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BREAKDOWN OF COVERED INTEREST PARITY: MYSTERY OR MYTH?

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Abstract

The emergence and persistence of basis spreads in cross-currency basis swaps (CCBSs) since the global financial crisis have become a mystery in international finance, as they violate the long-standing principle of covered interest parity (CIP). We argue that the phenomenon is no mystery but merely a reflection of the different risks involved between money market and CCBS transactions in the post-crisis era. Empirical results based on seven major currency pairs support our hypothesis that the swap dealer behaves as if he tries to align the risks of the transactions in pricing CCBSs, which causes CIP to break down. We also find that the basis spreads are well arbitraged among the currency pairs, which suggests they are fairly priced. Hence, it is a myth that CCBS basis spreads or CIP deviations are evidence of the market not functioning properly.

Keywords: covered interest parity, FX swap, cross-currency basis swap, basis spread, CIP deviation, Libor-OIS spread, counterparty credit risk, funding liquidity risk

JEL classification: F31, F32, G15

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1. Introduction

The phenomenon that a basis spread (hereafter referred to as basis for short) has emerged and continues to persist in cross-currency basis swaps (CCBSs) for practically all currency pairs is fast becoming a mystery in international finance. The persistence of the basis suggests that covered interest parity (CIP), a long-standing economic principle, no longer holds, which puzzles many economists.[1] However, we think it is not as perplexing as it seems.

Since the onset of the global financial crisis (GFC), there has been a major reappraisal of counterparty credit risk and funding liquidity risk in global financial markets. This is evident in the sustained spread of the London interbank offered rate (Libor) over the overnight indexed swap (OIS) rate in the interbank funding market across most major currencies (Figure 1). The presence of counterparty risk is extremely important for unsecured lending/borrowing, as the lending party can end up getting nothing back if the other party defaults on the loan. However, swaps are different. They are secured transactions; both parties to the swap do not take counterparty risk. As principals are exchanged at inception, counterparty risk is largely eliminated since the parties effectively hold each other's loan as collateral.[2] To understand why basis emerges in the CCBS, or why CIP no longer holds in a market where participants are cautious about counterparty risk, it is useful to understand how the swap dealer prices FX swaps since, as we shall see (in Section 3), a CCBS can be viewed as a series of shorter-term FX swaps.[3]

From the perspective of the swap dealer, quoting the price of an FX swap when approached by a client is essentially quoting the forward premium or discount.[4] It was a simple task before the GFC, as there was little concern for counterparty risk. All the dealer had to do was to multiply the spot exchange

[1] A recent study even likens CIP to a physical law in international finance (Borio et al., 2016).

[2] Counterparty risk refers to the risk of default on each other's loan in this paper. Both parties, however, still take the counterparty risk of the swap itself, which is negligible compared to that of the loan.

[3] A swap dealer is a market dealer of swaps who takes positions, and hence also risks, in matching opposite sides of a swap. Textbooks often describe swaps as two parties engaging in transactions directly. However, as one can imagine, it is difficult for a company or financial institution to find another party that can offer exactly what it needs and, at the same time, needs exactly what it can offer. In reality, most of the transactions in the swap market are indirectly conducted through a dealer.

[4] The forward premium or discount refers to the difference between the spot and forward exchange rates, depending on whether the difference is positive or negative. In the FX swap market, the forward premium or discount is most commonly quoted in terms of forward or swap points, the number of pips added to or subtracted from the spot rate. We shall hereafter call it the forward premium for brevity, bearing in mind that it can indeed be a discount if it is negative.

rate of the two currencies by their interest differential based on benchmark money market rates such as the Libors. In doing so, he is applying CIP, which basically says the ratio of the forward to spot exchange rates between the foreign and domestic currencies is equal to their interest differential. Today's money market is different as participants are acutely aware of counterparty and liquidity risks. If the dealer continues to quote the forward premium as he did in the past, then CIP would continue to hold. But this makes no sense, as CIP would then imply that the dealer ignores the fact that the FX swap effectively converts the two unsecured money market loans into secured ones.

Among financial institutions, there has been a huge difference between borrowing on an unsecured basis and borrowing by placing an equivalent amount of foreign cash as collateral since the GFC. Theoretically, in the latter case, the dealer would *ceteris paribus* be willing to lend at an interest rate that is lower than the benchmark money market rate. But in an FX swap, the dealer also simultaneously borrows from his client in foreign currency. Therefore, he should equally enjoy a lower foreign interest rate than the benchmark foreign money market rate for the same reason. Therefore, in calculating the forward premium, it is only rational for the dealer to adjust the old benchmark interest differential by an amount equivalent to what he judges to be the difference between the two counterparty risk premiums. In this case, the forward premium he quotes for his client differs from what he would quote in the past (unless the two counterparty risk premiums happen to be the same). As a result, CIP does not hold. But this makes sense!

The same is also true with CCBSs. As a CCBS is, in effect, a series of shorter-term FX swaps joined together, pricing a CCBS or quoting the basis of a CCBS is basically comparing the forward premium against the difference between the swap rates of the two currencies concerned.[5] Therefore, when CIP holds (i.e., there is no CIP deviation) the basis is equal to zero (see Section 3). This was the situation before the GFC. If the swap dealer continues to quote a zero or practically zero basis in the CCBS market, CIP would of course continue to hold. However, the question again arises, why would the swap dealer price secured loans using interest rates taken from unsecured markets?

[5] The market convention is to quote the basis over the non-USD leg. For example, the five-year USD/GBP CCBS with a basis of minus (plus) α basis points means the quarterly exchange of the three-month GBP Libor minus (plus) α basis points *versus* the three-month USD Libor flat for a period of five years.

Therefore, it is reasonable to postulate that, in the post-GFC trading environment, the swap dealer behaves as if he tries to take into account the (absence of) counterparty risks involved when quoting for his client the forward premium in the case of an FX swap or the basis in the case of a CCBS (Wong et al., 2017). This is consistent with the multi-curve modeling approach to interest rate swap (IRS) pricing in finance literature. The classic single-curve model, which worked fine in the pre-crisis era, no longer works post crisis, as the Libor curve is no longer risk-free.[6] This causes basis to occur even in the single-currency swap market (Figure 2).[7] The multi-curve model tackles the issue by using risk-embedded curves (e.g., Libor-based curves) to calculate the expected future cash flows and a risk-free curve to discount them (Bianchetti, 2010; Mercurio, 2010; Grbac et al., 2015). This pricing methodology dates back to Tuckman & Porfirio (2003) but gains popularity in practice only after the GFC as counterparty and liquidity risks explode in the interbank money market (Bianchetti, 2010).[8] However, it is imperative to note that the cross-currency swap (i.e., FX swap and CCBS) market differs from the single-currency swap (i.e., IRS) market in that principals are exchanged in the former but not in the latter.

The collateralized nature of the FX swap or CCBS transaction eliminates only the counterparty risks that are priced into the Libors but not the liquidity risks. The fact that both parties to the transaction swap their principals at inception means they still take a liquidity risk for the fund they lend but receive a liquidity premium for the fund they borrow. Hence, as the counterparty risk premiums in the domestic and foreign money market rates are removed, the difference between the liquidity risk premiums and the difference between the risk-free rates are left in the dealer's equation in pricing the swap. The presence of the liquidity risk premiums in the price reflects the fact that the liquidity risks of the two parties are swapped in the FX swap or CCBS transaction. This explains why there is still a basis or deviation when one replaces the Libor-differential in the CIP condition with risk-free or near risk-free interest differentials such as OIS spreads, repo spreads or government bond yield spreads (Bottazzi et al., 2013; Fukuda,

[6] Before the GFC, IRSs were valued using the single-curve model, in which the estimation and discounting of future cash flows are based on the same interest rate curve, usually a Libor curve. The emergence of counterparty and liquidity risks since the GFC has given rise to bases as the reference interest rates, which are risk-embedded, are no longer consistent with the risk-free nature of the transaction.

[7] Single-currency bases can be broadly classified into three types: (i) forward basis, the difference between the Libor-curve-implied forward rate and the traded forward rate agreement rate; (ii) fix-float basis, the deviation of the Libor-curve-implied fixed rate from the swap rate; and (iii) tenor basis, which occurs between two legs of a basis swap indexed to Libors of different tenors.

[8] The use of the multi-curve model has essentially become the standard market practice after LCH.Clearnet, which operates SwapClear, announced on June 17, 2010 that it would replace the Libor curve with the OIS curve to discount its entire IRS portfolio after extensive consultation with market participants. See press release by LCH.Clearnet.

2016; Du et al., 2017). The reason is that these interest rates contain not only minimal counterparty risk premium but also negligible liquidity risk premium.[9] However, in the swap market the forward premium must reflect, in addition to the risk-free interest differential, the difference between the liquidity risks that are present in the two money markets. This is supported by the important finding by Rime et al. (2017) that CIP deviations based on OIS rates tend to co-move strongly with measures of liquidity premium differentials.

Our explanation, therefore, differs distinctly from previous studies in recent CIP literature, which attribute the phenomenon to a global shortage of US dollars. Earlier ones argue that, during the GFC and in its aftermath, many foreign financial institutions needed US dollars to fund their US conduits but found themselves shut off from the Libor market because US financial institutions were concerned about their counterparty risk (Baba & Packer, 2009; Coffey et al., 2009; Genberg et al., 2009; Fong et al., 2010; Hui et al., 2011). As a result, they had to resort to the FX swap and CCBS markets to obtain dollar funding, and paid a premium for it. In these studies, the CIP deviation or CCBS basis essentially reflects this dollar premium. More recent studies relate the shortage of US dollars to regulatory reforms introduced following the GFC, growing demand for dollar hedging, capital and balance sheet constraints, and even global imbalances, which have singly or jointly resulted in limits to arbitrage as reflected by the persistence of the non-zero basis (Ivashina et al., 2015; Borio et al., 2016; Du et al., 2017; Sushko et al., 2017). The phenomenon arguably reflects the special role of the dollar as the global funding currency (Avdjiev et al., 2016; Shin, 2016).

Nonetheless, many of these explanations are not necessarily inconsistent with ours. We concur that the basis is a consequence of certain factors or considerations that did not exist before the GFC. The difference, however, is they believe these factors or considerations are external to the reference interest rates used in the pricing of the swap, while we argue that, if any such factors or considerations exist, they would be translated into counterparty or liquidity risk in money market transactions and hence the reference interest rates. For instance, Baba & Packer (2009) try to explain CIP deviation by credit default

[9] Theoretically, the liquidity risk premium contained in a repo rate or bond yield depends on the market liquidity of the collateral asset or debt security concerned. The more liquid the asset or security market is, the smaller the funding liquidity risk embedded in the repo rate or bond yield. See Brunnermeier & Pedersen (2009) for a more detailed discussion about the relationship between market liquidity and funding liquidity. Needless to say, the problem will also be compounded by factors that affect the supply of, and demand for, the underlying security other than the opportunity cost of borrowing/lending, e.g., the convenience yield.

swap spreads, while Avdjiev et al. (2016), Borio et al. (2016), Du et al. (2017) and Sushko et al. (2017) attempt to relate the basis to dollar strength or dollar hedging demand. In our view, all these are already priced in by the Libor-OIS spreads. Indeed, the quarter-end spikes in the basis as observed by Borio et al. (2016) and Du et al. (2017) are totally consistent with the quarter-end jumps we find in the Libor-OIS spread (Table 1). To them, the greater importance accorded to quarter-end reporting and regulatory ratios following regulatory reforms makes it harder to take arbitrage at those times, which is reflected in the basis. For us, these pressures are detectable in the Libor-OIS spread as they translate into higher funding liquidity risk at quarter ends.

In this paper, we examine the CCBS market for seven currency pairs in the post-GFC era: four involving a dollar leg (USD/EUR, USD/GBP, USD/CHF and USD/JPY) and the other three a euro leg (EUR/GBP, EUR/CHF and EUR/JPY). We find consistent evidence across the currency pairs that the CCBS basis essentially reflects the difference in the counterparty risk premiums embedded in the domestic and foreign money markets. Our results also contribute to the heated debate in literature about the proportions of the counterparty and liquidity risk premiums embedded in the Libor-OIS spread (Michaud & Upper, 2008; Sarkar, 2009; Acharya & Skeie, 2011; Garleanu & Pedersen, 2011; Gefang et al., 2011; McAndrews et al., 2017). Since the swap market, as we postulate, works as a risk filter that separates the two risk premiums, our model allows us to estimate econometrically the shares of the counterparty and liquidity risk premiums in the spread. For USD/EUR, for example, we find that, in this period, the counterparty risk premium, on average, accounts for about 22.3% of the total risk premium embedded in the USD Libor, and the liquidity risk premium about 76.1%. The counterparty risk premium contributes 75.8% to the total risk premium embedded in the EUR Libor and the liquidity risk premium only 23.6%. This means the swap dealer subtracts 22.3% of the USD Libor-OIS spread from the USD Libor and 75.8% of the EUR Libor-OIS spread from the EUR Libor in pricing the CCBS.

The implication of our hypothesis that CCBSs are fairly priced is also evident in the behavior of the CCBS market itself. As one can imagine, if market forces are hampered by some constraints or limits, the prices may be arbitrarily determined. However, we find that the CCBS bases relate to each other in a triangular relationship explicable by a matrix with special properties (Section 2.3). The relationship suggests that the CCBS market is well arbitraged, though not in the sense of eliminating the basis, and that the bases are not arbitrarily determined but fairly priced.[10] We argue that the well-arbitraged non-zero bases are driven by the difference between the counterparty risks of the two money markets concerned but acknowledge the possibility that they are determined by the limits to arbitrage caused by plausible constraints such as capital charges resulting from recent regulatory reforms. Nonetheless, the persistence of the bases (especially those between two non-USD currencies) and the considerable differences among them (even between the currency pairs with a USD leg) challenge the notion that CIP deviation or CCBS basis is essentially a dollar phenomenon.[11]

This paper is organized as follows. In the next section, we explain the basics of FX swaps and CCBSs, and also the relationship among CCBS bases across currency pairs under a no-arbitrage condition. In Section 3, we analyze the relationship between FX swaps and CCBSs, and show that CIP deviation and CCBS basis are equivalent. Section 4 explains the rationale behind the need to adjust the CIP condition for the difference in counterparty risk between the two interbank money markets. Section 5 sets out the model and discusses the data. Section 6 shows that the CCBS market is a well-arbitraged market and that our empirical results support the risk-adjusted version of CIP. Section 7 concludes.

2. FX swap and CCBS

The swap market is one of the largest derivatives markets and, among all kinds of swaps, FX swaps are the ones most traded.[12] An FX swap involves two parties exchanging two currencies in equal amount at the current spot exchange rate and, at the same time, agreeing to exchange them back on a future date at the pre-determined forward exchange rate. While there are no interest payments during the contract term, the interests accrued from the principals of the two currencies are embedded in the forward exchange rate. Therefore, a domestic investor buying (selling) an FX swap can be viewed as borrowing in foreign (domestic) currency while lending in domestic (foreign) currency at the same time,

[10] The triangular relationship does not imply that CIP holds, as the triangular arbitrage is different from the conventional CIP arbitrage.

[11] The fact that bases have also emerged and persisted in the single-currency swap market for practically all currencies provides further evidence that the phenomenon is no privilege of the dollar (Figure 2). Basis is principally an outcome of swapping two interest rates whose underlying risks are not aligned with the nature of the transaction.

[12] According to the Triennial Central Bank Survey of global foreign exchange and OTC derivatives markets by the Bank for International Settlements (BIS) in 2016, FX swaps accounted for 46.8% of the total turnover of all FX and OTC derivatives (BIS, 2016).

where the interests are netted on the foreign currency leg.

A CCBS can also be viewed as a synthetic borrowing involving two currencies. The transaction details are similar to an FX swap of the same maturity, except for the interest payment arrangement. As in an FX swap, the principals are also exchanged at the spot exchange rate. However, instead of adding the netted interests to the foreign currency leg at maturity, both parties in a CCBS contract agree to make periodic interest payments to each other throughout the contract term. Therefore, at maturity, both parties exchange the principals back at the initial spot exchange rate (instead of the forward exchange rate as in an FX swap).

Since the FX swap and CCBS serve the same purpose of borrowing foreign currency by deploying domestic currency as collateral, the embedded risks are identical. If reinvesting all periodic interests of a CCBS until maturity and converting domestic currency interests to foreign currency, the resulting net cash flows are the same as those of an FX swap. However, the slight difference in the interest payment arrangement makes the CCBS more attractive and popular for longer-term borrowing, whereas FX swaps are only fairly active up until maturity of two years (Chang & Lantz, 2013). Now, let's drill down to the fundamentals of the two derivative products before explaining in detail their equivalence under certain assumptions.

2.1 FX swap

An FX swap can be viewed as longing a currency in the spot and shorting it in the forward market. Figure 3 illustrates an example of an FX swap. For simplicity, we set the principal to one unit of domestic currency. In the FX swap, the relevant interests on both currencies are inherent in the forward exchange rate. According to CIP, the difference between the spot and forward rates reflects the interest differential between the two currencies, such that any interest loss from the lower-yield currency is compensated by an equivalent amount of forward premium and *vice versa*. This relationship can be written as below:

$$F_{0,n} = Se^{n(r^*_{0,n} - q^*_{0,n})} \tag{1}$$

where S is the spot exchange rate, $F_{k,m}$ is the time m forward exchange rate determined at time k, both expressed as the amount of foreign currency per unit of domestic currency; $r^*_{m,k}$ and $q^*_{m,k}$ are the implicit interest rate in an FX swap from time k to time m for foreign currency and domestic currency respectively, for $k, m = 0, 1, \ldots, n$ and $k < m$.

2.2 CCBS

CCBSs are a special type of basis swaps. Basis swaps are transactions in which both parties periodically exchange the floating interests indexed to a different reference rate based on a specified principal. If both legs are in the same currency, there is no exchange of principals at inception or maturity. If they are denominated in different currencies, the principals are exchanged at the initial spot exchange rate on both the inception and maturity dates. This type of basis swaps is called CCBSs. As for interest payments in a CCBS, the floating rate on each leg is based on a reference rate for the respective currency (e.g., Libor), where market convention is to quote the basis against the foreign currency leg, usually the non-USD or the non-EUR leg (Flavell, 2010). A positive basis suggests that one must pay a premium above $Libor_{FC}$ to borrow foreign currency while lending domestic currency at $Libor_{DC}$ flat and *vice versa*. By construction, a generic CCBS involves three components:

- At inception, the counterparty receives (pays) domestic currency and pays (receives) an equivalent amount of foreign currency at the spot exchange rate S.
- During the contract term (including at maturity), the counterparty pays (receives) $Libor_{DC}$ while receiving (paying) $Libor_{FC}$ plus a basis.
- At maturity, the counterparty pays (receives) back the same amount of domestic currency and receives (pays) back the same amount of foreign currency.

Let α denote the CCBS basis to be added to $Libor_{FC}$, and $r_{k,m}$ and $q_{k,m}$ denote the $Libor_{DC}$ and $Libor_{FC}$ from time k to time m respectively. Figure 4 illustrates the cash flows of a CCBS with annual interest payments under continuous compounding. The cash flows are equivalent to borrowing (lending) domestic currency at $Libor_{DC}$ flat while lending (borrowing) foreign currency at $Libor_{FC}$ plus a basis, which is the same as exchanging cash flows from two floating rate coupon bonds denominated in different currencies.

2.3 Basis matrix

Theoretically, there is a basis for any currency pair in the CCBS market. We observe there is a relationship among all CCBS bases such that any deviation from it would be arbitraged away. This relationship is reminiscent of that of the elements in an equitable matrix, a popular example of which is exchange rates, where the exchange rates between any two pairs of three currencies can imply the third (Parker, 1965).[13] In this section, we discuss the properties of the matrix for CCBS bases.

Let's first define the matrix of CCBS bases as

$$B = (\alpha_{i,j})_{i,j=1}^{n} \tag{2}$$

where $\alpha_{i,j}$ is the basis to be added to the foreign currency leg of a CCBS, with i being the domestic currency and j the foreign currency. It is, by definition, a skew-symmetric (or antisymmetric) matrix, a square matrix whose transpose is its negation. A skew-symmetric matrix has two important properties: first, $\alpha_{i,j} = -\alpha_{j,i}$ for $i, j = 1, 2, \ldots, n$, which also implies, second, $\alpha_{i,i} = 0$ for $i = 1, 2, \ldots, n$. In other words, the basis of currency i vis-à-vis currency j is equal to the negative of the basis of currency j vis-à-vis currency i, and the basis of any currency vis-à-vis itself (i.e., those on the diagonal) is zero.

When there is no arbitrage to take, the elements of the basis matrix should fulfill the fundamental relationship,

$$\alpha_{i,j} + \alpha_{j,k} + \alpha_{k,i} = 0 \tag{3}$$

for $i, j, k = 1, 2, \ldots, n$. An arbitrage opportunity exists if the three bases do not sum to zero. If the sum of the bases is greater than zero, i.e., $\alpha_{i,j} + \alpha_{j,k} + \alpha_{k,i} > 0$, one can arbitrage by entering into three CCBS contracts at the same time: borrow i and lend j; borrow j and lend k; and borrow k and lend i. During the contract term, the arbitrageur pays $Libor_i$ and receives $Libor_j$ plus $\alpha_{i,j}$; pays $Libor_j$ and receives $Libor_k$ plus $\alpha_{j,k}$; and pays $Libor_k$ and receives $Libor_i$ plus $\alpha_{k,i}$ at the end of every sub-period. Since his position is squared, he makes a risk-free profit equal to the sum of the three bases every time

[13] An equitable matrix, according to Eves (1966), "is a real square matrix $(a_{i,j})$ with positive elements such that $a_{i,j}a_{j,k} = a_{i,k}$ for all i, j, k".

when he exchanges interest payments with the other three counterparties.[14] If the sum of the bases is smaller than zero, i.e., $\alpha_{i,j} + \alpha_{j,k} + \alpha_{k,i} < 0$ (which implies $\alpha_{j,i} + \alpha_{k,j} + \alpha_{i,k} > 0$), then the arbitrageur should do exactly the reverse: borrow j and lend i; borrow k and lend j; and borrow i and lend k. The risk-free profit he makes in this case is equal to the negative of the sum of the three bases.

Equation (3) implies the third property of the basis matrix: the matrix can be entirely determined by its ith row, where $i = 1, 2, \ldots, n$. Theoretically, for any three currencies, if the no-arbitrage condition holds, the CCBS bases of any two pairs of three currencies implies the third since $\alpha_{i,k} - \alpha_{i,j} = \alpha_{j,k}$. This means that one can derive the whole matrix, if one knows the CCBS bases of only one currency vis-à-vis all other currencies, e.g., all CCBS bases with a dollar leg.

3. CIP deviation and CCBS basis

Let's first analyze the relationship between the FX swap and CCBS before proving they are equivalent to each other.

3.1 Relationship between FX Swap and CCBS

Cash flows from a CCBS can be synthetically converted into those of an FX swap with the same maturity at zero cost, using a series of FX swaps and forward rate agreements (FRAs).[15] This can be done in three steps:

- First, convert floating rates, $r_{k,m}$ and $q_{k,m}$, into fixed rates, r and q, using IRS as shown in Figure 5.[16] The interest on the foreign currency leg becomes $r + \alpha$.

[14] While the arbitrageur receives bases $\alpha_{i,j}$, $\alpha_{j,k}$ and $\alpha_{k,i}$ denominated in currencies j, k, and i respectively, the exchange rate risk embedded in these bases is negligible.

[15] FRAs are commonly used to lock in an expected future interest rate, which can be implied using interest rates of different tenors. Since FRAs are collateralized transactions, the expected future interest rate can be expressed as follows.

$$E[e^{(m-k)r_{k,m}}] = e^{mr^*_{0,m} - kr^*_{0,k}}$$

[16] The fixed rate in an IRS is calculated according to the following relationship. For details of the pricing of IRS, see Appendix.

$$e^q = \frac{1 + \sum_{t=1}^{n-1} e^{-tq_{0,t}}}{\sum_{t=1}^{n} e^{-tq_{0,t}}} \approx e^{q_{0,n}}$$

- Secondly, exchange the fixed domestic currency interests into foreign currency using forwards entered into at time 0 and then calculate the net cash flows in foreign currency throughout the contract term. The fixed cash flows in Figure 5 (i.e., $(e^q - 1)$ in domestic currency and $S(e^{r+\alpha} - 1)$ in foreign currency) are transformed into net cash flows in foreign currency (i.e., $S(e^{r+\alpha} - 1) - F(e^q - 1)$) at zero cost, as shown in Figure 6.

- Finally, reinvest the net interest payments through time n using FRAs, which lock in the expected future interest rates in $E[e^{(n-t)r_{t,n}}]$, $t = 1, 2, \ldots, n-1$. As a result, this synthetic product consists of cash flows at inception and maturity only, with no exchange of interests from time 1 to time $n-1$ (Figure 7).

Like an FX swap, this synthetic product is created at zero cost initially without introducing additional risks. Comparing the cash flows in Figure 3 and Figure 7, we can see that all cash flows except the last foreign currency one are exactly the same between these two products. If the final foreign cash flow of the synthetic product is different from that in a corresponding FX swap, there exists an arbitrage opportunity by longing the product with a larger final foreign currency cash flow and shorting the other. Therefore, under a no-arbitrage condition, the foreign currency cash flow at maturity should be equal to that of the FX swap in an efficient market. Therefore, two products with the same risk, same price and same cash flow can be regarded as equivalent. In sum, an FX swap can be synthetically constructed using a CCBS and a series of FX swaps and FRAs.[17]

3.2 Equivalence of CCBS basis and CIP deviation

The equivalence between CCBS and FX swap suggests that the final cash flow from the synthetic product (Figure 7) should not deviate from that in an FX swap (Figure 3), otherwise arbitrage opportunities exist between these two markets. As a result,

$$F_{0,n} = S + \sum_{t=1}^{n} (S(e^{r+\alpha} - 1) - F_{0,t}(e^q - 1))E[e^{(n-t)r_{t,n}}] \quad (4)$$

[17] There are other mathematical approaches to drawing the equivalence between CCBS and FX swap (Tuckman & Porfirio, 2003; Liao, 2016; Du et al., 2017).

Rewriting equation (4) using information known at time 0, we have

$$Se^{n(r^*_{0,n}-q^*_{0,n})} = S + \sum_{t=1}^{n}(S(e^{r+\alpha}-1) - Se^{t(r^*_{0,t}-q^*_{0,t})}(e^{q}-1))e^{nr^*_{0,n}-tr^*_{0,t}} \tag{5}$$

Rearranging the summation gives

$$e^{-nq^*_{0,n}} - e^{-nr^*_{0,n}} = \sum_{t=1}^{n}(e^{r+\alpha}-1)e^{-tr^*_{0,n}} - \sum_{t=1}^{n}(e^{q}-1)e^{-tq^*_{0,n}} \tag{6}$$

Under first order Taylor expansion of e^x around 0, equation (6) can be simplified as

$$\alpha \approx (r^*_{0,n} - q^*_{0,n}) - (r - q) \tag{7}$$

the right side of equation (7) is equal to the negative of CIP deviation as defined in equation (10) in the next section. This implies that when there is no CIP deviation, the CCBS basis should be zero.

4. Risk-adjusted CIP for CCBS

According to CIP, the interest differential between two currencies is always offset by the forward premium, so no risk-free profit can be earned by borrowing in the lower-yield currency and lending in the higher-yield one under a covered position. Therefore, when it is not, there is a CIP deviation:

$$\alpha^* \equiv r_{0,n} - q_{0,n} - \frac{\ln F_{0,n} - \ln S}{n} \tag{8}$$

Substituting (1) into equation (8) yields

$$\alpha^* \equiv (r_{0,n} - q_{0,n}) - (r^*_{0,n} - q^*_{0,n}) \tag{9}$$

In light of the equivalence of the CCBS basis and CIP deviation, we follow the first step in sub-section 3.1 to convert the floating money market rates, $r_{0,n}$ and $q_{0,n}$, into longer-term fixed IRS rates, r and q.

Equation (9) then becomes[18]

$$\alpha^* \equiv (r - q) - (r^*_{0,n} - q^*_{0,n}) \tag{10}$$

Comparing equations (7) and (10), we conclude that CIP deviation is approximately equivalent to the CCBS basis.

$$\alpha^* \approx \alpha \tag{11}$$

The key reason why CIP deviation emerges is that the nature of swap transactions is different from that of uncollateralized lending in the interbank money market (Wong et al., 2017). The principals exchanged at inception are essentially deployed as collateral to each other, which eliminates the counterparty risks for both parties. Indeed, even before the GFC, dealers had already pointed out that the "credit premium" embedded in the Libors made them "too high to be used" for forward pricing (Tuckman & Porfirio, 2003). However, since the counterparty and liquidity risks in the pre-GFC interbank money market were perceived to be limited across currencies, the CIP deviation or CCBS basis generally remained within 10 basis points. The limited counterparty and liquidity risks in the interbank money market have also kept Libors at levels comparable to the OIS rates, which are effectively risk-free.[19] When counterparty risk was considered negligible, there was little difference between the costs of collateralized and uncollateralized borrowing. However, the fund redemption suspension by BNP Paribas in 2007 and the collapse of Lehman Brothers the following year resulted in a major reappraisal of counterparty and liquidity risks in the interbank money market. Since the collaterals greatly reduce the possibility of default in the FX swap transaction, the implicit interest rates of both currencies $r^*_{0,n}$ and $q^*_{0,n}$ should be lower than the interbank borrowing costs $r_{0,n}$ and $q_{0,n}$ (or r and q).

Wong et al. (2017) propose a risk-adjusted version of CIP where the counterparty risk premiums of both sides, as measured by a proportion of the Libor-OIS spread, are excluded when determining the forward rate. In the case of the CCBS, we replace the Libor by the IRS rate so we can rewrite equation

[18] See Appendix for the valuation of IRS and the relationship between $r_{0,n}$ and r.

[19] OIS is a type of floating-for-fixed IRS, whose floating leg is the geometric mean of the overnight interbank rate, and the fixed leg is calculated by traders such that an OIS is entered into with zero initial cost. Therefore, the fixed leg of an OIS is often treated as the expected overnight index rate throughout the term of maturity. Therefore, the Libor-OIS spread is often used as an important indicator of counterparty and liquidity risk in the interbank money market.

(7) as

$$\alpha \approx \omega_{DC}(q - q_f) - \omega_{FC}(r - r_f) \tag{12}$$

where ω_{FC} and ω_{DC} represent the shares of counterparty risk premium in the IRS-OIS spread, and r_f and q_f are the OIS rates of foreign and domestic currencies, respectively.[20] The CCBS basis or (negative) CIP deviation is decomposed into the difference between the expected counterparty risk premiums of an average domestic currency borrower and an average foreign currency borrower, which implies that

$$r^*_{0,n} \equiv r - \omega_{FC}(r - r_f) \tag{13}$$

and

$$q^*_{0,n} \equiv q - \omega_{DC}(q - q_f) \tag{14}$$

5. Model and data

5.1 Model

While we can directly estimate the decomposition of the CCBS basis in equation (12), the approximate equality will probably generate less-trustworthy results. Therefore, we employ a similar approach adopted by Wong et al. (2017) using forward point as the dependent variable. Substituting equations (1) and (7) into equation (12) and rearranging the equation, we have

$$\frac{\ln F_{0,n} - \ln S}{n} = (1 - \omega_{FC})r + \omega_{FC}r_f - (1 - \omega_{DC})q - \omega_{DC}q_f \tag{15}$$

Based on this relationship, we build the unrestricted model to estimate the average share of counterparty risks and liquidity risks associated with different currencies in the Libor market. Since the dependent variable $(\ln F_{0,n} - \ln S)/n$ and independent variables r, r_f, q, and q_f all have a unit root, we

[20] In other words, we hypothesize that Libor (or IRS in the long-run) can be decomposed into three components, namely the risk-free rate, the counterparty risk premium, and the liquidity risk premium.

$$Libor = OIS + \omega(Libor - OIS) + (1 - \omega)(Libor - OIS)$$

take the first difference of all variables such that the unrestricted model becomes

$$\Delta Fp_t = C_0 + C_1 \Delta r_{f_t} + C_2 \Delta q_{f_t} + C_3 \Delta r_t + C_4 \Delta q_t + \epsilon_t \quad (16)$$

where Δ is the first difference operator, and $Fp = (\ln F_{0,n} - \ln S)/n$.

In the unrestricted model, the absolute values of the coefficients of the risk-free rates, C_1 and C_2, represent the shares of counterparty risk premium in the total risk premium, ω_{FC} and ω_{DC}, and the absolute values of the coefficients of the interbank borrowing rates, C_3 and C_4, represent the shares of liquidity risk in the total risk premium $1 - \omega_{FC}$ and $1 - \omega_{DC}$. According to our proposed theory of decomposing the CCBS basis, the constant C_0 is expected to be zero, and the coefficients of IRS and OIS of the foreign (domestic) currency should sum to unity. Therefore, we develop our hypotheses below.

Hypothesis 1: $C_0 = 0$

Hypothesis 2a: $C_1 + C_3 = 1$

Hypothesis 2b: $C_2 + C_4 = -1$

Imposing the restrictions in hypotheses 2a and 2b on the unrestricted model, we derive the restricted model as below:

$$\Delta Fp_t = C_0 + C_1 \Delta r_{f_t} + C_2 \Delta q_{f_t} + (1 - C_1) \Delta r_t + (-1 - C_2) \Delta q_t + \epsilon_t \quad (17)$$

where the coefficients of IRS and OIS of the same currency sum to unity.

5.2 Data

Data employed in this study are all collected from Bloomberg as at the London market close with daily frequency.[21] This paper focuses on the world's most actively traded currencies, namely USD, EUR,

[21] Global financial markets are probably most active in London at 6pm out of the three time choices available from Bloomberg, with the other two being Tokyo, 8pm and New York, 5pm.

GBP, JPY and CHF.[22] Among these five currencies, there are a total of 10 possible currency pairs, but only seven of them are actively traded in the CCBS market: four involving a USD leg (namely, USD/EUR, USD/GBP, USD/CHF and USD/JPY) and three a EUR leg (namely, EUR/GBP, EUR/CHF and EUR/JPY). The remaining three pairs of currencies (namely, GBP/CHF, GBP/JPY and CHF/JPY) do not have an active market, and there are no data reported by Bloomberg. Table 2 summarizes the descriptive statistics of key variables.

5.2.1 Choice of variables

The spot and forward exchange rates vis-à-vis USD are collected directly from Bloomberg, whereas those vis-à-vis EUR are calculated using the respective exchange rates vis-à-vis USD to keep inconsistency to a minimum.[23] The OIS rates for USD, EUR, GBP, CHF and JPY are the effective Fed funds rate, Euro overnight index average, sterling overnight index average, tom/next indexed swap and Tokyo overnight average rate, respectively. Details of each reference rate are summarized in Table 3.

For all currency pairs, the conventional CCBS contracts are based on their three-month interbank offered rates.[24] Correspondingly, we use the fixed rates of IRS, which are indexed to three-month Libors and are of five-year tenor as r and q.[25] As can be seen in Figure 8, the CIP deviations closely track the corresponding CCBS bases for all currency pairs. The slight differences between CIP deviations and CCBS bases are due to the approximation of r and q for $r_{0,n}$ and $q_{0,n}$.

5.2.2 Choice of sample

Like most previous studies, this paper focuses on the popular five-year tenor. The sample periods are defined by data availability, ranging from 1887 to 2029 observations in each regression. For USD/CHF

[22] According to BIS (2014, 2016), the average daily turnover of CCBS involving these currencies accounted for 79.16% of the total in April 2016, and 78.90% in April 2013.

[23] While direct quotes of cross exchange rates (i.e., non-USD exchange rates) are also available from Bloomberg, data quality for USD exchange rates is much better due to larger trading volumes.

[24] A CCBS vis-à-vis USD is referenced to Libors for both legs whenever available. A CCBS vis-à-vis EUR is referenced to Euribor for the EUR leg. In this paper, we use interest rates that refer to Euribor for the EUR leg whenever applicable.

[25] JPY is the only exception, as data for the three-month IRS is not available due to a lack of an active three-month market. We construct a proxy for the three-month IRS by subtracting the three-for-six-month basis swap spread from the six-month IRS which has a much more active market. This approximation is totally acceptable as the investor can swap his three-month JPY Libor interests into six-month ones by entering into a three-for-six-month basis swap at almost zero cost.

and EUR/CHF, the sample period is from January 13, 2010 to June 30, 2017, as the CHF OIS rate is only available from January 13, 2010. For the rest of the currency pairs, the sample period covers September 22, 2009 to June 30, 2017, as the five-year USD IRS rate is only available starting from September 21, 2009. To reduce the potential bias caused by data errors, data points lying five or more standard deviations away from the mean are deleted (Charles & Darné, 2005).[26]

6. Empirical findings

6.1 Basis matrix

The seven currency pairs under study can be divided into two groups: the first group includes four currency pairs with a USD leg (USD/EUR, USD/GBP, USD/CHF and USD/JPY), and the other includes three with a EUR leg (EUR/GBP, EUR/CHF and EUR/JPY). Figure 9 plots the bases of the four currencies vis-à-vis USD and Figure 10 those of the three vis-à-vis EUR. As can be seen, they stayed around zero before the GFC but have since consistently deviated from it. This shows that like the CCBS bases with a USD leg, those with a EUR leg bear the same characteristic in the sense that CIP also holds for them before the GFC but not after.

More importantly, these market data suggest that the fundamental relationship of the basis matrix is clearly observed. This relationship, as shown by equation (3), suggests that for any three currencies, the difference between the bases of any two of them vis-à-vis the third one is equal to the basis involving these two currencies. Figure 10 shows that the difference between the USD/EUR and USD/GBP bases, as depicted by the red dotted line, is always almost the same as the EUR/GBP basis traded in the market. The same is also true for the difference between the USD/EUR and USD/CHF bases, and the EUR/CHF basis; and the difference between the USD/EUR and USD/JPY bases, and the EUR/JPY basis. In our view, this is no coincidence. There must be players actively taking arbitrage in the market, which is reminiscent of what occurs in the FX market, where the exchange rates of any two non-USD

[26] As with most financial market data, our data set consists of some extreme outliers that possibly result from a variety of problems including typos by contributing banks to Bloomberg (Chen & Liu, 1993; Brownlees & Gallo, 2006). Using the five-standard-deviation cutoff, our sample still captures 99.0-99.7% of the full sample across all data series used in the study. We have also applied cutoffs of three and four standard deviations to the data. The results, which can be available upon request, change little.

currencies vis-à-vis USD can be used to derive the cross exchange rate between them.

To show how large (or small) the arbitrage opportunity is on a usual trading day, we calculate and compare two basis matrices using the data collected at the London market close on June 30, 2017.[27] Based on the properties of the basis matrix, we obtain the first matrix B_{USD} using only the CCBS bases with a dollar leg and the second one B_{EUR} using only the CCBS bases with a euro leg as follows,

$$B_{USD} = \begin{pmatrix} 0 & -33.1 & -7.4 & -35.5 & -57.8 \\ 33.1 & 0 & 25.8 & -1.9 & -24.7 \\ 7.4 & -25.8 & 0 & -27.6 & -50.4 \\ 35.0 & 1.9 & 27.6 & 0 & -22.8 \\ 57.8 & 24.7 & 50.4 & 22.8 & 0 \end{pmatrix}$$

$$B_{EUR} = \begin{pmatrix} 0 & -33.1 & -6.9 & -35.6 & -58.5 \\ 33.1 & 0 & 26.3 & -2.5 & -25.4 \\ 6.9 & -26.3 & 0 & -28.8 & -51.6 \\ 35.6 & 2.5 & 28.8 & 0 & -22.9 \\ 58.8 & 25.4 & 51.6 & 22.9 & 0 \end{pmatrix}$$

where currency $1, 2, 3, 4, 5$ represents USD, EUR, GBP, CHF and JPY respectively. As can be seen, the two matrices derived from the first (USD leg) and the second (EUR leg) rows are almost identical, with the largest difference between the corresponding bases being 1.2 basis points for GBP/JPY. However, since there is no active market for GBP/JPY, the largest difference among the seven pairs of currencies traded in the CCBS market actually lies with EUR/JPY, 0.7 basis points.

As discussed earlier, Bloomberg has CCBS basis data only for currency pairs that are actively traded. According to BIS (2016), of the seven pairs, the four pairs with a USD leg have by far much larger trading volumes.[28] The trading of USD/EUR and USD/JPY is most intense, while that of USD/GBP and USD/CHF is thinner. The transactions for the currency pairs without a USD leg are even smaller.

[27] June 30, 2017, the last day of our sample period, is arbitrarily chosen for illustrative purposes. One can pick any other day.

[28] The following table summarizes the average daily turnover of CCBSs in April 2016 for the seven currency pairs covered in this study (BIS, 2016).

(in millions of US dollars)	EUR	GBP	CHF	JPY
USD	17,834	8,157	1,326	17,247
EUR		1,490	235	432

Hence, the currency pairs with a USD leg, especially USD/EUR and USD/JPY, probably dominate the price discovery process whereas those without a USD leg are likely to be price followers. However, the relative small size of a market or its limited price setting power does not *a priori* impede arbitrage activity. As long as there is a reasonably active market, arbitrage can still take place when the price deviates enough from where it should be as implied by other markets. For the CCBS bases of the seven currency pairs, the largest price deviation on a normal trading day is only 0.7 basis points. In other words, the small differences between the two basis matrices suggest that the CCBS market is well arbitraged.

However, it is important to differentiate between this triangular arbitrage and the conventional CIP arbitrage under the new bank regulatory regime. In recent literature, there has been an increasing voice arguing that the persistent non-zero bases must be the result of some quantity constraints (Bottazzi et al., 2013; Gabaix & Maggiori, 2015; Borio et al., 2016; Duffie, 2016; Du et al., 2017). One such key constraint arises from bank regulatory reforms, in particular in relation to the risk-weighted and non-risk-weighted capital requirements.[29] For the risk-weighted capital requirement the charge, which to a large extent depends on the Value-at-Risk of the net position of the trade, is much smaller for the triangular arbitrage than for the conventional CIP arbitrage. For the non-risk-weighted capital requirement, while the triangular arbitrage involves only the swap positions, the conventional CIP arbitrage also requires the arbitrageur to go long (short) in one money market and short (long) in the other, which increases the size of the balance sheet by the notional of the trade due to these cash market positions. Hence, higher capital charges under the current regulatory regime possibly underscore why the triangular arbitrage works but the conventional CIP arbitrage does not.

Nonetheless, the fact that the no-arbitrage condition of the basis matrix holds does have two important implications. First, it shows that the CCBS bases are not arbitrarily determined, as it may be the case given all plausible constraints. From a microeconomic point of view, they are fairly priced, reflecting the difference between the counterparty risks of the two money markets in the context of the risk-adjusted CIP, or the limits to arbitrage from the perspectives of those in favor of the constraint story.

[29] In their example of a five-year CIP trade using CCBS, Du et al. (2017) estimate that capital charges attributable to the risk-weighted capital requirement surge from 0.4% to more than 4% of the notional principal under Basel III, while those due to the non-risk-weighted capital requirement (i.e., the leverage ratio) increase by 3%.

Second, the well-arbitraged CCBS bases are different across currency pairs, even between those with a USD leg. This seems to suggest that the persistence of bases in CCBSs is unlikely to reflect a dollar shortage. At best one may argue that the phenomenon is attributable to a relative dollar shortage, e.g., a dollar shortage relative to a euro or yen shortage. The same applies for those who try to link the bases to the role of the dollar as a global funding currency. In this connection, the particular challenge to the notion of the breakdown of CIP as a dollar phenomenon is how one accounts for the different bases across currency pairs, e.g., why some are more negative than the others.

6.2 Estimation results

A major objective of this study is to find out how the swap dealer sets the forward premium using the domestic and foreign risk-free and risk-embedded interest rates. This is what equations (16) and (17) set out to do. However, econometrically, unless the interest rates are exogenous, estimating the models by means of ordinary least squares (OLS) potentially invites the problem of endogeneity which, if exists, can cause the estimators to be biased. In particular, the concern about endogeneity arises from simultaneous causality between the forward premium and the four interest rates, as the forward premium may arguably also affect the interest rates.

While the (spot) exchange rate and the interest rates of the two countries concerned are likely to be co-determined, it is hard to imagine the same applies to the relationship between the forward premium (the difference between the spot and forward exchange rates) and the interest rates. Nonetheless, to address the concern, we first estimate a model by means of the generalized method of moments (GMM) assuming that endogeneity exists, and then test the validity of this specification. In the GMM model, the endogenous variables are the four interest rates and the exogenous instruments are the one-day to five-day lags of domestic and foreign government bond yields, domestic and foreign bank CDS spreads and the VIX index, all in first difference form. These instruments are hardly affected by the forward premium, but are correlated with the interest rates of the two countries through the risk-free opportunity cost of borrowing, counterparty risk and liquidity risk channels. Based on the GMM estimation, we conduct the Durbin-Wu-Hausman test to examine if the four endogenous variables are exogenous. The results show we cannot reject the null hypothesis that these variables are exogenous at the 10% or higher significance level for the seven currency pairs.[30] This means the estimators in the OLS models are unbiased. Since the OLS estimators are more efficient than those in the GMM, we stick with OLS in our final estimation.

The estimation results are shown in Table 4.[31] As can be seen from the first rows in the unrestricted and restricted models, the constant C_0 in all regressions are extremely close to zero and statistically insignificant. The estimation results from the unrestricted model according to equation (16) support hypotheses 2a and 2b. First, most coefficients are highly significant in the unrestricted models with signs consistent with our expectation. Secondly, all four coefficients (C_1 to C_4) in each regression fall between zero and one. Thirdly, the sum of the coefficients of IRS and OIS in the same currency is very close to unity. They are plotted in Figure 11 for ease of inspection. For the four currency pairs with a USD leg, i.e., USD/EUR, USD/GBP, USD/CHF and USD/JPY, the sum of the shares of counterparty and liquidity risk premiums for USD is 99.2%, 96.1%, 100.2% and 98.0% respectively. For the three currency pairs with a EUR leg, i.e., EUR/GBP, EUR/CHF and EUR/JPY, the sum for EUR is 100.3%, 100.1% and 98.5% respectively. To formally examine the validity of hypotheses 2a and 2b, we further apply Wald tests, $C_1 + C_3 = 1$ and $C_2 + C_4 = 1$, on each regression separately. As can be seen from Table 6, eight out of the 14 tests show that we cannot reject hypotheses 2a or 2b at the 10% or higher significant levels. For the other six tests, while we can reject the hypothesis, it is worth noting that the rejection is mainly caused by the small size of the standard errors.

It is also interesting to see that the share of counterparty risk premium associated with any currency is relatively stable regardless of which currency is in the other leg. For example, the share of counterparty risk premiums for USD is 17.5%, 18.9% and 16.1% when the other leg is the EUR, CHF and JPY respectively; that for EUR is 76.2%, 79.9%, 71.0% and 76.1% when the other leg is USD, GBP, CHF and JPY respectively. This indicates that, on average, counterparty risk premium accounts for a consistently smaller share in the total risk premium in the USD Libor market when compared to Libor

[30] The Durbin-Wu-Hausman test statistics for each currency pair are listed below. The null hypothesis is that the first differences of domestic and foreign currency IRS and OIS are exogenous.

Curr pairs	USD/EUR	USD/GBP	USD/CHF	USD/JPY	EUR/GBP	EUR/CHF	EUR/JPY
Diff. in J-stat	3.9757	5.8490	2.7510	5.8828	2.8020	2.3178	4.5259
Probability	0.4093	0.2107	0.6003	0.2081	0.5915	0.6775	0.3395

[31] As a robustness check, we present the results based on winsorized data between 0.5% and 99.5% percentiles in Table 5. They are broadly consistent with those using the five-standard-deviation outlier-detection method in Table 4.

markets of the other currencies, while counterparty risk premium takes up a much larger share in the EUR Libor market. Perhaps, the only exception is GBP, as the share of counterparty risk premium for USD vis-à-vis GBP is 36.8%, which is still small but somewhat larger when compared to the other currencies. Hence, overall, the evidence seems to suggest that the share of counterparty risk premium is perceived to be fairly consistent across the non-USD currencies.

In light of the above results, we estimate the restricted model to improve the precision of the estimates. As can be seen, the results are consistent with those of the unrestricted one, where the coefficient representing the share of counterparty risk premium falls strictly between zero and one, and remains broadly consistent across currency pairs. The average shares of counterparty risk premiums for USD and EUR in the restricted model are 23.7% and 76.7% respectively, which are close to their unrestricted counterparts of 22.3% and 75.8%. In both restricted and unrestricted models, the fitness of regression is surprisingly good, considering that the variables are in the form of first differences. Adjusted R-squared, for both restricted and unrestricted estimations, lies between 0.62 and 0.80 for most regressions except for EUR/CHF (0.36) and EUR/JPY (0.52). Since the adjusted R-squared reduces only marginally, the restrictions are reasonable and sound.

However, an important caveat to the estimates of the shares of these risk premiums is how well the Libor-OIS spread can represent the risks involved for CCBS pricing or, in other words, how applicable Libors are for CCBS participants to borrow on an unsecured basis. Admittedly, the Libor-OIS spread is not a perfect measure of the risks for the CCBS market. First, the Libor scandal is well known and therefore its reliability as a measure of the cost of funding accessible by banks in general seems questionable (Hou & Skeie, 2014). Second, there is a considerable difference in the composition between the Libor and CCBS markets. The Libor market consists of mainly banks, while the CCBS market is composed of a wide range of financial and non-financial institutions, including banks, insurers, investment managers, hedge funds and large corporations. It is clear, therefore, that most of the CCBS market participants are unable to access funds at Libors on an uncollateralized basis. As a result, the risks are likely to be underestimated. Nonetheless, the spread is still arguably the best available measure that can serve as a reasonably good approximation of the risks for our estimation, especially since first difference data are employed.

7. Conclusion

The breakdown of CIP is more of a myth in the sense that the returns on investing in different currencies are no longer the same even after exchange rate risk is covered. True, exchange-rate-risk-covered returns, taken at face value, are no longer the same because the uncovered returns, as commonly represented by Libors in testing CIP, consist of considerable counterparty and liquidity risk premiums in today's money market. Hence, CIP breaks down as Libors, which are interest rates for unsecured borrowing/lending, are no longer fit for use in pricing CCBSs, which are secured transactions. Therefore, the uncovered returns must be adjusted for the counterparty risks involved in the transaction. This is precisely what the swap dealer is trying to do in the CCBS market.

In short, therefore, the CCBS basis is no mystery. It merely reflects the price adjustment the swap dealer has to undertake in order to make the transaction fair to both sides. This adjustment is absolutely necessary due to one important fact: the counterparty risk in the domestic currency money market differs from that in the foreign currency money market. Therefore, the invalidity or inobservance of CIP as manifested by the non-equivalence between the Libors of two currencies does not mean that the market has failed. Quite the contrary, the change in the behavior of market participants reflects that the market has functioned particularly well as it prices in the associated risks in CCBS transactions. Expecting CCBS bases to be zero in today's financial markets is failing to recognize the importance that market participants, in pricing or trading a financial product, must consider the risks that are factored into the prices of its reference financial products instead of taking them at face value. CIP asks the swap dealer to take money market rates at face value. Obviously he would not be obliged.

In this paper, we have argued that the swap dealer behaves as if he tries to remove the counterparty risk premium in the money market rates when pricing the CCBS. Given that the CCBS basis is the same as CIP deviation, we have estimated the forward premium using the domestic and foreign OIS rates and IRS rates for seven currency pairs using the risk-adjusted CIP model. The empirical results support our thesis that the forward premium is largely determined by the difference between the weighted averages of OIS and IRS rates for both the domestic and foreign currencies as predicted by the model. Because the swap market, as we argue, functions effectively as a device to separate counterparty risk and liquidity risk, the model also allows us to estimate the shares of the two risk premiums that make up the Libor-OIS spread. Generally speaking, liquidity risk premium, on average, accounts for a much greater proportion relative to counterparty risk premium for USD, while the other way round is true for the other currencies. Hence, the USD lender (*cum* foreign currency borrower) tends to receive a greater discount from the foreign currency loan, causing the CCBS bases to be negative.

We have also shown that the so-called market anomaly exists not only in the CCBSs with a dollar leg but also in those without one. This finding poses a challenge to the economists who argue that CIP deviation or CCBS basis is attributable to a global shortage of US dollars or reflects the role of the US dollar as a global funding currency, for if it were purely a dollar phenomenon there is no reason why the CCBS bases vis-à-vis USD are considerably different from each other or why cross CCBS bases (i.e., those CCBSs without a dollar leg) are non-zero. We have further demonstrated how to arbitrage in the CCBS market. Interestingly, we have found that the CCBS bases satisfy a no-arbitrage condition, which means they are not arbitrarily determined but rigorously priced.

Appendix. Interest rate swap and Libor

Two parties entering into an interest rate swap (IRS) contract are obliged to make periodic interest payments to each other, based on a notional value. Since settlements in IRS are usually made on a net cash basis, the notional face values are not exchanged at inception or maturity. The interest rates of each leg can be floating or fixed. As a result, IRS becomes a commonly used tool to change the borrowing terms of an existing debt instrument, e.g., from fixed-rate to floating-rate, or from shorter-tenor to longer-tenor. In this paper, the IRS refers to the Libor-for-fixed IRS where the IRS rate is the interest rate of the fixed leg, which is often called the swap rate by dealers.

Libor-for-fixed IRS is a commonly used type of IRS where two parties swap a series of floating interest payments against a stream of fixed payments. For example, Figure 12 illustrates the cash flows in an IRS, which exchanges the Libor flat $q_{t-1,t}$ for a fixed rate q, where

$$q_{t-1,t} = tq_{0,t} - (t-1)q_{0,t-1} \tag{18}$$

The fixed rate q is set such that both legs have the same net present value, as IRS is usually initiated with zero inception cost.

According to the traditional theory of pricing fixed-income securities, the net present value of a floating-rate bond equals 1:

$$\sum_{t=1}^{n}(e^{q_{t-1,t}} - 1)e^{-tq_{0,t}} + e^{-nq_{0,n}} = 1 \tag{19}$$

Therefore, the fixed rate q is determined by equating the net present values of both legs:

$$\sum_{t=1}^{n}(e^{q} - 1)e^{-tq_{0,t}} + e^{-nq_{0,n}} = 1 \tag{20}$$

We can express the fixed rate as a function of the floating rates:

$$e^{q} = \frac{1 - e^{-nq_{0,n}}}{\sum_{t=1}^{n} e^{-tq_{0,t}}} + 1 \tag{21}$$

Based on first-order Taylor expansion around zero,

$$e^x \approx 1 + x \tag{22}$$

We can rewrite the IRS rate approximately as

$$q \approx \frac{q_{0,n}}{1 - \sum_{t=1}^{n} \frac{t}{n} q_{0,t}} \tag{23}$$

In financial markets, n is a finite (usually small) integer and $q_{0,t}$ is close to zero, such that approximating $\sum_{t=1}^{n} tq_{0,t}/n$ as zero can be roughly accepted. Therefore, q can be viewed as a close approximation of $q_{0,n}$.

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Table 1: Quarter-end spikes in the one-week Libor-OIS spreads

	USD		EUR		GBP		CHF		JPY		Panel	
							Whole period					
Constant	0.1257	***	0.0460	*	0.0917	***	-0.0758	***	0.0366	***	0.0522	***
	(0.0184)		(0.0250)		(0.0146)		(0.0208)		(0.0072)		(0.0017)	
Quarter	0.0528	***	0.0275	**	0.0182	**	0.0092		0.0100	**	0.0247	***
	(0.0085)		(0.0135)		(0.0071)		(0.0167)		(0.0047)		(0.0063)	
Obs.	2501		2535		2501		1815		2255		11607	
R-squared	0.0023		0.0041		0.0011		0.0002		0.0010		0.1217	
							Positive interest rate period					
Constant			0.0735	**			0.0250	***	0.0417	***		
			(0.0291)				(0.0060)		(0.0105)			
Quarter			0.0398	**			0.0230	***	0.0170	***		
			(0.0201)				(0.0065)		(0.0053)			
Obs.			1,751				1,244		1,896			
R-squared			0.0069				0.0023		0.0027			
							Negative interest rate period					
Constant			-0.0156				-0.2951	***	0.0092			
			(0.0070)				(0.0055)		(0.0609)			
Quarter			0.0056	**			-0.0242	***	-0.0259	*		
			(0.0024)				(0.0084)		(0.0141)			
Obs.			784				571		359			
R-squared			0.0047				0.0109		0.0322			

1. *Quarter* is a dummy variable that equals one when the observation is within the last five trading days of a quarter, and equals zero otherwise.
2. Regressions for individual currencies are estimated using Newey-West standard errors with 65 lags (average number of trading days in a quarter) and pre-whitening with 22 lags (average number of trading days in a month). The panel regression includes currency fixed effects.
3. The whole sample period spans from August 9, 2007, to June 30, 2017, which is divided into positive and negative interest rate periods depending on the currency (if applicable). The negative interest rate period for EUR, CHF and JPY starts from June 14, 2014; January 15, 2015; and January 29, 2016, respectively.

Table 2: Descriptive statistics of key variables

	USD	EUR	GBP	CHF	JPY
	Five-year forward premium (annualized, %) vis-à-vis USD				
Mean		-0.93	-0.15	-1.77	-2.01
Median		-0.75	-0.04	-1.51	-2.06
Maximum		0.69	0.62	-0.57	-1.10
Minimum		-2.58	-1.59	-3.19	-2.93
Std. Dev.		0.82	0.47	0.66	0.40
Obs.		2,029	2,029	2,029	2,029
	Five-year forward premium (annualized, %) vis-à-vis EUR				
Mean			0.78	-0.84	-1.08
Median			0.65	-0.80	-0.94
Maximum			2.02	-0.26	0.01
Minimum			-0.36	-1.57	-3.11
Std. Dev.			0.51	0.28	0.69
Obs.			2,029	2,029	2,029
	Five-year IRS rate (%)				
Mean	1.60	1.01	1.55	0.27	0.26
Median	1.60	0.83	1.45	0.25	0.25
Maximum	2.94	3.10	3.34	1.73	0.78
Minimum	0.72	-0.34	0.30	-1.00	-0.24
Std. Dev.	0.50	0.93	0.69	0.72	0.19
Obs.	2,012	2,029	1,978	2,015	2,029
	Five-year OIS rate (%)				
Mean	1.34	0.78	1.30	0.14	0.14
Median	1.37	0.63	1.18	0.13	0.15
Maximum	2.79	2.82	3.11	1.60	0.57
Minimum	0.47	-0.47	0.13	-0.95	-0.37
Std. Dev.	0.53	0.85	0.68	0.61	0.17
Obs.	2,029	2,029	2,029	1,899	2,029
	Five-year IRS-OIS spread (bps)				
Mean	26.3	22.7	25.6	5.2	11.2
Median	25.1	19.6	22.7	9.2	10.5
Maximum	55.7	57.6	66.4	32.3	21.6
Minimum	13.0	7.3	12.1	-18.1	2.6
Std. Dev.	7.1	9.6	8.4	9.3	4.0
Obs.	2,012	2,029	1,978	1,887	2,029

1. This table reports the summary statistics for forward premiums, IRS, OIS and IRS-OIS spreads of five major currencies, namely US dollar, euro, British pound, Swiss franc and Japanese yen.
2. The forward premium is calculated as the annualized premium or discount between the spot and forward exchange rate, which is continuously compounded.
3. The sample period is from September 22, 2009, to June 30, 2017, subject to data availability.

Source: Bloomberg

Table 3: Metadata of IRS and OIS rates

	USD	EUR	GBP	CHF	JPY
			IRS rates		
Reference rate	3M Libor	3M Euribor	3M Libor	3M Libor	6M Libor
Payment frequency	Quarterly	Annually	Quarterly	Annually	Semi-annually
			OIS rates		
Reference rate	Effective Fed funds rate	Euro overnight index average	Sterling overnight index average	Tom/next indexed swap in CHF fixing	Tokyo overnight average rate
Description	A weighted average of rates on trades arranged by major brokers	A weighted average of overnight unsecured lending rates in the interbank market, initiated within the euro area by contributing banks	A weighted average rate of unsecured sterling overnight cash transactions brokered in London by WMBA member firms	Based on quotations from approximately 30 reference banks for its Tom/next unsecured lending rate to prime banks, supplied to Cosmorex AG	Based on uncollateralized overnight average call rates for lending among financial institutions, published by Bank of Japan
Published by	Federal Reserve Bank New York	European Central Bank	Wholesale Markets Brokers' Association	Cosmorex AG	Bank of Japan

Source: Bloomberg and FTSE Russel

Table 4: Estimation results of unrestricted and restricted models

Foreign currency	EUR		GBP		CHF		JPY		GBP		CHF		JPY	
							Unrestricted model							
			USD as domestic currency						*EUR as domestic currency*					
Constant	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
	(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)	
C1 (FC OIS)	0.7616	***	0.4480	***	0.1175	***	0.1882	***	0.4262	***	0.0936	***	0.2143	***
	(0.0382)		(0.0446)		(0.0346)		(0.0643)		(0.0505)		(0.0365)		(0.0694)	
C2 (DC OIS)	-0.1747	***	-0.3682	***	-0.1893	***	-0.1606	***	-0.7986	***	-0.7096	***	-0.7609	***
	(0.0333)		(0.0386)		(0.0556)		(0.0495)		(0.0486)		(0.0723)		(0.0629)	
C3 (FC IRS)	0.2246	***	0.4979	***	0.7899	***	0.7243	***	0.5343	***	0.7506	***	0.6860	***
	(0.0368)		(0.0445)		(0.0453)		(0.0703)		(0.0514)		(0.0483)		(0.0742)	
C4 (DC IRS)	-0.8176	***	-0.5927	***	-0.8128	***	-0.8196	***	-0.2042	***	-0.2913	***	-0.2239	***
	(0.0329)		(0.0376)		(0.0548)		(0.0495)		(0.0468)		(0.0699)		(0.0616)	
R-squared	0.7986		0.7104		0.6278		0.6873		0.6398		0.3742		0.5183	
Adj. R-squared	0.7982		0.7098		0.6270		0.6866		0.6390		0.3729		0.5173	
DW Statistics	2.3565		2.7895		2.5773		2.5067		2.5514		2.6928		2.6482	
Log Likelihood	14317		13587		12275		13400		13477		12328		13460	
							Restricted model							
			USD as domestic currency						*EUR as domestic currency*					
Constant	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
	(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)	
C1	0.7717	***	0.4763	***	0.1295	***	0.2129	***	0.4425	***	0.1175	***	0.2499	***
	(0.0365)		(0.0440)		(0.0345)		(0.0607)		(0.0503)		(0.0364)		(0.0655)	
C2	-0.1796	***	-0.3998	***	-0.1997	***	-0.1703	***	-0.7993	***	-0.7238	***	-0.7738	***
	(0.0326)		(0.0373)		(0.0544)		(0.0490)		(0.0465)		(0.0698)		(0.0612)	
R-squared	0.7985		0.7086		0.6254		0.6868		0.6377		0.3643		0.5175	
Adj. R-squared	0.7983		0.7083		0.6250		0.6864		0.6374		0.3636		0.5170	
DW Statistics	2.3618		2.8025		2.5797		2.5117		2.5587		2.6781		2.6547	
Log Likelihood	14317		13581		12269		13398		13471		12313		13458	

1. This table reports the coefficients estimated from equation (16) (unrestricted model) and equation (17) (restricted model). Standard errors are included in parentheses.

2. The equations are estimated at daily frequency over the sample period from September 22, 2009, to June 30, 2017, subject to data availability.

3. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels.

Table 5: Estimation results of unrestricted and restricted models using winsorized data

Foreign currency	EUR		GBP		CHF		JPY		GBP		CHF		JPY	
							Unrestricted model							
			USD as domestic currency								*EUR as domestic currency*			
Constant	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
	(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)	
C1 (FC OIS)	0.6008	***	0.4035	***	0.1249	***	0.2072	***	0.3598	***	0.0779	***	0.2474	***
	(0.0450)		(0.0389)		(0.0340)		(0.0641)		(0.0481)		(0.0337)		(0.0617)	
C2 (DC OIS)	-0.1378	***	-0.2215	***	-0.2390	***	-0.1140	**	-0.6223	***	-0.4827	***	-0.5752	***
	(0.0364)		(0.0386)		(0.0577)		(0.0523)		(0.0563)		(0.0830)		(0.0693)	
C3 (FC IRS)	0.3728	***	0.5401	***	0.7747	***	0.6959	***	0.5897	***	0.7187	***	0.6902	***
	(0.0444)		(0.0390)		(0.0440)		(0.0690)		(0.0490)		(0.0458)		(0.0660)	
C4 (DC IRS)	-0.8466	***	-0.7495	***	-0.7647	***	-0.8558	***	-0.3551	***	-0.4917	***	-0.4166	***
	(0.0364)		(0.0386)		(0.0576)		(0.0529)		(0.0555)		(0.0818)		(0.0689)	
R-squared	0.7908		0.7627		0.6342		0.6843		0.6538		0.3716		0.5532	
Adj. R-squared	0.7904		0.7622		0.6334		0.6837		0.6530		0.3703		0.5523	
DW Statistics	2.3335		2.4985		2.6048		2.4091		2.4206		2.6338		2.5088	
Log Likelihood	14086		13600		12190		13228		13400		12271		13493	
							Restricted model							
			USD as domestic currency								*EUR as domestic currency*			
Constant	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
	(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)		(0.0000)	
C1	0.6174	***	0.4292	***	0.1390	***	0.2314	***	0.3798	***	0.1080	***	0.2702	***
	(0.0440)		(0.0384)		(0.0339)		(0.0595)		(0.0479)		(0.0337)		(0.0582)	
C2	-0.1458	***	-0.2457	***	-0.2485	***	-0.1232	**	-0.6390	***	-0.5205	***	-0.5808	***
	(0.0359)		(0.0381)		(0.0571)		(0.0520)		(0.0550)		(0.0818)		(0.0683)	
R-squared	0.7905		0.7605		0.6312		0.6835		0.6517		0.3568		0.5529	
Adj. R-squared	0.7903		0.7603		0.6308		0.6831		0.6513		0.3561		0.5524	
DW Statistics	2.3396		2.5194		2.6115		2.4142		2.4305		2.6233		2.5149	
Log Likelihood	14085		13591		12183		13225		13394		12249		13492	

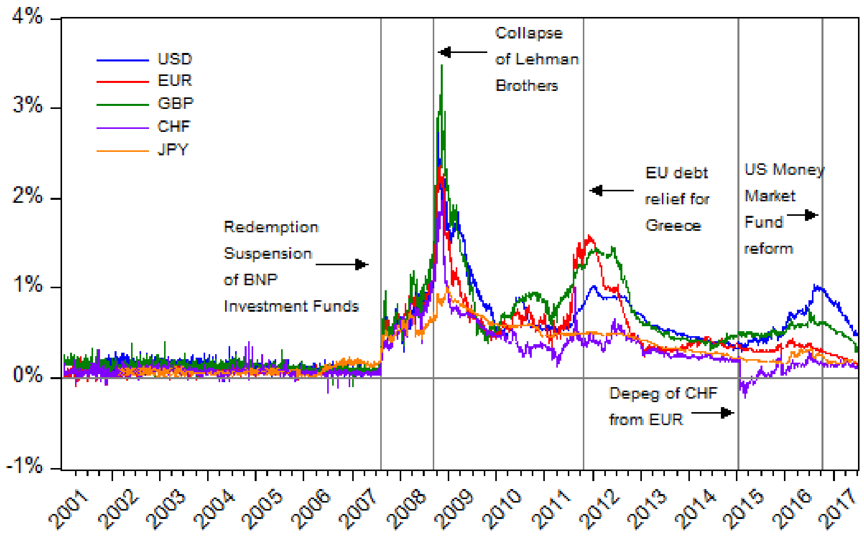
1. This table reports the coefficients estimated from equation (16) (unrestricted model) and equation (17) (restricted model) using winsorized data between 0.5% and 99.5% percentiles. Standard errors are included in parentheses.
2. The equations are estimated at daily frequency over the sample period from September 22, 2009, to June 30, 2017, subject to data availability.
3. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels.

Table 6: Wald test results of unrestricted models

Foreign currency	EUR	GBP	CHF	JPY	GBP	CHF	JPY
		Domestic currency is USD			*Domestic currency is EUR*		
$C1 + C3 = 1$ (FC)		***	***		**	***	*
t-statistic	-0.9015	-3.4070	-2.8285	-1.6158	-2.3411	-4.1489	-1.8361
F-statistic	0.8126	11.6076	8.0005	2.6107	5.4808	17.2132	3.3711
p-value	0.3675	0.0007	0.0047	0.1063	0.0193	0.0000	0.0665
$C2 + C4 = -1$ (DC)		***					
t-statistic	0.6708	2.6604	-0.1149	1.3169	-0.1343	-0.0307	0.7126
F-statistic	0.4499	7.0778	0.0132	1.7343	0.0180	0.0009	0.5078
p-value	0.5025	0.0079	0.9086	0.1880	0.8932	0.9755	0.4762

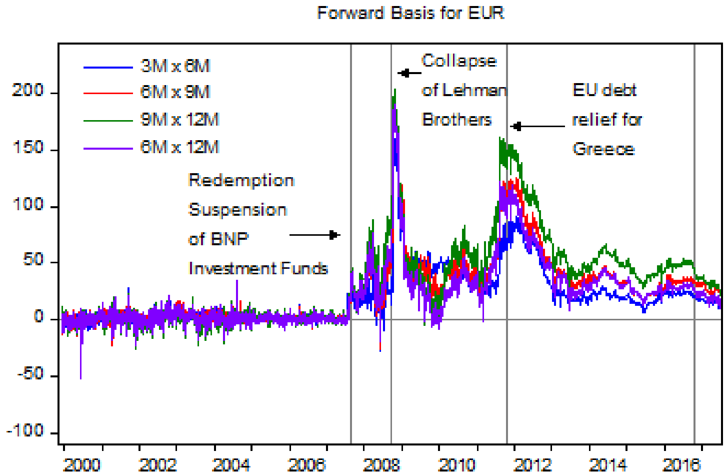
1. This table reports the Wald test t-statistics, F-statistics and p-values of the unrestricted models. For foreign currency and domestic currency, we separately test whether the sum of the coefficients of IRS and OIS is equal to one.
2. *, ** and *** denote statistical significance at 10%, 5% and 1% levels.

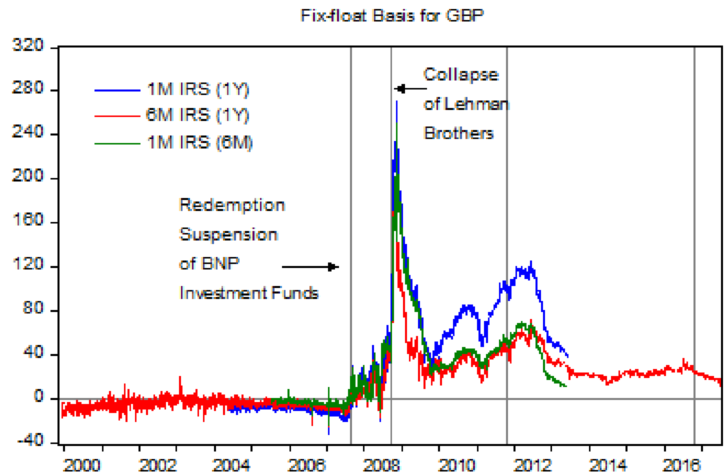
Figure 1: 12-month Libor-OIS spreads of major currencies

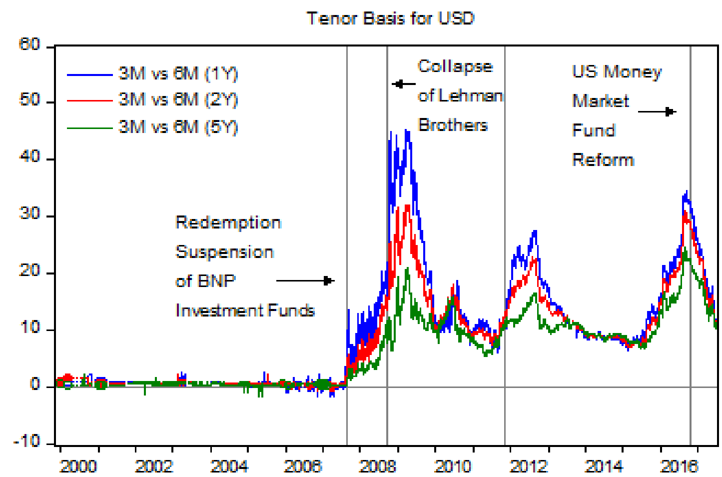


Source: Bloomberg

Figure 2: Single currency basis spreads

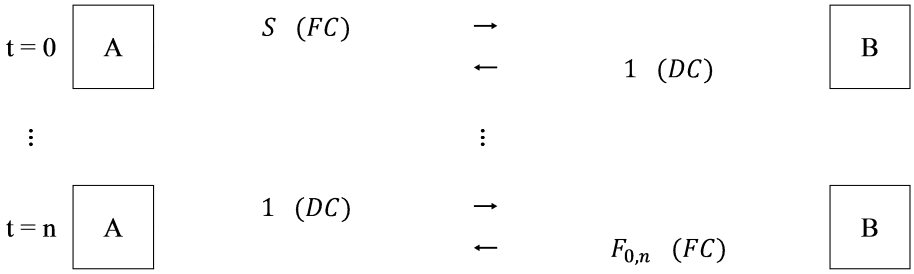






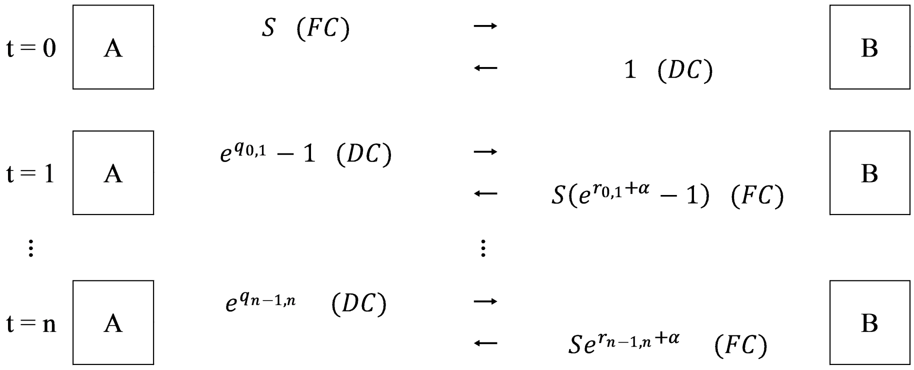
Source: Bloomberg

Figure 3: Cash flows of an n-period FX swap



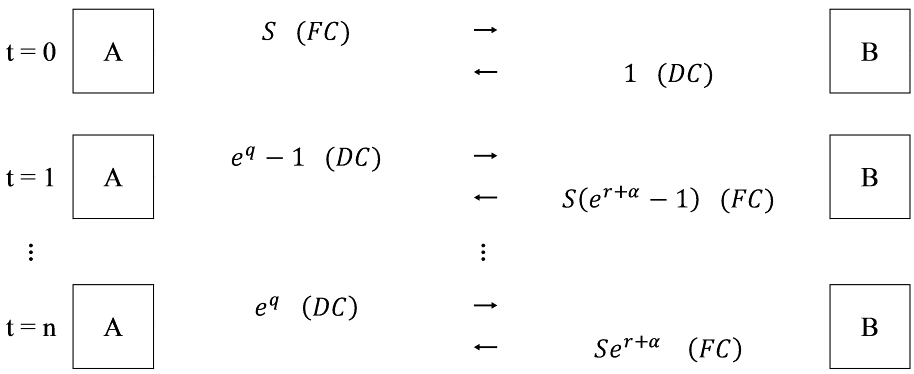
This figure shows the cash flows of an n-period FX swap between domestic and foreign currencies. S is the spot exchange rate and $F_{k,m}$ is the time m forward exchange rate determined at time k, both expressed as the amount of foreign currency per unit of domestic currency. For simplicity, we set the notional principal to one unit of domestic currency or S units of foreign currency.

Figure 4: Cash flows of an n-period CCBS



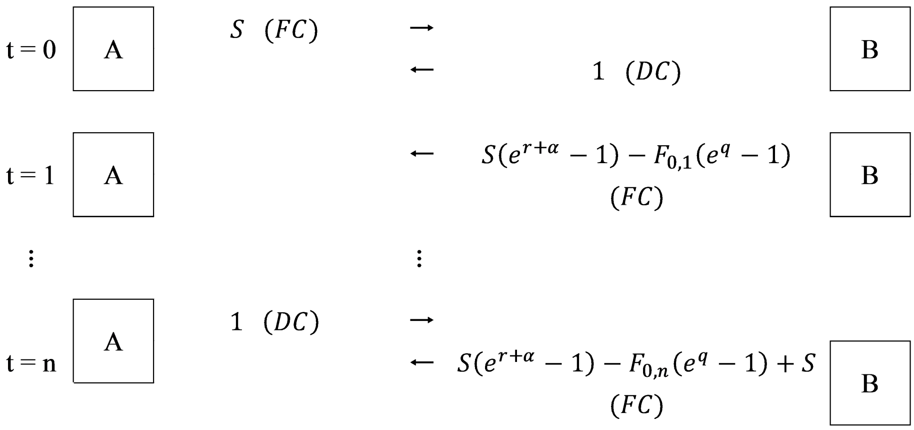
This figure shows the cash flows of an n-period CCBS between domestic and foreign currencies. α denotes the CCBS basis to be added to $Libor_{FC}$, and $r_{k,m}$ and $q_{k,m}$ are the $Libor_{DC}$ and $Libor_{FC}$ from time k to time m respectively.

Figure 5: Cash flows of an n-period CCBS after floating-to-fixed conversion



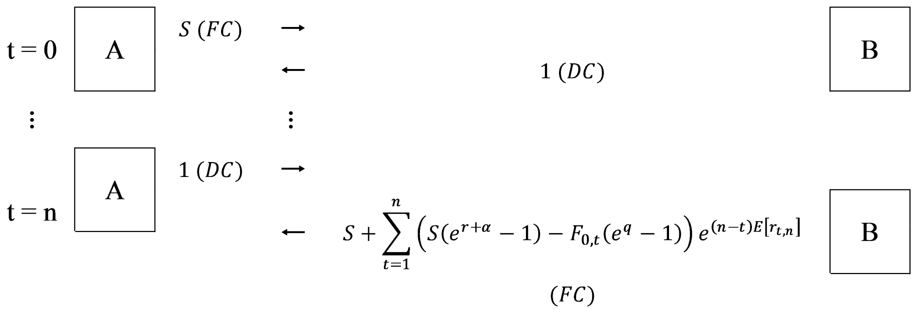
This figure shows the cash flows of an n-period CCBS between domestic and foreign currencies with the floating-rate interest payments ($r_{k,m}$ and $q_{k,m}$) converted to fixed-rate ones (r and q) using IRS. r and q are the IRS rates of floating interest curves constructed using $r_{k,m}$ and $q_{k,m}$.

Figure 6: Cash flows of an n-period CCBS after floating-to-fixed and domestic-to-foreign conversions



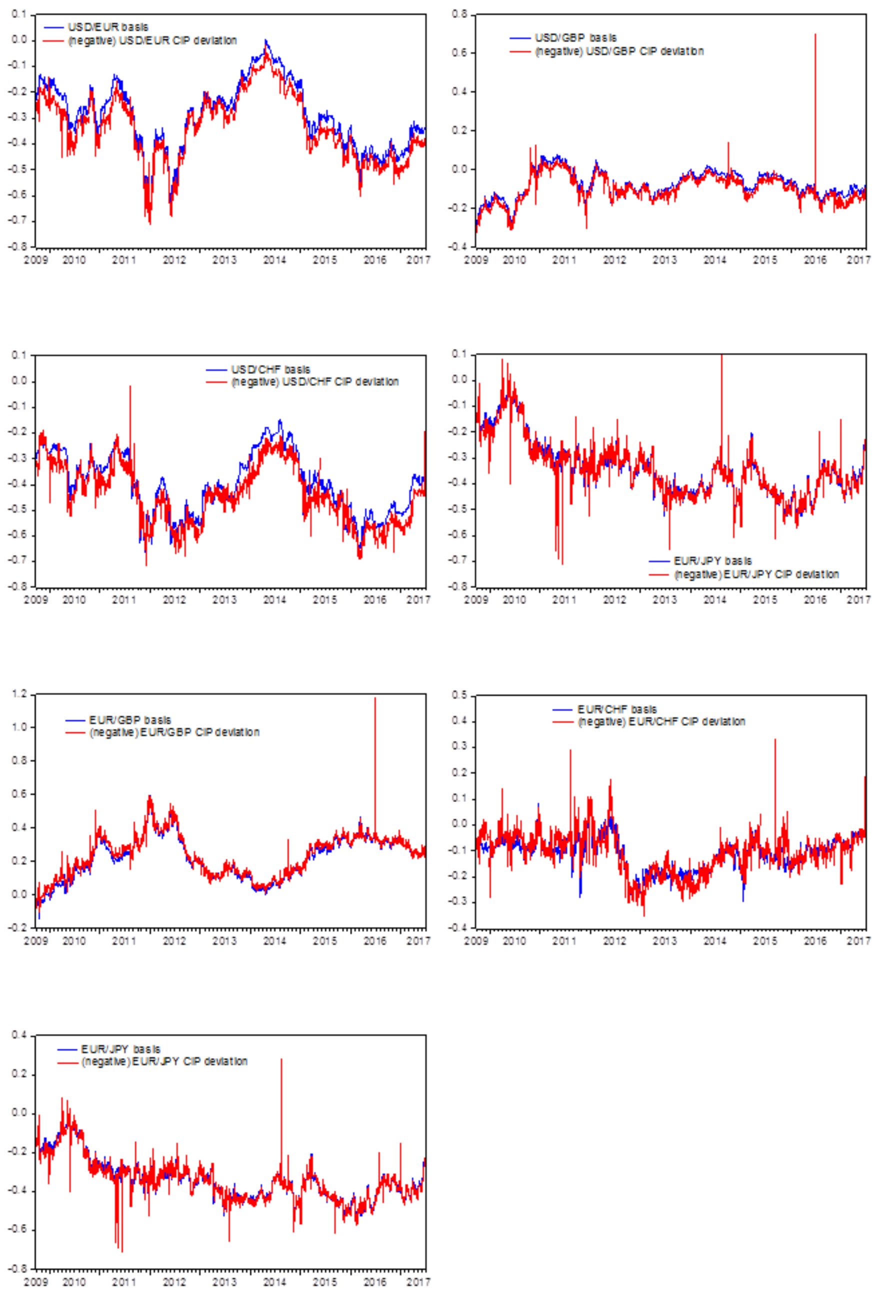
This figure shows the cash flows of an n-period CCBS between domestic and foreign currencies with the floating-rate interest payments ($r_{k,m}$ and $q_{k,m}$) converted to fixed-rate ones (r and q) using IRS, and domestic currency interest payments converted to foreign currency ones using FX swaps.

Figure 7: Cash flows of an n-period CCBS after floating-to-fixed and domestic-to-foreign conversions and reinvesting interests until maturity



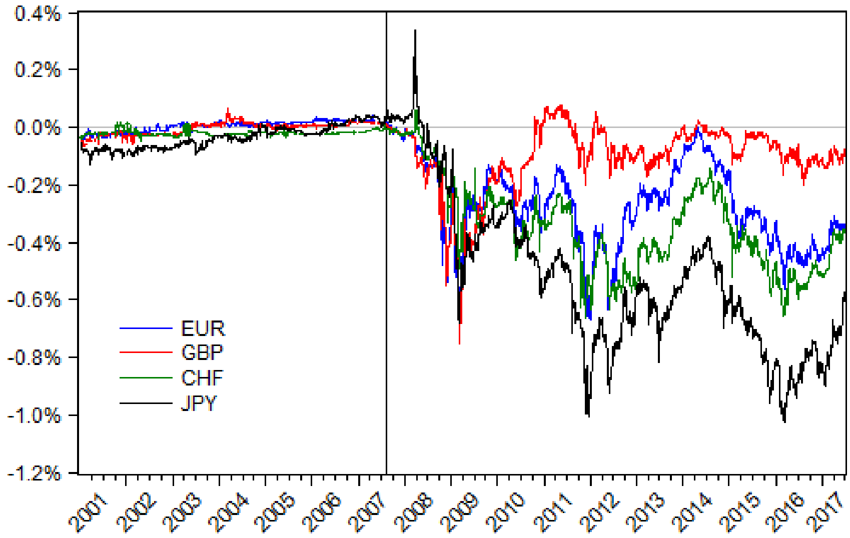
This figure shows the cash flows of an n-period CCBS between domestic and foreign currencies with the interest payments converted from floating-rate domestic-currency to fixed-rate foreign-currency ones using IRS and FX swaps, and reinvested to maturity using FRAs.

Figure 8: Five-year CCBS basis and CIP deviation



Source: Bloomberg

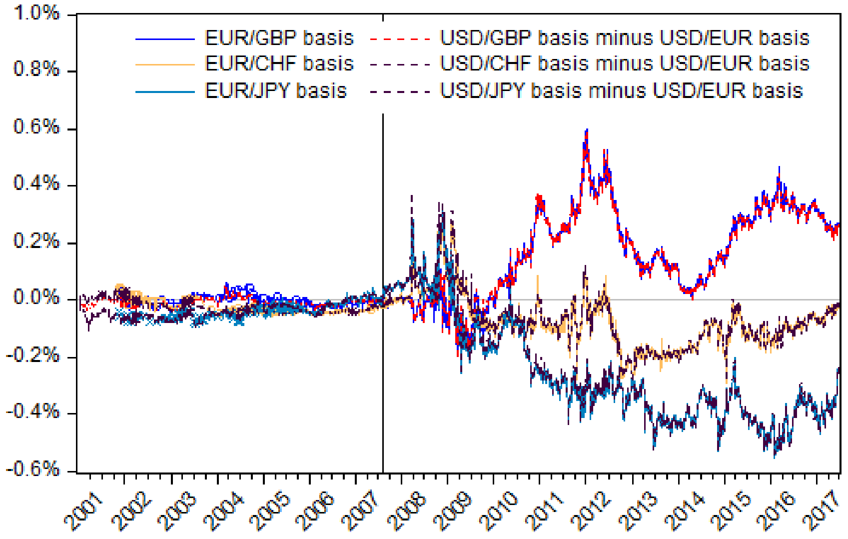
Figure 9: CCBS basis with a USD leg



The vertical line represents August 9, 2007 (BNP Paribas suspended redemption for three of its investment funds).

Source: Bloomberg

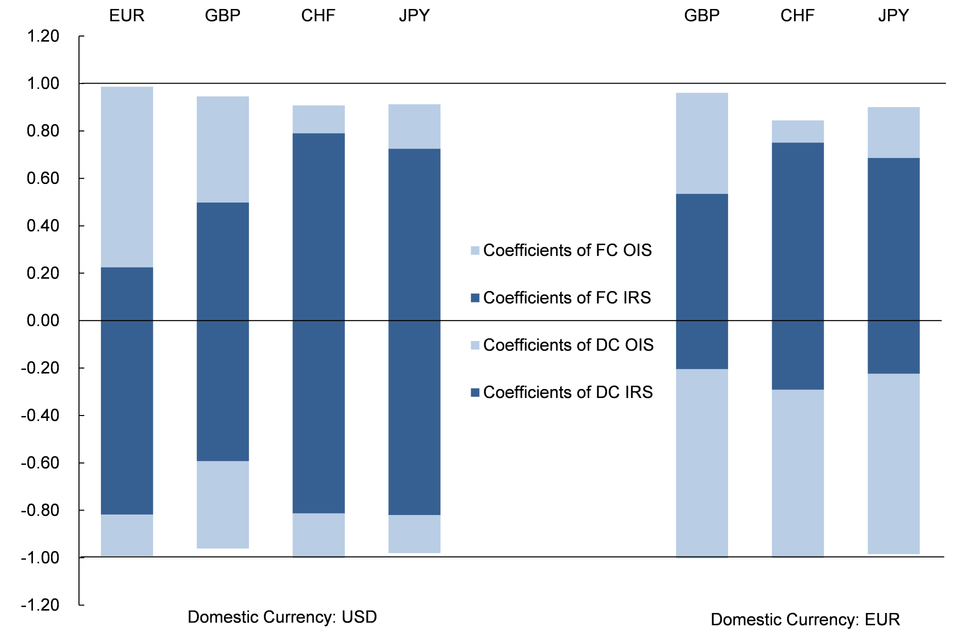
Figure 10: CCBS basis with a EUR leg



The vertical line represents August 9, 2007 (BNP Paribas suspended redemption for three of its investment funds).

Source: Bloomberg

Figure 11: Sum of unrestricted coefficients of IRS and OIS



Source: Table 4

Figure 12: Cash flows of an n-period Libor-for-fixed IRS