that credit risk may not be the main culprit: the currency basis also exists for repo rates and KfW bonds, leading to clear arbitrage opportunities. Section 4 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 5 presents four characteristics of the currency basis: its cross-sectional and time-series links with interest rates, its surge at the end of the quarters post-crisis, its high correlation with other liquidity-based strategies in different fixed-income markets and its relationship with the IOER. Section 6 concludes.

2 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.

2.1 Covered Interest Rate Parity

Let $y^{\$}_{t,t+n}$ and $y_{t,t+n}$ denote the n-year risk-free interest rates 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:

$$(1 + y^{\$}_{t,t+n})^n = (1 + y_{t,t+n})^n \frac{S_t}{F_{t,t+n}} \tag{1}$$

In logs, the forward premium, $\rho_{t,t+n}$, is equal to the interest rate difference between interest rates in the two currencies:

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

The intuition behind the CIP condition is simple: an investor with one U.S. dollar in hand today would own $(1+y^{\$}_{t,t+n})^n$ 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 $(1 + y_{t,t+n})^n S_t$ units of foreign currency n years from now. A currency forward contract signed today would convert the foreign currency earned into $(1+y_{t,t+n})^n S_t/F_{t,t+n}$ 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.

2.2 Definition of the Cross-Currency Basis

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

$$(1 + y^{\$}_{t,t+n})^n = (1 + y_{t,t+n} + x_{t,t+n})^n \frac{S_t}{F_{t,t+n}}. \tag{3}$$

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

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

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 by swapping the foreign currency interest rate into dollars.

As already noted, CIP holds in the absence of arbitrage. As soon as the basis is not zero, arbitrage opportunities theoretically appear. 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. The cash flow diagram of this CIP arbitrage strategy is summarized in Figure 1. 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. Such arbitrage strategies rely on forwards and futures contracts. In practice those contracts are traded for short horizons, up to a few years. To hedge cash flows at longer horizons, practitioners rely on long-term cross-currency swaps.

2.3 Failure of Textbook Libor-Based Covered Interest Parity

The CIP condition is presented in every textbook in international finance and international economics at the undergraduate and graduate levels. Textbook tests of the CIP condition usually rely on Libor rates.[2] 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.

2.3.1 Short-Term Libor Cross-Currency Basis

We define the Libor basis as equal to:

$$x_{t,t+n}^{Libor} \equiv y_{t,t+n}^{\$,Libor} - (y_{t,t+n}^{Libor} - \rho_{t,t+n}), \tag{5}$$

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.[3] Mid-rates (average of bid and ask rates) are used for benchmark basis calculations. Daily Libor/interbank fixing rates are also obtained from Bloomberg. While the Libor basis used to be close to zero before the crisis, it is now large and significant. Figure 4 presents the three-month Libor basis for G10 currencies between 1/1/2000 and 12/31/2015.

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

[2]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.

[3]In practice, since forward points are often quoted with a higher level of precision that outright forwards, we compute the forward premium $\rho_{t,t+n}$ directly from forward points, defined as $FP_{t,t+n} = S_t + FP_{t,t+n}$. Thus, the forward premium is: $\rho_{t,t+n} \approx (1/n)FP_{t,t+n}/S_t$.

CIP, especially around the Lehman bankruptcy announcement, with some bases reaching −200 basis points. But the deviations from 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 1 summarizes the mean and standard deviation of the Libor currency basis across three different periods: 2000–2006, 2007–2009, and 2010–2015. 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 25 and 33 basis points, 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 −61 basis points, a stark contrast to its pre-crisis average of 1 basis point.

2.3.2 Long-Term Libor Cross-Currency Basis

At long maturities, the long-term CIP deviations 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 2 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 $t+j$.[4] In return, Bank A receives from Bank B a floating yen cash flow equal to $(y_{t+j}^{Libor,¥} + x_{t,t+n}^{xccy})$

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

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. cash flows. In the case of the yen/U.S dollar cross-currency swap over the recent period, $x_{t,t+n}^{xccy}$ is often negative. Let us assume for simplicity that Bank B is able to lend risk-free in yen at the 3-month yen Libor rate, $y_{t+j}^{Libor,¥}$. Then, according to the cross-currency basis swap contract, Bank B has 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 2, 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. As Figure 3 illustrates, 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.

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

$$\left(1+y_{t,t+n}^{\$,IRS}\right)^n = \left(1+y_{t,t+n}^{IRS}+x_{t,t+n}^{xccy}\right)^n \frac{S_t}{F_{t,t+n}}.$$

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

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

The cross-currency basis swap rate, $x_{t,t+n}^{xccy}$, thus measures deviations from the CIP condition where interest rates are Libor interest rate swap rates. Once we have the long-term forward premium $\rho_{t,t+n}$, the long-term Libor basis is given by

$$\begin{aligned} x_{t,t+n}^{Libor} &\equiv y_{t,t+n}^{\$,Libor}-(y_{t,t+n}^{Libor}-\rho_{t,t+n}) \\ &= y_{t,t+n}^{\$,IRS}-[y_{t,t+n}^{IRS}-(y_{t,t+n}^{IRS}+x_{t,t+n}^{xccy}-y_{t,t+n}^{\$,IRS})] \\ &= x_{t,t+n}^{xccy}. \end{aligned}$$

Therefore, the long-term Libor basis is exactly equal to the spread on the cross-currency basis swap. For short maturities, the deviations from CIP measured using Libor rates, $x_{t,t+n}^{Libor}$, will thus be the same as those measured using cross-currency basis rates, $x_{t,t+n}^{xccy}$. With this result in mind, we now turn to the data.

Data on cross-currency basis swaps come from Bloomberg. Figure 5 shows the five-year Libor basis for G10 currencies between 1/1/2000 and 12/31/2015, while the Panel B of Table

1 reports averages and standard deviations by sub-periods. Before 2007, the five-year Libor basis was slightly positive for Australia, Canada, and New Zealand and negative for all the other countries, 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, Australia and New Zealand exhibit the most positive bases, equal to 25 and 33 basis points on average, while Japan and Denmark exhibit the most negative bases, equal to -56 and -42 basis points on average. Switzerland and the euro area also experience very negative bases, with average values less than -25 basis points.

3 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.

3.1 Credit Risk in the Libor CIP Arbitrage

The failure of the Libor-based CIP reported in the previous section suggests some potential arbitrage opportunities. As previously described, a potential arbitrageur, noticing for example a negative 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 can be ruled out, as exchange rate forward contracts are fully collateralized and do not exhibit significant deviations from their clearinghouse-based futures counterparts. But the previous two concerns remain: 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 is in Appendix A. If CDS measure credit spreads perfectly, Equation (8) suggests a slope coefficient of -1 and an R^2 of 1. Table 2 reports the regression results from January 2007 to January 2016. In the pooled panel regression with currency fixed effects reported in the first column, the coefficient on the CDS spread differential is negligible and statistically insignificant from zero. Results based on individual currencies in the following columns show that the slope coefficient is only significantly negative for the Swiss franc and euro. In all the other cases, the slope coefficient are either insignificant or positive. Even in the case of the Swiss franc and the euro, the negative coefficients on the CDS differential are far from being equal to -1. In all cases, R^2 are tiny. Assuming that bank CDS proxy for the credit risk of potential CIP arbitrageurs, there is therefore some doubt that the credit spread differential is the most important driver for the Libor cross-currency basis of G10 currencies in the post-crisis period.[5] We rule out credit risk by turning to repo contracts.

[5]The credit spread differential, however, has a much more significant effect on the currency basis of emerging market currencies.

3.2 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 supply and demand of cash, as opposed to supply and demand of individual collateral assets. Given the U.S. dollar GC repo rate $y_{t,t+n}^{\$,Repo}$ and the foreign currency GC repo rate $y_{t,t+n}^{Repo}$, the general definition of the basis in Equation (4) leads to the following repo basis:

$$x_{t,t+n}^{Repo} = y_{t,t+n}^{\$,Repo} - (y_{t,t+n}^{Repo} - \rho_{t,t+n}). \tag{10}$$

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. 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 GC repo rates come from JP Morgan, while the Swiss and Danish repo rates come from Bloomberg. The Japanese repo rates come from the Bank of Japan and the Japan Securities and Dealer Association. Bid and ask spreads are only available for U.S. dollar and Danish krone repos. Anecdotal evidence suggests that the bid-ask spreads are an order of magnitude larger for the Danish krone repos than for the other foreign currencies.

Figure 6 reports the one-week Libor and repo basis for the Swiss Franc, the Danish Krone, the euro, and the yen since 2009. The repo basis tracks the Libor basis very closely for the Swiss Franc and the yen, and remains negative throughout the sample. For the Danish krone

and the euro, the repo basis was closer to zero than the Libor basis during the peak of the European debt crisis, but it tracks the Libor basis very closely overall. Most of the time, the Libor- and repo-based deviations from CIP are undistinguishable from each other in Figure 6.

The first two columns of Table 3 report the annualized mean and standard deviation of Libor- and repo-based bases during the 1/1/2009–12/31/2015 period. The Danish krone exhibits the most negative mean repo basis, equal to −43 basis points if Libor-based and −34 basis points if repo-based. The euro exhibits the least negative mean repo basis equal to −10 basis points with repo rates and −19 with Libor rates. For the Swiss franc, the Libor and repo rates deliver similar basis: −20 and −23 basis points. For the yen, the repo basis is larger for repo than for Libor rates: −22 vs −17 basis points. Clearly, CIP deviations exist even for interest rates that are free of credit risk.

The third column of Table 3 reports the same summary statistics but conditional on a negative basis. The repo basis is negative 99% of the days for the swiss franc, 96% for the Danish krone and 100% for the yen; it is negative 84% of the time for the euro. As a result, the conditional and unconditional average basis are close, ranging from −13 basis points for the euro to −35 basis points for the Danish krone.

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:

$$\pi^{Repo-}_{t,t+n} \equiv [y^{Repo}_{t,t+n,Bid} - (1/n) \times FP_{t,t+n,Ask}/S_{t,Bid}] - y^{\$,Repo}_{t,t+n,Ask}, \tag{11}$$

$$\pi^{Repo+}_{t,t+n} \equiv y^{\$,Repo}_{t,t+n,Bid} - [y^{Repo}_{t,Ask} - (1/n) \times FP_{t,t+n,Bid}/S_{t,t+n,Ask}]. \tag{12}$$

We assume that the transaction cost for each step of the arbitrage strategy is equal to one half of the posted bid-ask spread. As already noted, unfortunately, our database does not contain the repo bid-ask spreads for the Swiss franc, euro, and yen. But 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.[6] The fourth column of Table 3 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 9 to 18 basis points after taking into transaction costs. The profits vary over time, with standard deviations ranging from 8 basis points to 23 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.

3.3 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 construct an alternative long-term currency basis 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 KfW, a German government-owned development bank, with all its liabilities fully backed by the German government. 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 are in the Appendix. 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

[6]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.

borrowing cost of KfW in a foreign currency j:

$$x_{t,t+n}^{KfW} = y_{t,t+n}^{\$,KfW} - \left(y_{t,t+n}^{j,KfW} - \rho_{t,t+n}^{j} \right), \tag{13}$$

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. We define the z-spread of bond j, $zsp_{t,t+n}^{j}$, as the difference between the bond yield and the Libor interest rate swap rate of the same currency and same maturity. Using the definition of the long-term forward premium in Equation (6), we decompose the KfW basis in terms of z-spread differentials and Libor cross-currency basis swap:

$$\begin{aligned} x_{t,t+n}^{KfW} &= y_{t,t+n}^{\$,KfW} - \left[y_{t,t+n}^{j,KfW} - \left(y_{t,t+n}^{IRS,j} + x_{t,t+n}^{xccy,j} - y_{t,t+n}^{\$,IRS} \right) \right], \\ &= \left(y_{t,t+n}^{\$,Kfw} - y_{t,t+n}^{\$,IRS} \right) - \left(y_{t,t+n}^{j,KfW} - y_{t,t+n}^{IRS,j} \right) + x_{t,t+n}^{xccy,j}, \\ &= \left(zsp_{t,t+n}^{\$,KfW} - zsp_{t,t+n}^{j,KfW} \right) + x_{t,t+n}^{xccy,j}. \end{aligned} \tag{14}$$

If KfW borrowing costs were the same across currencies, the basis $x_{t,t+n}^{KfW}$ should be zero and the cross-currency Libor basis should be completely offset by the z-spread differential. As we shall see, however, the KfW basis is not zero; it measures the difference between the direct dollar borrowing cost, $zsp_{t,t+n}^{\$}$, and the synthetic dollar borrowing cost, $zsp_{t,t+n}^{j,KfW} - x_{t,t+n}^{xccy,j}$, both measured as spreads over U.S. Libor interest rate swap rates.

Figure 7 displays the KfW currency basis for the Australian dollar, the Swiss franc, the euro, and the Japanese yen, along with their decomposition into Libor-based basis and z-spreads. In the case of the Australian dollar, the Libor basis is significantly positive post-crisis, but the KfW basis is closer to zero: there, the Libor-based basis is offset by differences in credit and default risk prices. For the three currencies with negative Libor basis post crisis (Swiss franc, the euro, and the Japanese yen), however, the KfW basis is also negative and tracks the Libor basis very closely.

The first column of Table 4 reports summary statistics on the KfW basis during the 1/1/2009–12/31/2015 period. The mean post-crisis KfW basis is very close to zero for the Australian dollar (0.8 basis points) but is significantly negative for the other three currencies: −21 basis points for the Swiss franc, −15 basis points for the euro, and −35 basis points for the yen. The second column of Table 4 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 59% of the time, the other bases are negative at least 94% of the sample. As a result, the average conditional basis is 9 basis points for the Australian dollar, and close to their unconditional values for the other currencies: −23 basis points for the Swiss franc, −16 basis points for the euro, and −35 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 cash flows into U.S. dollars, and short-sell the KfW bond denominated in U.S. dollars. When the KfW basis is positive, the arbitrage strategy would be the opposite. Arbitrage profits under the negative and positive strategies, denoted by $\pi^{KfW-}_{t,t+n}$ and $\pi^{KfW+}_{t,t+n}$, are:

$$\pi^{KfW-}_{t,t+n} \equiv [(y^{j,KfW}_{t,t+n,Ask} - y^{IRS,j}_{t,t+n,Bid}) - x^{xccy,j}_{t,t+n,Bid}] - (y^{\$,Kfw}_{t,t+n,Bid} - y^{\$,IRS}_{t,t+n,Ask}) - fee^{\$}_{t,t+n}, \quad (15)$$

$$\pi^{KfW+}_{t,t+n} \equiv (y^{\$,Kfw}_{t,t+n,Bid} - y^{\$,IRS}_{t,t+n,Ask}) - [(y^{j,KfW}_{t,t+n,Ask} - y^{IRS,j}_{t,t+n,Bid}) + x^{xccy,j}_{t,t+n,Bid}] - fee^{j}_{t,t+n}. \quad (16)$$

where $fee^{\$}_{t,t+n}$ and $fee^{j}_{t,t+n}$ denote the short-selling fee of the dollar and foreign currency bonds. We obtain all bid and ask prices for bond and swap rates from Bloomberg. Since interest rate swaps and cross-currency swaps are very liquid derivatives for G10 currencies, the total swap transaction cost is on average about 5 basis points since 2009. We obtain KfW shorting costs from transaction-level data provided by Markit Securities Finance (formerly

known as Data Explorer).[7] Post crisis, the median shorting cost fluctuates around 15 basis points.

The last three columns of Table 4 describe the profits net of transaction costs for the positive Australian dollar arbitrage and the negative Swiss franc, euro, and Japanese yen arbitrages. The 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 10 to 25 basis points. The positive arbitrage strategy of the Australian dollar yields positive profits only 15% 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 80% of the sample for the Japanese yen. The positive basis arbitrage only yields profits in less than 10% 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 18 basis points, with standard deviations ranging from 5 to 11 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.

3.4 Issuer-Specific Basis for Risky Issuers

In addition, near-arbitrage opportunities exist for bonds issued by the same risky issuer in different currencies. Under some additional assumptions, the CIP condition can be expressed

[7] Figure 16 in the Appendix reports the 25 percentile, median, and 75 percentile of shorting costs for U.S. dollar bonds issued by KfW. There is a significant cross-sectional dispersion in terms of shorting costs across transactions. During the peak of the global financial crisis, the 25 percentile and median shorting costs were negative, which reflects demand for U.S. dollar cash or U.S. Treasury collateral.

in terms of defaultable rates. In a frictionless market, if $y^{\$}_{t,t+n}$ and $y_{t,t+n}$ correspond to yields on defaultable bonds with the same default probability and recovery rates, as long as the exchange rate process and the default process are independent, the currency basis is zero: $x_{t,t+n} = 0$ (see Buraschi, Menguturk, and Sener, 2015, or Proposition 2 in Du and Schreger, forth.). In practice, the same default and recovery rates hold for bonds of the same issuer under the pari passu clause and the impact of the covariance between currency and corporate credit risk appears small.[8]

As for the KfW basis, we define the issuer-specific basis for any issuer k as follows:

$$x^k_{t,t+n} = y^{\$,k}_{t,t+n} - (y^{j,k}_{t,t+n} - \rho^j_{t,t+n}), \tag{17}$$

where $y^{\$,k}_{t,t+n}$ denotes the dollar bond yield of issuer k and $y^{i,k}_{t,t+n}$ denotes the bond yield of currency j issued by the same issuer k. We focus on a large panel of multi-currency issuers including global banks headquartered in Australia, the euro area, Japan, Switzerland, the U.K., and the U.S., as well as multinational firms (General Electric, Honda and Tokyo) and the European Investment Bank (EIB), a supranational organization). We construct the issuer-specific basis by matching the maturity year and seniority of the dollar and foreign currency bonds of issuer k. All data on bond yields in the secondary market are from Bloomberg.

Figure 8 shows the issuer specific bases for the Australian dollar, the Swiss franc, the euro and the yen across different issuers, together with the Libor cross-currency basis. Issuer-specific bases were also close to zero before the global financial crisis. Since the crisis, there has been a large cross-sectional dispersion in the basis across issuers. The sign of

[8]Du and Schreger (Forthcoming) give a simple calibration as follows. Assume that the foreign currency depreciates against the U.S. dollar by α percents in the event of a corporate default compared to the non-default state, and assume that the U.S. dollar bond yield is equal to $y^{*\$}_t + sp_t$, where $y^{*\$}_t$ is the risk-free rate in the U.S. dollar and sp_t is the credit spread. Then the synthetic dollar yield by swapping a foreign currency bond into the U.S. dollar should be equal to $(1-\alpha)s_t + \rho_t + y^{*\$}_t$. Suppose that the credit spread is equal to $sp_t = 100$ basis points and that $\alpha = 5\%$, and then the deviations from CIP for the corporate issuer should be around $\alpha s_t = 5$ basis points. Even an exchange rate depreciation of 20% at the time of a corporate default would only entail a CIP deviation of 20 basis points. As we shall see, the CIP deviations are much larger than that.

the cross-currency basis for each currency depends on the specific issuer. In particular, as shown in Figure 9, U.S. financials and supranationals, on average, have a persistently lower issuer-specific basis than foreign banks since the global financial crisis, which points to a comparative advantage of U.S. financials and supranationals over foreign banks in direct funding in dollars. The significant differences in relative funding costs can potentially explain why foreign banks heavily rely on funding in their local currencies and then swap into U.S. dollars rather than borrowing directly in the U.S. dollar markets, especially during the periods of distress (Ivashina, Scharfstein, and Stein, 2015). For U.S.-domiciled entities and AAA-rated agencies and supranationals, it is more advantageous, from a pure funding cost perspective, to borrow directly in U.S. dollars.

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.

4 Potential Explanations

Deviations from CIP are at odds with a frictionless financial market. In this section, we hypothesize that the persistent and systematic CIP deviations can be explained by a combination of two factors: (1) costly financial intermediation, which affects the supply of exchange rate forwards and swaps, and (2) global imbalances in safe assets, which affects the demand for exchange rate forwards and swaps. The absolute value of the basis measures the cost of hedging: naturally when this cost increases, supply increases and demand decreases.

In this section, we first discuss the effects of recent regulatory reforms on the cost of arbitrage and banks' market making activities. We then consider a stylized framework that features imbalances in savings supply and investment demand across currencies in the presence of costly financial intermediation. Finally, we derive some testable hypotheses, which will be tested in the rest of the paper.

4.1 Costly Financial Intermediation

Before the global financial crisis, global banks actively arbitraged funding costs 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 (i) risk-weighted capital requirements, (ii) non-risk weighted capital requirements, for example, the leverage ratio, and (iii) the restrictions on proprietary trading.

First, from the perspective of risk-weighted capital, global banks face significantly higher capital requirements since the global financial crisis. For example, the minimum common equity Tier 1 capital ratio against risk-weighted assets (RWA) increased from 2% in Basel II to 4.5% in Basel III (effective January 2014 in the United States). An additional 2.5% capital conservation buffer was also introduced in Basel III, which increased the required common equity Tier 1 capital ratio to 7%. The minimum total capital ratio increased from 8% to 10.5%. In addition to higher capital ratios against RWA, the estimation of RWA increased because of novel estimation procedures.

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) calibrated for the stress period. As Figure 5 shows, the cross-currency basis became significantly more volatile after the crisis, thus increasing the VaR on the CIP trade.

Table 5 illustrates the increase in capital charges against a five-year Libor CIP trade in recent years. For simplicity, we assume that only VaR and SVaR matter for RWA, while ignoring all other add-on risk charges. The first column reports the 99% VaR measure for

the trade based on the 10-business-day holding period; the VaR is annualized (multiplied by 26). The VaR measure was below 5% before the crisis, but increased to 20% during the peak of the crisis and remained elevated after the crisis. The second column reports the SVaR, implemented in January 2013 in the United States under Basel II.5, which equals the VaR in 2009.The third column reports the minimum total capital ratio for U.S. banks. Finally, the fourth column presents the total capital charges against the CIP trade. It is obtained by multiplying the sum of VaR and SVaR by the minimum capital ratio and scaling by a factor of 12.5 times 3, as specified by the Basel rules. Capital charges against the five-year CIP trade increase dramatically from less than 0.4% before the crisis to more than 4% of the trade notional after both Basel II.5 and Basel III went into effect. In other words, banks engaging in CIP arbitrages could trade a volume equal to 250 times their equity before the crisis; now, they can only trade a volume equal to 25 times their equity. While the RWA is likely to be very small for short-term CIP arbitrage, it appears as a significant concern for long-term CIP arbitrage.

Second, from the perspective of non-risk-weighted capital, the leverage ratio requires banks to hold a minimum amount of capital against all on-balance-sheet assets and off-balance-sheet exposure, regardless of their risk. Short-term CIP trades have very little market risk, but but still expand bank balance sheets and thus make the leverage ratio more binding. For foreign banks, the leverage ratio did not exist before the crisis; it is now equal to 3% under Basel III. 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. 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 hold 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 in the trade. In a nutshell, many of the arbitrage

opportunities that we document may not be attractive enough for banks: CIP arbitrage has become balance sheet-intensive post crisis. As a result, banks shy away from this activity.

Third, a host of other financial regulations have also reduced banks' willingness to engage in CIP arbitrage. For example, the Volcker Rule as 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.[9] In addition, the over-the-counter derivative reform set higher capital and minimum margin requirements for cross-currency swaps, which are generally uncleared, further increasing the capital on the CIP trade.

The regulatory reforms on banks also have spillover effects on 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 its client, hedge funds would need to lever up the arbitrage strategy ten or twenty times to make it attractive for their clients. When borrowing large amounts, their borrowing costs may increase significantly as these positions show up in their prime brokers' balance sheets, making their leverage ratios more binding.

4.2 Global Imbalances

Even thought costly financial intermediation is alone particularly useful in explaining the persistence of the basis post the crisis, it cannot explain cross-country variations in the basis. We now turn to the implications of costly financial intermediation in a world with global imbalances.

In particular, the global imbalance we focus on refers to an over demand for investment in high interest rate currencies, such as the Australian and New Zealand dollars, and an

[9] In practice, however, the distinction between arbitrage and market making may be difficult to draw. As an example of such difficulty, the final version of the Dodd-Frank rule on proprietary trading, entitled "Prohibitions and Restrictions on Proprietary Trading and Certain Interests In, and Relationships With, Hedge Funds and Private Equity Funds" contains 1089 pages.

over supply of saving in low interest rate currencies, such as the Japanese yen, the Swiss franc, and more recently, the euro. This imbalance can be driven by search for yield and carry trade motives. Consistent with this imbalance, countries with high nominal interest rates (Australia and New Zealand) exhibit negative net international investment positions and are importers of capital, whereas countries with low nominal interest rates (Japan and Switzerland) exhibit positive net international investment positions and are exporters of capital (Lane and Milesi-Ferretti, 2007).

Financial intermediaries, such as an foreign exchange swap maker, trade against this imbalance by swapping low interest rate funding into high interest rates, but do not want to bear the currency risk. To do so, the financial intermediaries can hedge the currency exposure in the cash market by going long in high interest rate currencies, and short in low interest rate currencies. The profit per unit of notional is equal to the absolute value of the cross-currency basis, which justifies for the cost of capital associated with the trade.

The combination of costly financial intermediation and global imbalances generate the following simple predictions.

Prediction #1: 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 interest rate, the higher the excess demand to swap foreign currency funding into the U.S. dollar funding. A capital-constrained arbitrageur charges higher excess returns for taking the opposite of the trade due to diminishing returns to investment, which corresponds to a more negative basis.

Prediction #2: The cross-currency basis is wider when the banks' balance sheet costs are higher.

In particular, we should expect quarter-end effects on the cross-currency basis as the cost of balance sheet is particularly high near quarter-end reporting dates.

Prediction #3: The cross-currency basis is correlated with other fixed income arbitrage bases.

This is because capital constraints faced by financial intermediaries are likely to affect other types of arbitrage as well beyond the currency markets.

With these hypotheses in mind, we turn now to additional empirical evidence on CIP deviations.

5 Characteristics of the Basis

In this section, we characterize the systematic nature of the basis and test the three predictions outlined in the previous section. First, we show that the basis increases with the level of interest rates in the cross-section and in the time-series. Second, in a simple difference-in-difference experiment, we show that the basis is particularly high at the end of the quarter since the crisis. Third, we show that the currency basis is highly correlated with other liquidity premia in fixed-income markets. Finally, we argue that that the IOER rate at the Fed, which is above the Fed Fund rate, provides a better measure for the cost of dollar funding for global depositary institutions after taking into bank balance sheet costs. The cross-currency basis based on the IOER differential across major central banks is often closer to zero than other short-term cross-currency bases.

5.1 Cross-Currency Basis and Nominal Interest Rates

CIP deviations appear linked to nominal interest rates in the cross-section and in the time-series.

5.1.1 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 basis or positive bases. The cross-sectional pattern holds across Libor, OIS, Treasuries, KfW and other multinational bonds. 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 low interest rate currencies. For multinational issuers, the cross-sectional pattern has a robust funding cost implication that on the currency-hedged basis, currencies with high nominal interest rates are cheaper funding currencies, and currencies with higher nominal interest rates are more expensive funding currencies.

Figure 10 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 first two panels show that 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 89 percent for G10 currencies. By contrast, the mean CDS spread of the interbank panel exhibits a correlation of -33 percent with the five-year Libor basis.

In addition, we examine the cross-sectional differentials in synthetic dollar borrowing costs for KfW. Since KfW bond yields are not observed for all currencies at all tenors on each trading date, we obtain the mean KfW basis by running a fixed-effect regression controlling for the trading date and tenor over the 2010–2015 sample:

$$\tilde{s}_{t,t+n}^{KfW,j} = \sum_{j \neq USD} \beta_j^{KfW} D_j + \alpha_{t,n}, \tag{18}$$

where $\tilde{s}_{t,t+n}^{KfW,j}$ denotes the synthetic dollar spread of a n-year KfW bond denominated in currency j over the U.S. Libor interest rate swap of the corresponding maturity, D_j is a dummy indicating currency j, and $\alpha_{t,j}$ is a tenor-date pair fixed effect. Since the U.S.

dollar-denominated bonds are the omitted category in the regression, (minus) the coefficient $-\beta_j^{KfW}$ on currency dummy D_j gives the mean KfW basis for currency j. As shown in the middle left panel of Figure 10, the KfW basis is strongly correlated with the nominal KfW bond yields. For KfW, all mean bases are negative, suggesting that the KfW is better off funding in U.S. dollars instead of any other G10 currencies. The Australian and New Zealand dollars are the cheapest funding currencies after the U.S. dollar, despite of their high nominal yields, and the Japanese yen and the Swiss franc are the most expensive funding currencies even though their nominal yields are among the lowest.

Moreover, the same relationship between basis and interest rates holds for other multi-currency issuers, as shown in the middle right panel of Figure 10: the multinational basis again increases with nominal yield differentials.[10] For both the KfW and multinational basis, the gap between the most expensive and the cheapest funding currency is about 30 to 40 basis points, which is smaller than the 100 basis point cost differentials between the Australian dollar and the Japanese yen based on Libor, but remains economically significant nevertheless. OIS rates and Treasury lead to similar results, as shown in the bottom two panels of Figure 10.

We find evidence that supranational organizations do take advantage of this funding cost arbitrage. Figure 11 plots the ratio of total issuance by KfW and supranational issuers over total issuance by other non-financial issuers during the sample 2010–2015 period against the mean Libor cross-currency basis. Data come from Dealogic. Relative to the universe of non-financial issuers, supranational issuers issue more in high-basis and high-interest-rate currencies, such as the Australian and New Zealand dollars, and issue less in low-basis and low-interest-rate currencies, such as the Swiss franc, the Danish Krone, and the Japanese yen.[11]

[10]The following issuers with diverse funding currency mix are included in the regression: the European Investment Bank, the World Bank, the four largest Australian banks (Commanwealth Bank, Westpac, Australia and New Zealand Banking Group and National Australia Bank), Citi, JP Morgan, Goldman Sachs and General Electric.

[11]Issuances in U.S. dollars and in euros are excluded from Figure 11 because some benchmark issues often need to be maintained even though it might be economically costly to do so.

5.1.2 Time Series of CIP Deviations and Interest Rates

Consistent with the cross-sectional pattern, the nominal interest rate differential between two currencies is also a significant driver of the cross-currency basis in the time series. We establish the time series relationship between the basis and the nominal interest rate by regression analysis and a high-frequency event study using a narrow window around monetary policy announcements by the ECB.

We first perform panel and time series regressions of weekly changes in the five-year Libor cross-currency basis on changes in the interest rate differential based on the five-year Libor interest rate swap rate, controlling for the changes in the CDS spreads across credit panels. The sample window runs from January 2007 to January 2016. Table 6 presents the regression results. Similar to the results reported in Table 2, the credit spread does not appear significantly in the pooled regression with currency fixed effects. In contrast, the interest rate differential between country i and the U.S. exhibits a significant slope coefficient equal to -0.03. At the individual currency level, the interest rate differential enters with a significantly positive coefficient for seven out of ten currencies. These regression results provide suggestive evidence on the time-series relationship between the cross-currency basis and the interest rate differential.

We then use an event-study approach to study the effect of unexpected shocks to the interest rate differential on the cross-currency basis during the narrow window around monetary policy announcements. Assuming that the monetary policy is exogenous to the basis — a reasonable assumption prior to our work, this event-study measures the causal impact of monetary policy on the cross-currency basis.

Our event study focuses on changes in the dollar/euro basis and changes in the yield differential between German Bunds and U.S. Treasuries around the European Central Bank (ECB)'s monthly releases of monetary policy decisions of the Governing Council and the following press conferences hosted by the ECB president since 2010. 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.[12] 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 ($\Delta y_i^{GE} - \Delta y_i^{US}$):

$$\Delta x_i = \alpha + \beta(\Delta y_i^{GE} - \Delta y_i^{US}) + \epsilon_i. \tag{19}$$

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 12 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 (19) 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. In summary, results from the high-frequency event study suggest that the nominal interest rate is an important time-series driver for variations in the basis. More accommodative-than-expected monetary policy by the ECB results in a more negative cross-currency-basis for the euro.

[12]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.

More generally, monetary policy has a potential role to correct the imbalance in investment demand and savings supply across currencies. Higher interest rates in Japan may lead to higher domestic investment by domestic households and firms, and lower borrowing in yen by carry traders. Similarly, lower interest rates in Australia may curtail carry traders with long positions in the Australian dollar and encourage borrowing by Australian household and firms. The CIP deviations would narrow as the monetary policy stances across central banks converge. The similar monetary stances between the U.S. and the U.K. help narrow the pound cross-currency basis. However, rather than a convergence in monetary policy, the uneven pace in economic recovery causes monetary policy to diverge significantly in recent years. As the U.S. starts a monetary policy normalization, the cross-currency basis become larger in magnitude in countries with very accommodative policies.

We turn now to evidence suggesting that financial intermediaries matter for the level of the currency basis.

5.2 Quarter-End Dynamics

Financial intermediaries typically face greater balance sheet constraints at the end of the quarter ahead of quarterly regulatory filings, as key balance sheet variables, risk metrics, and leverage ratios are reported at the quarterly frequency and scrutinized by regulators and investors. Increased banking regulation since the recent crisis allegedly makes quarter-end balance sheet constraints more prevalent than before. We test whether CIP deviations are more pronounced at the end of the quarters vs. any other point in time, especially so since the global financial crisis. Our simple difference-in-difference test takes the following form:

$$|x_{it}| = \alpha_i + \beta QEND_t + \gamma POST_t + \delta QEND_t \times POST_t + \epsilon_{it}, \tag{20}$$

where $|x_{it}|$ is the absolute value of the basis for currency i at time t, α_i is a currency fixed effect, $QEND_t$ is an indicator variable indicating if t is within the last calendar week of

the corresponding quarter, and $POST_t$ is an indicator variable equal to one after January 1, 2007. The regression is estimated on the 1/1/2000–12/31/2014 sample on one-week and one-month Libor, OIS and repo bases. The coefficient δ is of main interest as it captures the change in the quarter-end effect in the 2007–2014 sample compared to the quarter-end effect in the 2000–2006 pre-crisis sample.

Table 7 reports the regression results. The slope coefficients δ are positive and statistically significant across different instruments at the one-week and one-month horizons. The quarter-end CIP deviation relative to the mean deviation in the rest of the quarter is on average 5 to 10 basis points higher in the post-2007 sample than over the pre-2007 sample. The slope coefficients β on $QEND_t$ are largely insignificant; there is no quarter-end effect pre-2007. In line with our previous findings, the slope coefficients γ on $POST_t$ are statistically significant: CIP deviations are much larger post- than pre-crisis. These regression results are consistent with tightened balance sheet constraints at quarter ends that translates into wider CIP deviations in the post-crisis period.

5.3 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. We review these four spreads rapidly.

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, obtained from Bloomberg. The five-year KfW bond yield is estimated by the Nelson-Siegel methodology on individual KfW bond prices also obtained from Bloomberg. Since the KfW bonds are fully guaranteed by the German government, the KfW-German Bund spread should not contain any credit risk component. As previously noted, Schwartz (2015) uses that spread to measure the liquidity premium.

The 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 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.

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.

Figure 13 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 2005–2015 and the 2010–2015 samples. Table 8 reports the monthly regression results. 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.

5.4 CIP Arbitrage Based on Excess Reserves at Central Banks

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, currently including $2.4 trillion at the Fed and $0.5 trillion at the ECB. Excess reserves are remunerated at an interest rate set by the central bank, which is referred to as the interest rate on excess reserves (IOER).

One interesting feature of the IOER at the Fed is that it is often above interest rates paid on private money market instruments, for example, the Fed Fund rate. The main reason that the Fed fund rate stays persistently below the IOER in the United States is that government-sponsored enterprises (GSEs), such as Federal Home Loan Banks, do not have access to the IOER deposit facility and are willing to lend at rates below the IOER in the Fed Fund market. This creates the well-known IOER-Fed Fund arbitrage for depositary institutions with access to the IOER deposit facility, in which 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 Fund spread. The trade is risk-less as central bank cash is risk-free and dominates private money market instruments in terms of liquidity and fungibility.

Figure 15 shows the one-week IOER, OIS and Libor 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 rate starting in 2011. If borrowing funds at the Fed fund or Libor rate did not carry additional costs, banks would amass even more reserves at the Fed in order to profit from this arbitrage opportunity. The spread earned on the IOER-OIS (Libor)

arbitrage thus gives us a concrete a measure for the cost of balance sheets for depositary institutions that engage in arbitrage opportunities. The leverage ratio is likely to be the most important factor for the cost of balance sheets on this trade due to its risk-free nature. For U.S. banks, the Federal Deposit Insurance Corporation (FDIC) widened the assessment base for deposit insurance fees in 2011 to include wholesale funding. As a result, in addition to making the leverage ratio more binding, the cost of the IOER-OIS/Libor arbitrage trade for U.S. banks also includes additional deposit insurance fees paid on wholesale funding.

Instead of using the Libor and OIS rates as the direct U.S. dollar funding costs when computing the cross-currency basis, we turn to the IOER as a proxy for the U.S. dollar "funding" cost after taking into account balance sheet constraints and regulatory costs for wholesale funding. Table 9 shows the results for the 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. Therefore, the gap between the IOER and OIS/Libor in the U.S. can explain about one-third to one-half of the one-week CIP deviations. Summary statistics for the IOER basis based on "funding" in USD IOER and investing in foreign IOER are reported in the last column. The average IOER basis is -6 basis points, much closer to zero than the Libor and OIS basis at -22 basis points. Figure 15 plots the IOER basis, together with the Libor basis and the modified Libor basis by "funding" in 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. As a result, the banks' balance sheet and regulation costs, as proxied by the IOER-Libor spread, appear as a key determinant of the CIP deviations.

6 Conclusion

In this paper, we show that the CIP condition has failed persistently since the global financial crisis for a constellation of interest rates including Libor, OIS, repo, Treasuries, bond yields of KfW and other risky issuers. The cross-currency basis measures CIP deviations. We find that the basis is highly correlated with nominal interest rate levels in the cross-section and in the time series; it increases at quarter ends post-crisis; and it is correlated with several other fixed-income arbitrage strategies. These findings are at odds with a frictionless financial market, but can be rationalized by the interaction between costly financial intermediation and global imbalances in funding supply and investment demand across currencies.

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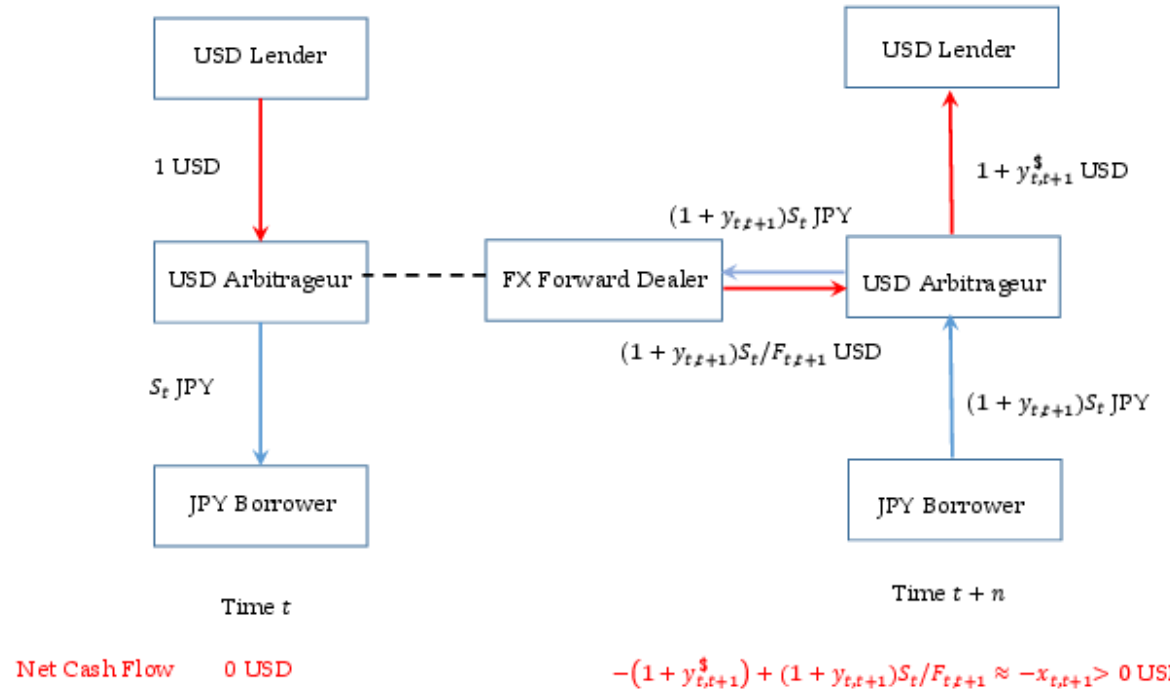


Figure 1: **Cash Flow Diagram for CIP Arbitrage with a Negative Basis** ($x_{t,t+1} < 0$): This figure plots the cash flow exchanges of an arbitrageur profiting from a negative cross-currency basis between the Yen and the U.S. dollar. To arbitrage the negative cross-currency basis, the USD arbitrageur borrows 1 U.S. dollar at the interest rate $y^{\$}_{t,t+n}$, convert it into S_t yen, lends in yen at the interest rate $y_{t,t+n}$, and finally signs a forward contract at date t. There is no cash flow at date t. At date $t + n$, the arbitrageur receives $(1 + y_{t,t+n})^n S_t$ yen, and convert that into $(1 + y_{t,t+n})^n S_t/F_{t,t+n}$ 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 JPY and short in USD, with the JPY cash flow fully hedged by a forward contract.

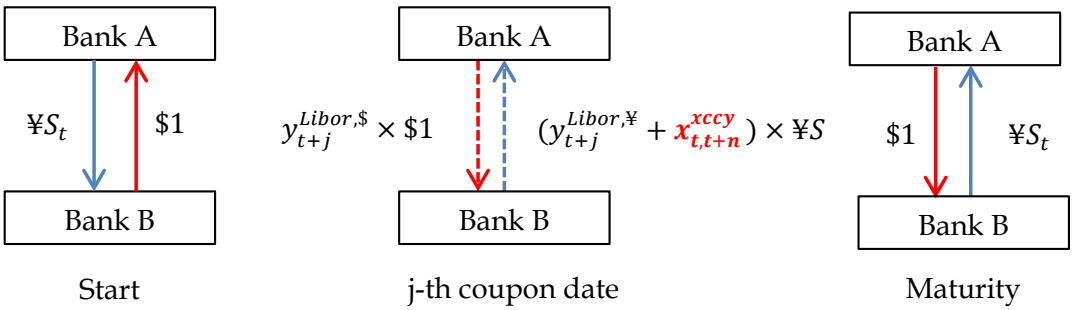


Figure 2: **Cash Flow Diagram for JPY/USD Cross-Currency Basis Swap**: This figure shows the cash flow exchanges of a standard yen/dollar cross-currency basis swap. At the inception of the swap, Bank A receives \$1 from Bank B in exchange of ¥S_t. At the j-th coupon date, Bank A pays a dollar floating 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.

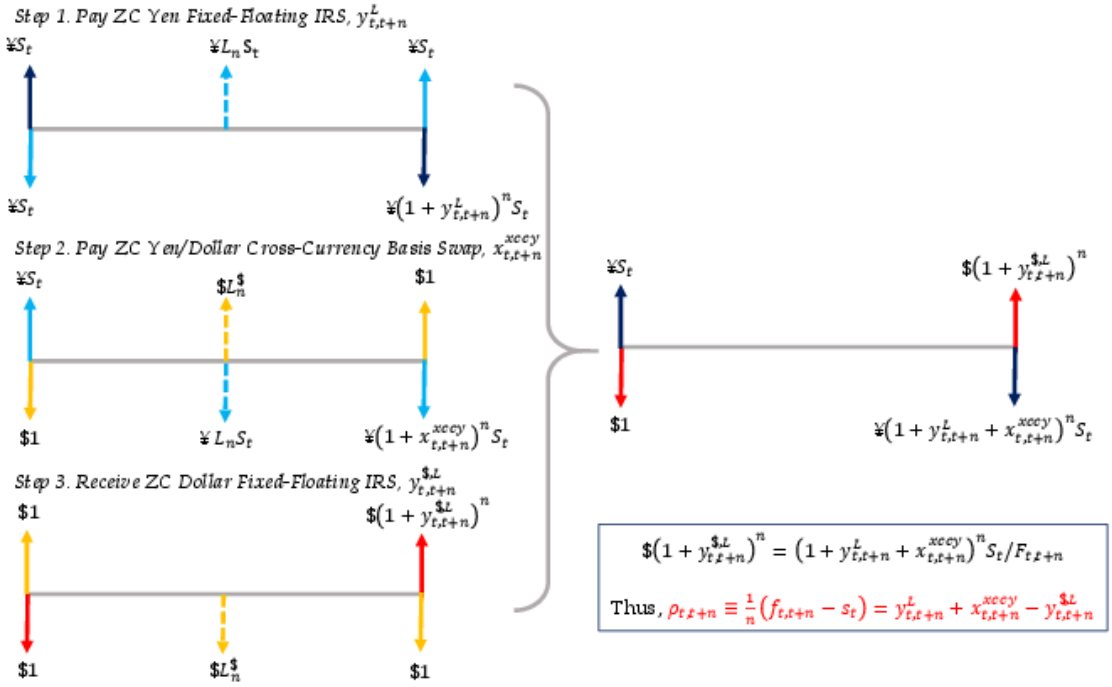


Figure 3: **Cash Flow Diagram for Long-Term Forward Premium**: This figure shows that the long-term forward premium is equal to the zero fixed-for-fixed cross-currency swap rate. The zero-coupon fixed-for-fixed cross-currency swap can be constructed using the following three steps: (1) paying a zero-coupon foreign currency fixed for floating interest rate swap indexed to the foreign currency Libor; (2) paying a zero-coupon foreign currency-Libor for USD-Libor cross-currency basis swap; and (3) receiving a USD fixed for floating interest rate swap. By summing up cash flows of the three steps, all floating cash flows are canceled and we are left exchanges of fixed cash flows at the inception and maturity of the swap in two currencies.

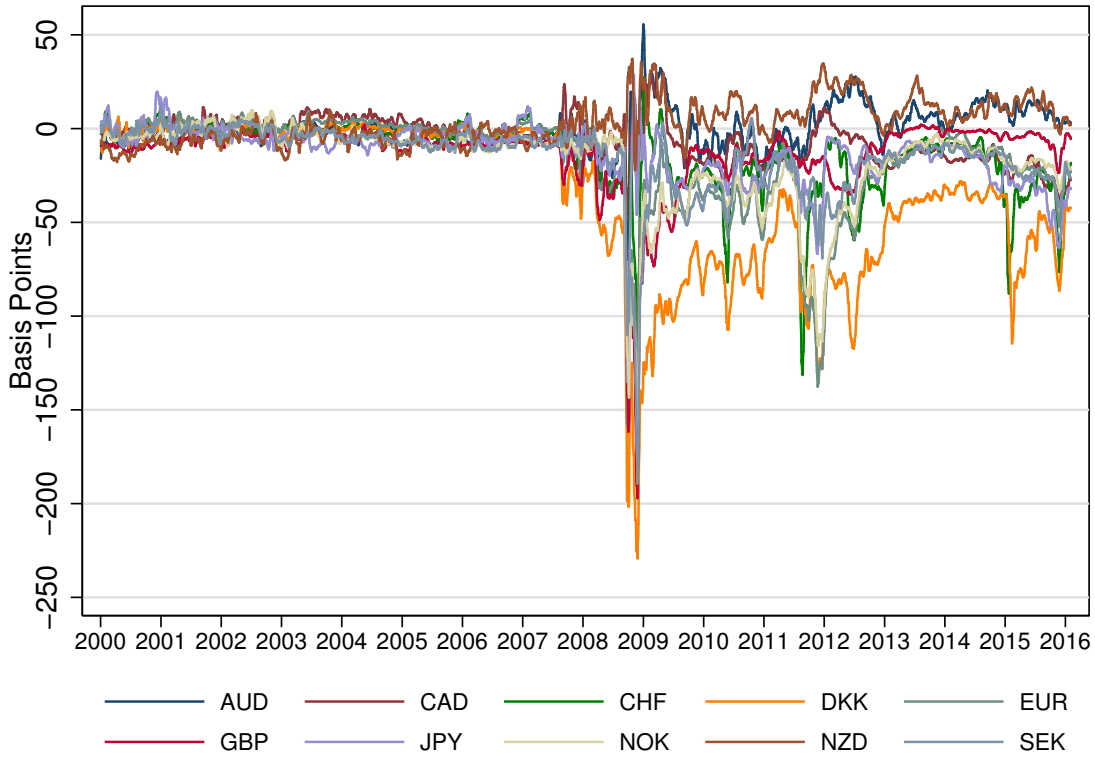


Figure 4: **Short-Term Libor-Based Deviations from Covered Interest Rate Parity:** This figure plots the 10-day moving averages of the three-month Libor cross-currency basis, measured in basis points, for G10 currencies. The covered interest rate parity implies that the basis should be zero. One-hundred basis points equal one percent. The Libor basis is equal to $y_{t,t+n}^{\$,Libor} - (y_{t,t+n}^{Libor} - \rho_{t,t+n})$, where n = three months, $y_{t,t+n}^{\$,Libor}$ and $y_{t,t+n}^{Libor}$ 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 sample starts in 1/1/2000 and ends in 12/31/2015.

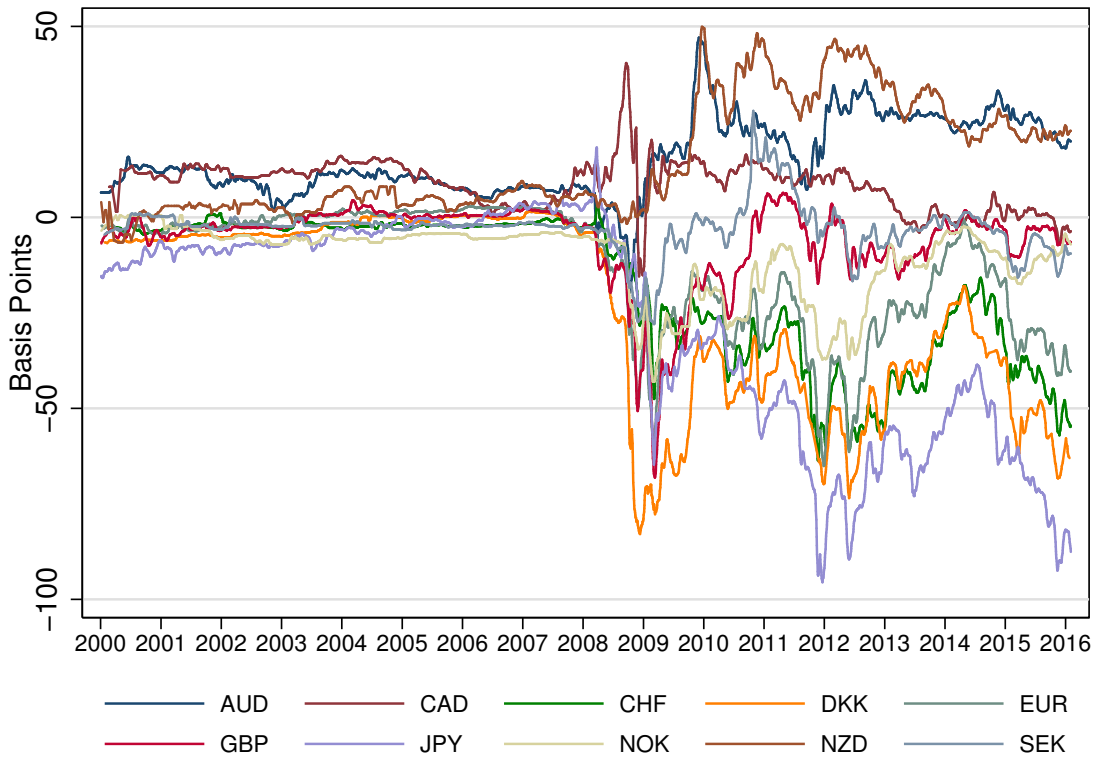


Figure 5: **Long-Term Libor-Based Deviations from Covered Interest Rate Parity**: This figure plots the 10-day moving averages of the five-year Libor cross-currency basis, measured in basis points, for G10 currencies. The covered interest rate parity implies that the basis should be zero. One-hundred basis points equal one percent. The sample starts in 1/1/2000 and ends in 12/31/2015.

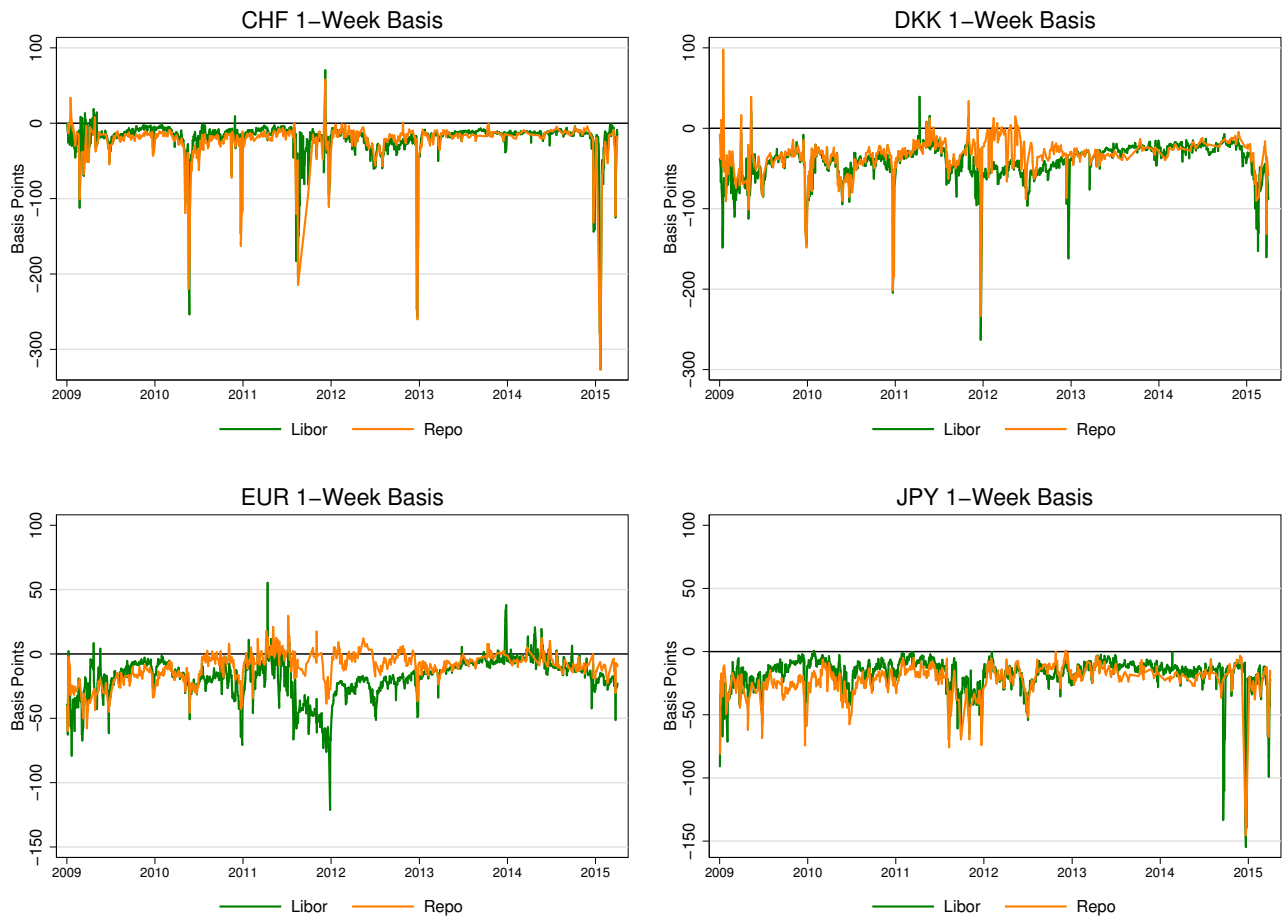


Figure 6: **One-week Repo- and Libor-based CIP Deviations**: The green line plots the one-week Libor cross-currency basis and the orange line plots the one-week repo cross-currency basis for the Swiss Franc (CHF), the Danish Krone (DKK), the euro (EUR) and the yen (JPY). The sample starts in 1/1/2009 and ends in 12/31/2015.



Figure 7: **KfW Cross-Currency Basis: The red line plots the KfW cross-currency basis**: The orange line plots the difference in z-spreads over interest rate swap rates of the respective currency between U.S. dollar and foreign currency denominated KfW bonds. The z-spreads are defined as the difference between the bond yield and the Libor interest rate swap rate of the same currency. The KfW basis is the sum of z-spread differentials and Libor cross-currency basis: $x_{t,t+n}^{KfW} = \left(zsp_{t,t+n}^{\$,KfW} - zsp_{t,t+n}^{j,KfW}\right) + x_{t,t+n}^{xccy,j}$. The green line plots the Libor cross-currency basis. All U.S. dollar and foreign currency KfW bonds are matched by their maturity in years. The sample period is 1/1/2009–12/31/2015.

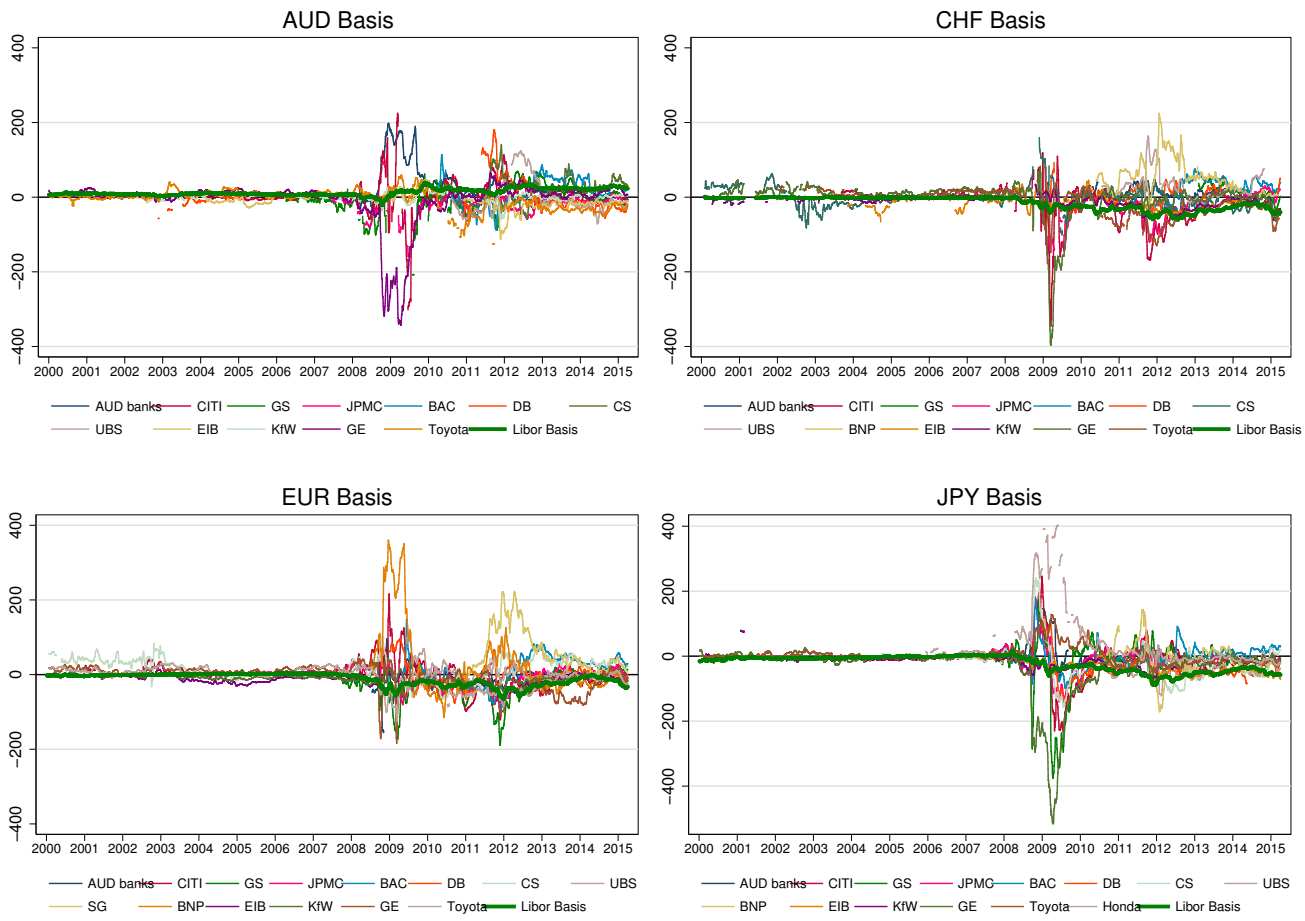


Figure 8: **Issuer-Specific Cross-Currency Bases for Multi-currency Issuers**: The figure shows issuer-specific cross-currency bases, together with the Libor cross-currency basis. All bonds for the same issuer are matched by the maturity year and seniority.

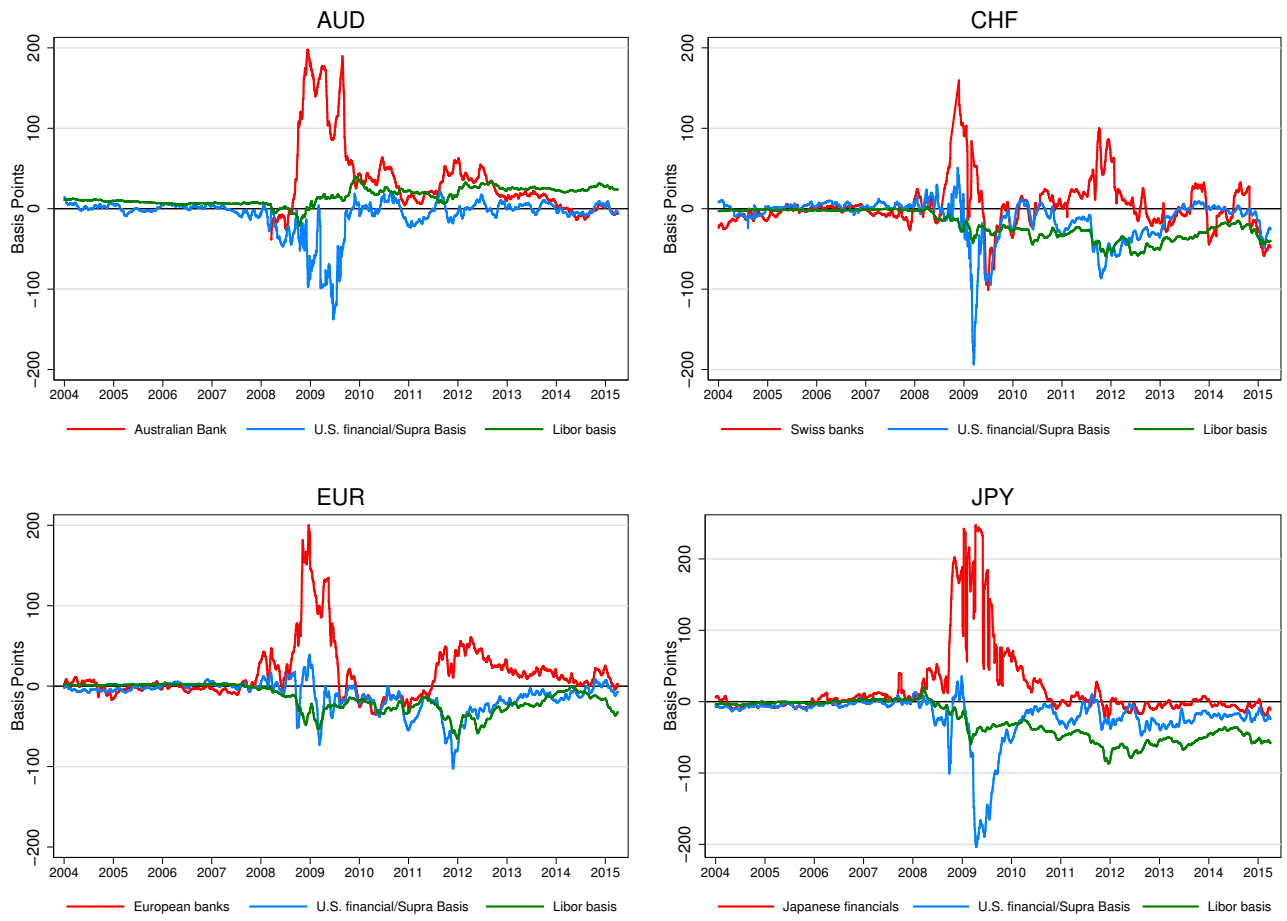


Figure 9: **Average Issuer-Specific Basis by Issuer Type**: The figure shows the average issuer-specific cross-currency bases by issuer types, together with the Libor cross-currency basis. All bonds for the same issuer are matched by the maturity year and seniority. "Australia Banks" include Australia and New Zealand Banking Group, Commonwealth Bank of Australia, National Australia Bank, and Westpac Banking Corporation; "Swiss Banks" include Credit Suisse and UBS; "European Banks" include Barclays, Deutsche Bank, BNP Parisbas, Societe Generale, Credit Suisse and UBS; "Japanese Financials" include Bank of Tokyo, Honda and Toyota; "U.S. financials/Supranationals" include Citi, Goldman Sachs, JP Morgan, General Eletric, KfW and EIB.

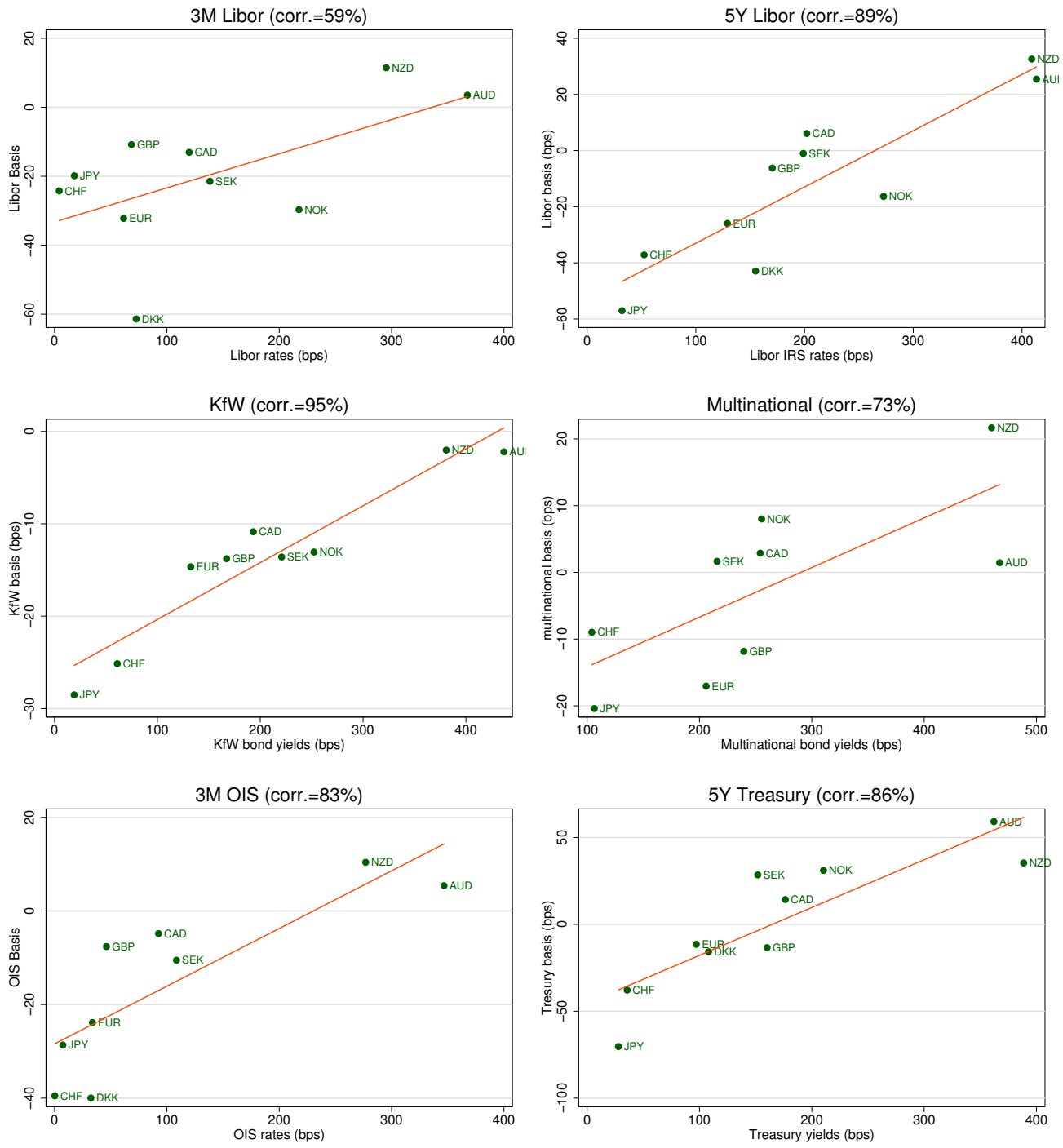


Figure 10: **Cross-Sectional Variations in Currency Basis (2010-2015)**: This figure shows the cross-currency relationship between various cross-currency bases on the y-axis and nominal interest rates on the x-axis. The top two panels plot the relationship for Libor at 3-month and 5-year. The middle two panels plot the relationship for KfW and average multinational issuers. The bottom two panels plot the relationship for 3-month OIS rates and 5-year Treasuries. The correlation between cross-currency bases and nominal interest rates for each interest rate instrument are indicated in the title of each panel.

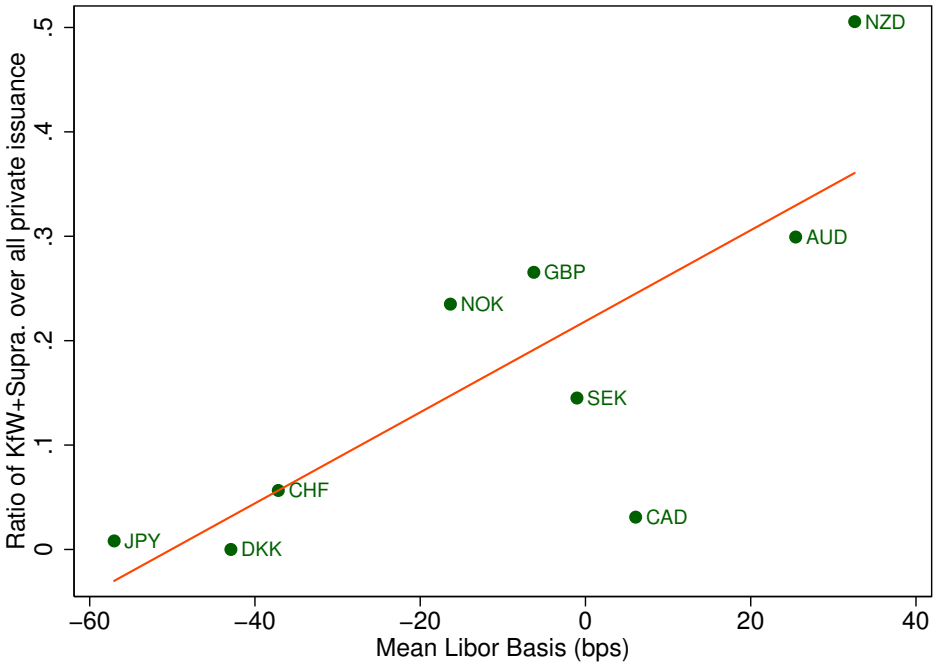


Figure 11: **SSA Relative Issuance and the Libor Cross-Currency Basis**: On the vertical axis, we plot the ratio of total issuance by KfW and suprantional issuers over the total issuance by all non-financial firms across currencies. On the horizontal, we plot the mean Libor cross-currency basis. The issuance data are from Dealogic and the sample period is 2010-2015.

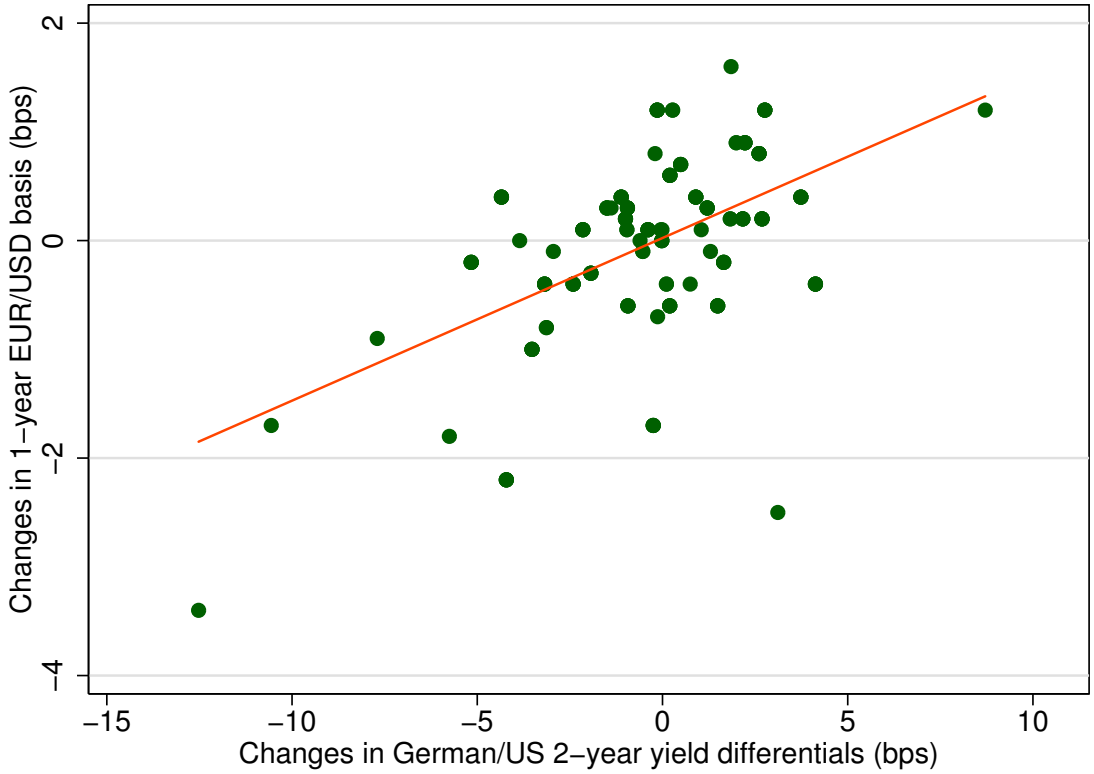


Figure 12: **Monetary Policy Shocks and Deviations from CIP**: This figure plots intraday changes in the two-year German bund and U.S. Treasury yield differential around the ECB monetary policy announcements on the horizontal axis and intraday changes in the one-year euro/dollar cross-currency basis 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.

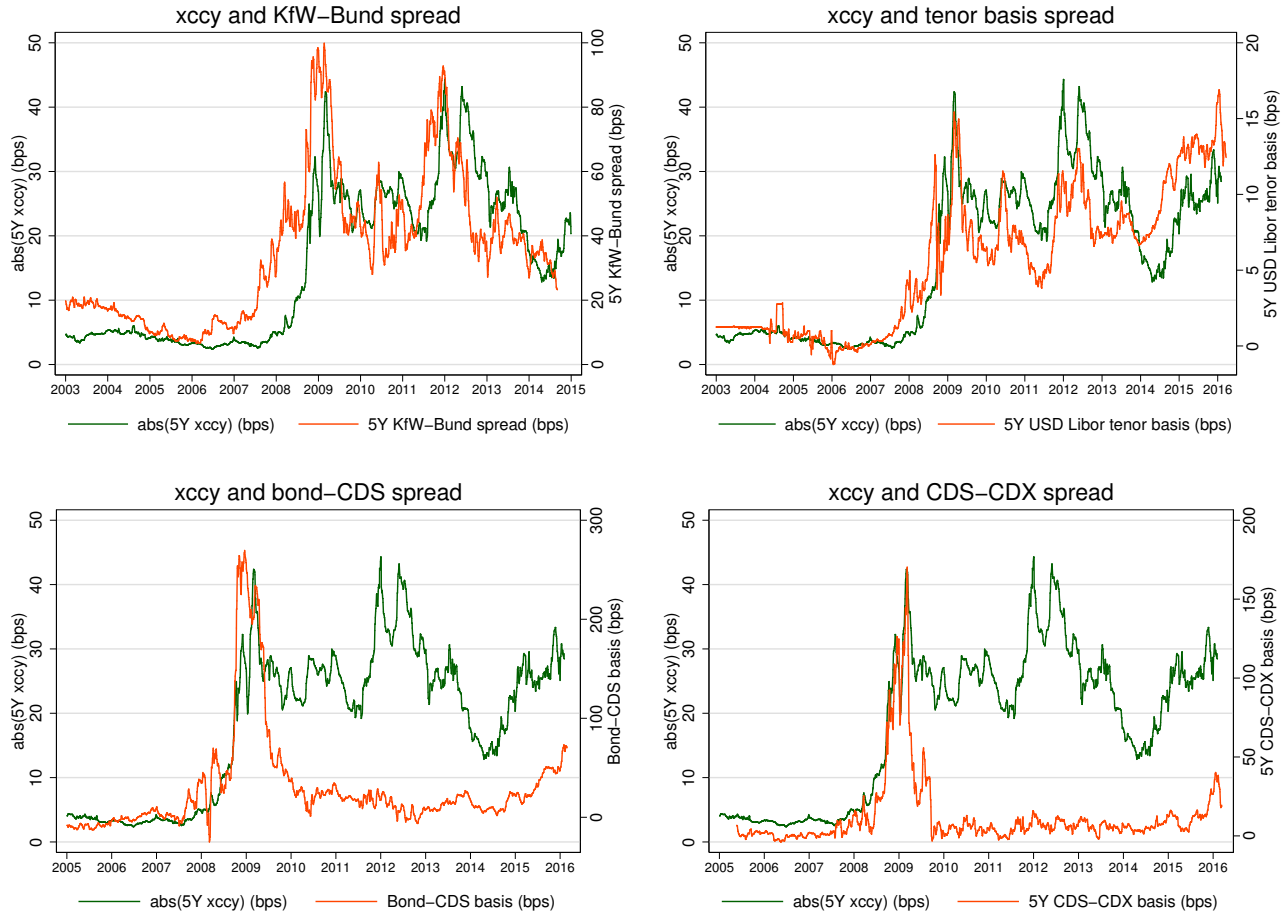


Figure 13: **The Cross-Currency Basis and Other Near-Riskfree Arbitrages** Each panel compares the time-series of the average currency basis to the time-series of other fixed-income spreads. The average currency basis corresponds to the average of the absolute value of the five-year Libor cross-currency 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.



Figure 14: **IOER, OIS and Libor rates for the U.S. Dollar**: This figure the one-week interest on excess reserves (IOER), overnight interest swap (OIS), and Libor rates for the U.S. dollar from 1/1/2009 to 1/31/2016.

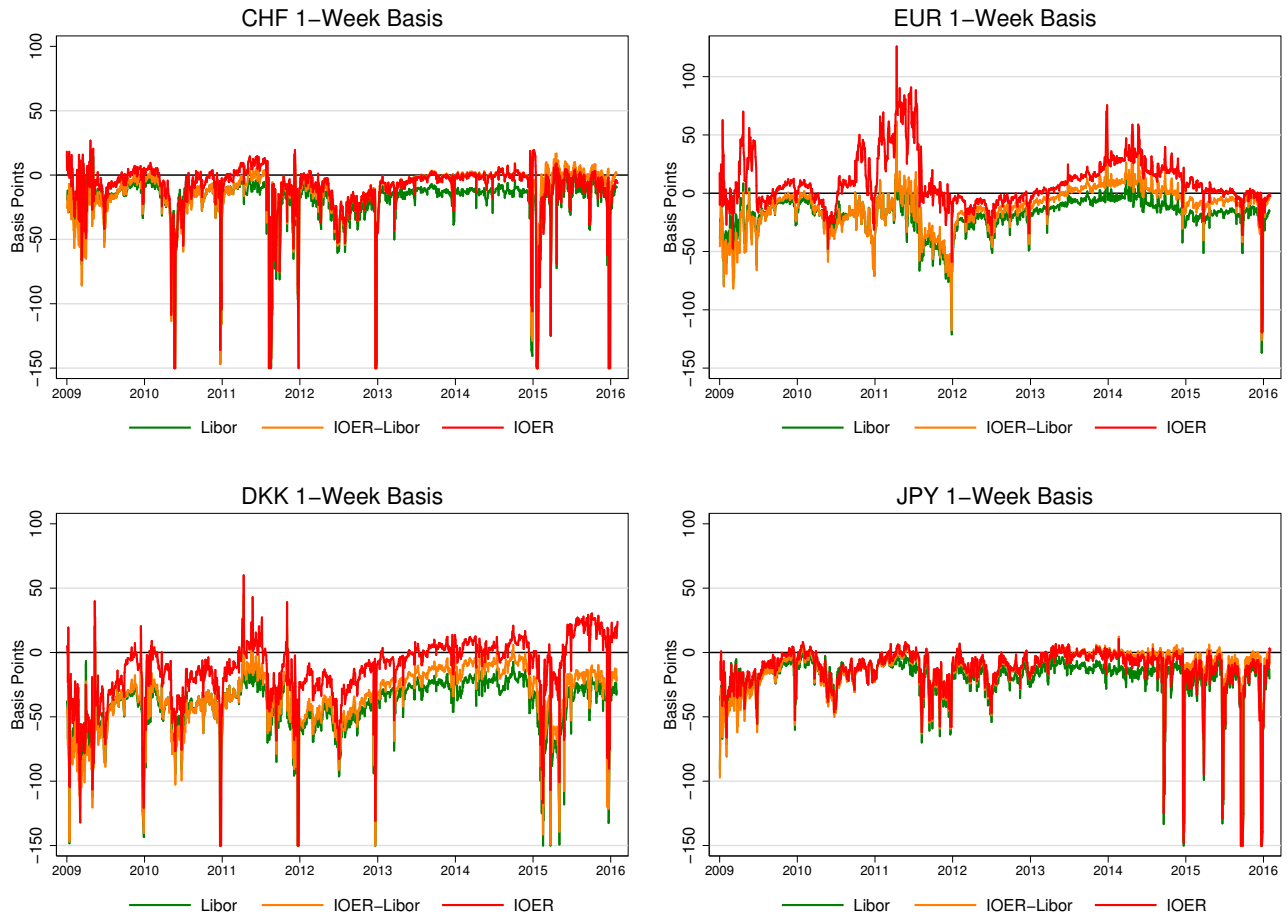


Figure 15: **CIP Deviations using Interest on Excess Reserves:** This figure plots the one-week cross-currency basis for the Swiss franc (CHF), the euro (EUR), the Danish Krone (DKK), and the Japanese yen (JPY). The green line, denoted "Libor," refers to the conventional Libor cross-currency basis. The orange line, denoted "IOER-Libor," refers to the basis obtained by borrowing at the U.S. IOER rate and investing in foreign currency at the Libor rate, while hedging the currency risk. The red line, denoted "IOER," refers to the basis obtained by borrowing at the U.S. IOER rate and investing in foreign currency at the IOER rate, while hedging the currency risk.

Table 1: Summary Statistics for Libor-based Covered Interest Parity Deviations

		Panel A: 3-month			Panel B: 5-year		
Currency	Benchmark	2000-06	2007-09	2010-15	2000-06	2007-09	2010-15
AUD	BBSW	-3.7	-2.7	3.5	9.5	9.3	25.4
		(4.8)	(21.2)	(11.7)	(2.8)	(11.8)	(5.8)
CAD	CDOR	1.7	-3.8	-13.1	10.7	10.8	6.3
		(5.2)	(16.6)	(7.9)	(3.7)	(9.5)	(5.5)
CHF	Libor	-0.4	-18.0	-24.2	-2.2	-12.8	-37.0
		(4.5)	(28.4)	(20.9)	(0.9)	(12.8)	(11.6)
DKK	Cibor	-1.0	-62.7	-61.4	-2.6	-30.2	-42.2
		(4.6)	(54.4)	(25.5)	(2.4)	(30.1)	(11.9)
EUR	Euribor	1.8	-27.8	-32.2	0.0	-15.0	-25.7
		(3.9)	(32.4)	(28.0)	(2.0)	(16.2)	(13.4)
GBP	Libor	-6.7	-35.3	-10.8	-0.9	-17.1	-6.3
		(3.8)	(38.1)	(9.9)	(2.3)	(18.1)	(7.0)
JPY	Libor	-3.7	-15.6	-19.9	-5.3	-13.5	-56.4
		(7.0)	(23.9)	(11.3)	(4.2)	(20.1)	(14.6)
NOK	Nibor	-4.1	-29.1	-29.7	-4.7	-14.8	-16.5
		(6.5)	(33.6)	(23.8)	(1.9)	(12.3)	(9.6)
NZD	BKBM	-5.3	4.5	11.5	3.7	7.9	33.1
		(6.8)	(15.1)	(9.0)	(2.9)	(8.7)	(7.8)
SEK	Stibor	-3.8	-26.5	-21.4	-1.8	-7.2	-0.5
		(5.7)	(33.6)	(12.9)	(1.0)	(7.9)	(8.1)
Average		-2.5	-21.7	-19.7	0.6	-8.2	-11.6
		(6.0)	(36.6)	(26.0)	(6.0)	(20.5)	(29.4)

Notes: 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 1/1/2010–12/31/2015. Standard deviations are shown in the parentheses. Panel A focuses on the three-month currency basis, while Panel B focuses on the five-year currency basis. The three-month Libor basis is equal to: $y_{t,t+n}^{\$,Libor} - (y_{t,t+n}^{Libor} - \rho_{t,t+n})$, where $y_{t,t+n}^{\$,Libor}$ and $y_{t,t+n}^{Libor}$ 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: Australia (AUD), Canada (CAD), Switzerland (CHF), Denmark (DKK), euro area (EUR), U.K. (GBP), Japan (JPY), Norway (NOK), New Zealand (NZD) and Sweden (SEK). For each currency, the table reports the precise benchmark interest rates used to compute the basis.

Table 2: Credit Spread Differentials and Libor-based Covered Interest Parity Deviations

	Pooled	AUD	CAD	CHF	DKK	EUR
$\Delta(cds^i - cds^{USD})$	-0.00465	-0.0251	-0.00809	-0.190***	0.00944	-0.0639*
	(0.0110)	(0.0425)	(0.0357)	(0.0581)	(0.0310)	(0.0340)
Observations	4,527	473	318	471	429	473
R-squared	0.000	0.005	0.000	0.016	0.000	0.022
		GBP	JPY	NOK	NZD	SEK
$\Delta(cds^i - cds^{USD})$		-0.0244	0.143	0.00638	0.0344**	0.0250**
		(0.112)	(0.0914)	(0.0115)	(0.0145)	(0.0127)
Observations		473	473	473	473	471
R-squared		0.000	0.008	0.001	0.017	0.009

Notes: This table shows the regression results of weekly changes in the five-year Libor cross-currency basis of currency i on monthly changes in mean five-year CDS spreads differential between the interbank panel of currency i and U.S. dollar Libor panel. The sample period is January 2007 to January 2016. Newey-West standard errors with 13-week lag are shown in the parentheses, and one, two, and three stars denote significance levels at 10, 5, and 1 percent confidence levels.

Table 3: One-week Libor- and Repo-based Basis and Repo CIP Arbitrage

		Libor Basis Full Sample	Repo Basis Full Sample	Repo Basis Conditional neg.	Repo Arbitrage Profits
CHF	Mean	-20.2	-23.0	-23.4	14.1
	S.D.	(26.1)	(27.3)	(27.1)	(22.7)
	Count	655	655	648	556
	% sample			99%	85%
DKK	Mean	-43.4	-33.5	-35.3	18.7
	S.D.	(24.3)	(24.8)	(23.2)	(23.2)
	Count	655	655	630	437
	% sample			96%	67%
EUR	Mean	-19.1	-10.0	-12.8	9.1
	S.D.	(14.2)	(11.4)	(10.0)	(7.7)
	Count	693	693	584	396
	% sample			84%	57%
JPY	Mean	-16.9	-22.4	-22.4	14.4
	S.D.	(12.6)	(12.8)	(12.7)	(10.5)
	Count	686	686	685	651
	% sample			100%	95%

Notes: The first two columns report the annualized mean, annualized standard deviation, and the number of observations for one-week Libor and GC repo basis by currency during the 1/1/2009–12/31/2015 period. The next column reports the same summary statistics conditional on observing a negative repo basis. For each currency, the last row of the panel reports the percentage of observations with a negative basis. The last column reports the arbitrage profits for the negative basis repo arbitrage provided that the arbitrage profits are positive after taking into account the transaction costs on the forward and spot exchange rates. Transaction costs are taken into accounts for the U.S. and Danish krone repo rates, but not for the Swiss franc, euro, and yen repo rates.

Table 4: KfW Basis and KfW CIP Arbitrage

		Basis full sample	Basis conditional	Pos. Profits ex. shorting fee	Pos. Profits 25 pct fee	Pos. Profits median fee
AUD	Mean	0.8	8.7	5.8	6.5	6.2
	S.D.	(13.5)	(7.2)	(4.8)	(4.1)	(4.1)
	Count	1610	943	245	120	61
	% sample		59%	15%	7%	4%
CHF	Mean	-21.4	-23.4	15.6	12.1	11.5
	S.D.	(17.1)	(15.4)	(11.7)	(10.2)	(10.3)
	Count	1596	1496	1082	723	518
	% sample		94%	68%	45%	32%
EUR	Mean	-15.2	-16.5	10.3	7.1	6.4
	S.D.	(10.0)	(8.7)	(6.8)	(5.5)	(5.0)
	Count	1624	1527	1253	710	503
	% sample		94%	77%	44%	31%
JPY	Mean	-35.1	-35.1	24.8	19.6	18.2
	S.D.	(14.1)	(14.1)	(12.9)	(11.6)	(11.0)
	Count	927	927	889	814	720
	% sample		100%	96%	88%	78%

Notes: The first column reports the annualized mean, annualized standard deviation, and number of observations for the KfW basis by currency during the 1/1/2009–12/31/2015 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.

Table 5: An Illustration of U.S. Banks Capital Charges Against a Five-year Libor CIP Trade

Year	VaR	SVaR	Capital Ratio	Capital Charge (% of notional)
2000	4.87%		8%	0.56%
2001	3.34%		8%	0.39%
2002	3.65%		8%	0.42%
2003	3.64%		8%	0.42%
2004	3.12%		8%	0.36%
2005	2.07%		8%	0.24%
2006	1.92%		8%	0.22%
2007	3.26%		8%	0.38%
2008	19.21%		8%	2.22%
2009	20.28%		8%	2.34%
2010	12.03%		8%	1.39%
2011	12.78%		8%	1.47%
2012	14.39%		8%	1.66%
2013	8.94%	20.28%	8%	3.37%
2014	6.43%	20.28%	10.50%	4.05%
2015	9.20%	20.28%	10.50%	4.46%

Notes: This table illustrates the capital charges against a five-year Libor CIP trade. The first column reports the 99% Value-at-Risk (VaR) measure for the trade by year. The VaR are obtained using 10-day rolling windows and annualized (multiplied by 26). The second column reports the 99% Stress Value-at-Risk (SVaR), which is equal to the VaR in 2009. The third column reports the minimum total capital ratio over time. The fourth column computes the capital charges as (VaR+SVaR)/26 $\times$ 12.5 $\times$ 3 $\times$ capital ratio.

Table 6: Credit Spread Differentials and Libor-based Covered Interest Parity Deviations

	Pooled	AUD	CAD	CHF	DKK	EUR
$\Delta(r^i - r^{USD})$	0.0314***	0.0524**	-0.00843	0.0589***	0.0970**	0.0658**
	(0.00756)	(0.0242)	(0.0308)	(0.0209)	(0.0393)	(0.0266)
$\Delta(cds^i - cds^{USD})$	-0.00156	-0.0115	-0.00762	-0.227***	0.0302	-0.0644*
	(0.0109)	(0.0377)	(0.0342)	(0.0644)	(0.0360)	(0.0330)
Observations	4,527	473	318	471	429	473
R-squared	0.000	0.005	0.000	0.016	0.000	0.022
		GBP	JPY	NOK	NZD	SEK
$\Delta(r^i - r^{USD})$		0.0609**	-0.0423*	0.0290***	0.00532	0.0473***
		(0.0290)	(0.0243)	(0.00729)	(0.00607)	(0.0129)
$\Delta(cds^i - cds^{USD})$		-0.0430	0.104	0.0103	0.0346**	0.0332***
		(0.100)	(0.0904)	(0.0110)	(0.0144)	(0.0118)
Observations		473	473	473	473	471
R-squared		0.000	0.008	0.001	0.017	0.009

Notes: This table shows the regression results of weekly changes in the five-year Libor cross-currency basis of currency i on monthly changes in mean five-year CDS spreads differential between the interbank panel of currency i and U.S. dollar Libor panel. The sample period is January 2007 to January 2016. Newey-West standard errors with 13-week lag are shown in the parentheses, and one, two, and three stars denote significance levels at 10, 5, and 1 percent confidence levels.

Table 7: Quarter-End Effects, Pre-2007 vs Post-2007

	1w Libor	1w OIS	1w Repo	1m Libor	1m OIS	1m Repo
$QEND_t \times POST_t$	0.0778***	0.107***	0.0914**	0.0404***	0.0580***	0.0705**
	(0.0129)	(0.0324)	(0.0396)	(0.00973)	(0.0183)	(0.0360)
$QEND_t$	0.00743	0.0209	0.0476*	-0.00256	-0.00696	0.00270
	(0.00996)	(0.0293)	(0.0272)	(0.00733)	(0.0151)	(0.0257)
$POST_t$	0.113***	0.184***	0.216***	0.145***	0.152***	0.251***
	(0.00993)	(0.0275)	(0.0226)	(0.00981)	(0.0192)	(0.0240)
Observations	30,843	21,210	9,655	40,005	30,320	9,047
R-squared	0.137	0.070	0.084	0.167	0.106	0.140

Notes: This table reports regression results of the absolute value of the daily one-week and one-month Libor, OIS and GC repo bases in percentage points on different dummies:

$$|x_{it}| = \alpha_i + \beta QEND_t + \gamma POST_t + \delta QEND_t \times POST_t + \epsilon_{it},$$

where $QEND_t = 1$ if t is within the last calendar week of the corresponding quarter (otherwise, $QEND_t = 0$), and $POST_t = 1$ if t is on or after January 1, 2007 (and $POST_t = 0$ if t is before January 1, 2007). 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 1/1/2000–12/31/2015.

Table 8: Currency Basis and Other Fixed-Income Near-Arbitrages

	Panel A: 2005-2015				Panel B: 2010-2015			
ΔKfW-Bund	0.189***				0.183***			
	(0.0342)				(0.0424)			
ΔLibor Tenor Basis		0.836***				1.130***		
		(0.199)				(0.266)		
ΔCDS-CDX			0.155***				0.0880	
			(0.0204)				(0.100)	
ΔBond-CDS				0.0413***				0.0622
				(0.0134)				(0.0515)
Constant	0.0989	0.101	0.157	0.158	-0.0599	-0.0737	-0.00190	0.00848
	(0.212)	(0.192)	(0.197)	(0.206)	(0.321)	(0.229)	(0.294)	(0.299)
Observations	117	134	129	133	57	74	74	74
R-squared	0.215	0.122	0.318	0.074	0.262	0.214	0.013	0.020

Notes: This table reports the regression results of monthly changes in average currency basis on the changes in other fixed-income spreads. The average currency basis is obtained as the average of the absolute value of the five-year Libor cross-currency bases of G10 currencies. 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. The first four columns focus on the 1/1/2005–12/31/2015 sample and the last four columns on the 1/1/2010–12/31/2015 sample. Newey-West standard errors are used with 12-month lags. One, two, and three stars denote significance levels at 10, 5, and 1 percent confidence levels.

Table 9: One-Week Deviations from CIP and Interest Rates on Excess Reserves

Currency	Libor basis	IOER-Libor	OIS basis	IOER-OIS	IOER basis
CHF	-19.7	-14.1	-33.6	-21.6	-11.8
	(26.1)	(27.2)	(35.7)	(36.1)	(29.5)
DKK	-41.1	-35.4	-28.7	-15.6	-13.3
	(22.5)	(25.5)	(25.)	(25.7)	(26.3)
EUR	-18.3	-12.6	-21.2	-9.5	9.2
	(14.8)	(17.9)	(13.9)	(15.5)	(22.)
GBP	-10.4	-4.7	-9.1	2.6	-1.4
	(10.8)	(14.2)	(10.9)	(12.2)	(12.9)
JPY	-19.6	-14.0	-23.7	-11.5	-13.6
	(24.3)	(25.1)	(26.1)	(26.3)	(25.5)
Total	-21.7	-16.1	-22.3	-10.2	-6.1
	(22.9)	(24.7)	(24.5)	(25.)	(25.6)

Notes: 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), the U.K. pound (GBP), and the Japanese yen (JPY). The first column, denoted "Libor basis," refers to the Libor cross-currency basis. The second column, 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. The third column, denoted "OIS basis," refers to the overnight interest rate swap (OIS) cross-currency basis. The fourth column, 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. The fifth column, denoted "IOER basis," refers to the IOER cross-currency basis. The sample starts in 1/1/2009 and ends in 1/31/2016.

Appendix

A CDS Spreads for Interbank Panels

We compute the average CDS spread for banks on the interbank panel in the respective currencies. The banks on each interbank panel are listed as follows. We obtain 5-year CDS spreads from Markit. A few banks do not have liquid CDS quotes and hence are excluded from the calculation. The asterisk denotes banks with CDS spreads.

- AUD: Australia and New Zealand Banking Group*, Commonwealth Bank of Australia*, National Australia Bank*, and Westpac Banking Corporation*.
- CAD: BMO Nesbitt Burns, CIBC World Markets*, HSBC Bank Canada*, National Bank Financial, RBC Dominion Securities, Scotia Capital Inc., and TD Securities Inc.
- CHF: Bank of Tokyo-Mitsubishi UFJ Ltd*, Barclays Bank plc*, Citibank NA*, Credit Suisse*, Deutsche Bank AG*, HSBC*, JP Morgan Chase*, Lloyds Banking Group*, Société Générale*, The Royal Bank of Scotland Group*, and UBS AG*
- DKK: Danske Bank*, Deutsche Bank*, Nordea Bank*, Jyske Bank, Nykredit Bank, Sydbank Spar, and Nord Bank.
- EUR: Belfius*, Nordea*, Pohjola, BNP-Paribas*, Crédit Agricole s.a.*, HSBC France*, Natixis-BPCE*, Société Générale*, Commerzbank*, Deutsche Bank*, DZ Bank Deutsche Genossenschaftsbank*, National Bank of Greece*, Intesa Sanpaolo*, Monte dei Paschi di Siena*, Unicredit*, Banque et Caisse d'Épargne de l'État*, ING Bank*, Caixa Geral De Depósitos (CGD)*, Banco Bilbao Vizcaya Argentaria*, Banco Santander Central Hispano*, CECABANK, CaixaBank S.A.*, Barclays Capital*, Den Danske Bank*, Bank of Tokyo - Mitsubishi*, and J.P. Morgan Chase & Co*.
- GBP: Abbey National plc*, Bank of Tokyo-Mitsubishi UFJ Ltd*, Barclays Bank plc*, BNP Paribas*, Citibank NA*, Credit Agricole CIB*, Deutsche Bank AG*, HSBC*,

JP Morgan Chase*, Lloyds Banking Group*, Mizuho Corporate Bank*, Rabobank*, Royal Bank of Canada, The Royal Bank of Scotland Group*, Société Générale* and UBS AG*.

- JPY: Bank of Tokyo-Mitsubishi UFJ Ltd*, Barclays Bank plc*, Credit Agricole CIB*, Deutsche Bank AG*, HSBC*, JP Morgan Chase*, Lloyds Banking Group*, Mizuho Corporate Bank*, Société Générale*, Sumitomo Mitsui Banking Corporation*, The Norinchukin Bank*, The Royal Bank of Scotland Group*, and UBS AG*.

- NOK: DNB Bank ASA*, Danske Bank*, Handelsbanken*, Nordea Bank*, Norge ASA*, SEB AB*, and Swedbank*.

- NZD: ANZ National Bank*, ASB Bank Ltd, Bank of New Zealand Ltd, Kiwibank Ltd, and Westpac Banking Corporation Ltd*.

- SEK: Danske Bank*, Handelsbanken*, Länsförsäkringar Bank, Nordea*, SEB*, and Swedbank*.

- USD: Bank of America*, Bank of Tokyo-Mitsubishi UFJ Ltd*, Barclays Bank plc*, BNP Paribas*, Citibank NA*, Credit Agricole CIB*, Credit Suisse*, Deutsche Bank AG*, HSBC*, JP Morgan Chase*, Lloyds Banking Group*, Rabobank*, Royal Bank of Canada, Société Générale*, Sumitomo Mitsui Banking Corporation*, The Norinchukin Bank*, The Royal Bank of Scotland Group*, and UBS AG*.

B Basis Definition with Coupon Bonds

For each individual bond issued by KfW denominated in currency j, we denote the coupon rate of a n-year bond by c, paid q times per year. The principal is paid at the maturity time

$t+n$. The price of the bond in currency j is equal to

$$P^j_{t,t+n} = \sum_{i=1}^{n/q} \frac{c}{(1+y^{j,YTM}_{t,t+\tau})^\tau} + \frac{1}{(1+y^{j,YTM}_{t,t+n})^n},$$

where $y^{j,YTM}_{t,t+\tau}$ is the yield to maturity of the bond in currency j. We first compute the z-spread of bond over the Libor interest rate swap rate of the respective currency. Using the term structure of zero-coupon interest rate swap rates $y^{j,IRS}_{t,t+\tau}$ in currency j, the z-spread of the bond in currency j, $s^j_{t,t+n}$, is given as by the following equation:

$$P^j_{t,t+n} = \sum_{i=1}^{n/q} \frac{c}{(1+y^{j,IRS}_{t,t+\tau}+s^j_{t,t+n})^\tau} + \frac{1}{(1+y^{j,IRS}_{t,t+n}+s^j_{t,t+n})^n},$$

To compare z-spreads in different currencies, we use the term structure of the cross-currency basis swaps to convert all floating benchmarks to the U.S. dollar Libor, and define synthetic spread of bond in currency j over the U.S. dollar Libor, $\tilde{s}^j_{t,t+n}$, by

$$P^j_{t,t+n} = \sum_{i=1}^{n/q} \frac{c}{(1+y^{j,IRS}_{t,t+\tau}+x^{xccy}_{t,t+\tau}+\tilde{s}^j_{t,t+n})^\tau} + \frac{1}{(1+y^{j,IRS}_{t,t+n}+x^{xccy}_{t,t+\tau}+\tilde{s}^j_{t,t+n})^n}.$$

Therefore, the KfW basis between the U.S. dollar and currency j is defined as

$$x^{KfW,j}_{t,t+n} \equiv s^{\$}_{t,t+n} - \tilde{s}^j_{t,t+n},$$

which gives the difference between the direct dollar borrowing cost, $s^{\$}_{t,t+n}$, and the synthetic dollar borrowing cost, $\tilde{s}^j_{t,t+n}$, both measured as spreads over U.S. Libor interest rate swap rates.

C Shorting Costs

Figure 16 reports the 25 percentile, median and 75 percentile of shorting costs for U.S. dollar bonds issued by KfW.

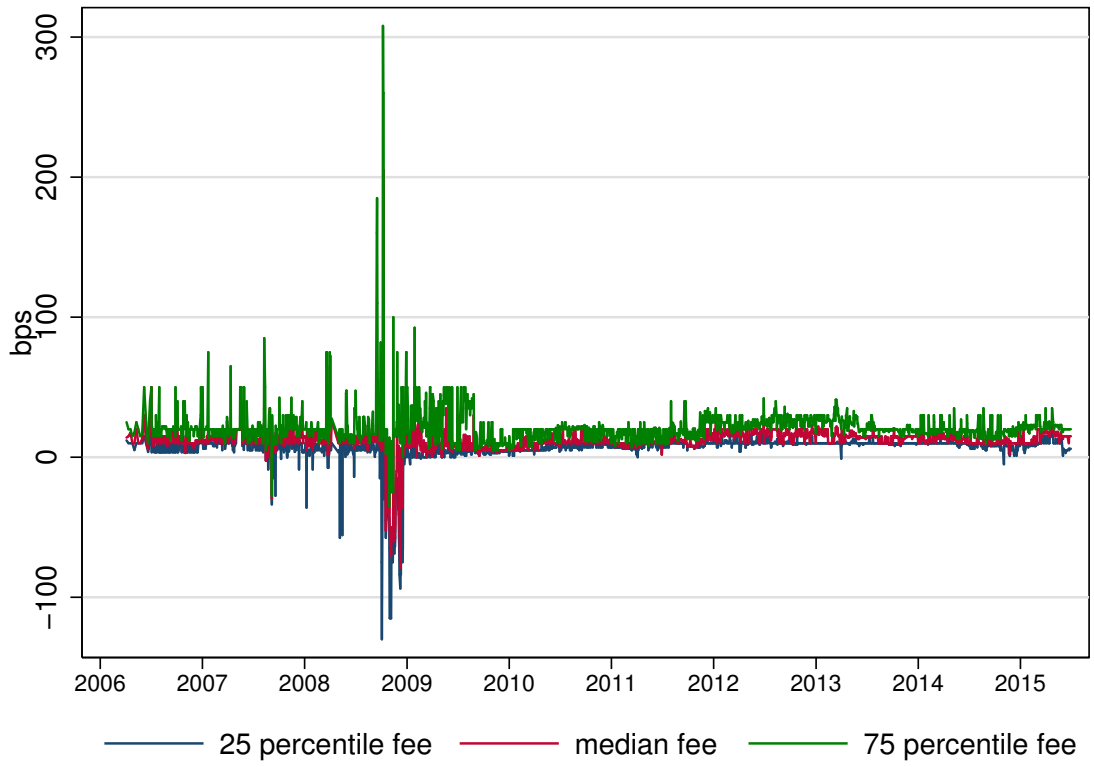


Figure 16: Shorting Costs for KfW USD Bonds: This figure shows the 25 percentile, median and 75 percentile of fees across all transactions for shorting U.S. dollar denominated KfW bonds. Data Source: Markit Securities Finance.