Covered Interest Rate Parity Deviation and Global Banks Dollar Funding

Yida Li*

October, 2021

Abstract

The persistence of covered interest rate parity (CIP) deviations has been a fundamental puzzle in international finance. Since global financial crisis (GFC), these deviations have implied a persistent dollar financing premium for banks versus other major currencies, and have long attracted the attention from academia and policy makers. In this paper, using a model of dollar funding of global banks in the foreign exchange (FX) swap market, I study the contributions of credit spread differential, bank's default premium, and the global banks' liquidity needs, to CIP deviations. Then I empirically examine whether the data is consistent with the model predictions, and find that the relative significance of each component in CIP deviation has changed over time, as default premium was the dominant driver around GFC, credit spread differential has been contributing to the rise in CIP deviations in recent years. I also show that the CIP dollar basis for one currency is affected by the financial conditions in other countries, who may also participate swap transactions of USD in the FX market.

*Department of Economics, University of Washington, liyida@uw.edu

1 Introduction

Covered interest rate parity (CIP) is one of the most fundamental building blocks of international finance. As a no-arbitrage relationship, it states that the rate of return on equivalent domestic and foreign assets should be equal upon covering exchange rate risk with a forward contract. The CIP is the cornerstone linkage to integrate money and foreign exchange markets, and has appeared to hold quite closely for several decades until the Global Financial Crisis (GFC). But as an emerging number of studies document, CIP has broken down since the onset of GFC. The initial deviation from CIP in 2008 was plausibly attributable to the financial crisis, during which increases in default risk for non-U.S. banks in inter-bank markets translated into a significant premium for borrowing dollars. What has been more puzzling is the continuation and persistence of the deviation, and it's especially more difficult to explain that since 2014, given measures of default risk in inter-bank markets have returned to pre-crisis levels. An explanation to it resting entirely on arbitrage frictions will be incomplete, given that the FX swap market is one of the deepest and most liquid financial markets, with an average daily turnover equal to $3.2 trillion USD (BIS, 2019). With a non-negligible post-crisis violation of approximately 50 basis points, CIP deviation suggests a sizable hedging cost to bank balance sheets that may cause inefficiencies in the bank's portfolio and erode bank profits.

In this paper, I first develop a static model of dollar funding of global banks in the foreign exchange swap market, and then decompose the CIP deviation into three parts of the economic environment: credit spread differential between U.S. and non-U.S. economies, bank's default premium, and the liquidity needs of global banks. According to the decomposition of CIP deviation, the credit spread differential influences the relative attraction of assets denominated in USD or other currencies, hence influences CIP deviations through investment decisions made by U.S. and non-U.S. banks. The default premium influences CIP deviations through banks' funding decisions, by changing the relative funding cost between money market and FX swap market. And lastly, when more USD liquidity is desired, the demand for USD through the FX swap market increases and will drive up the CIP deviations.

I further empirically examine the data and find it generally accords with the model predictions. There are two observations that are particularly noteworthy. First, the relative significance of credit spread differential has been increasingly important contributing to a rise in CIP deviation, particularly after 2014. Second, banks' default premium was the dominant driver during and soon after the crisis, however, its contribution has been relatively minor for some currencies, especially when credit spread differential has been contributing more in recent years. With the third country introduced into our model, I also show that the CIP dollar basis for one currency is affected by the financial conditions in other countries, who may also participate swap transactions of USD in the FX market.

The rest of this paper is organized as follows. The next section reviewed the related literature on CIP deviation. Section 3 describes the CIP condition and the measure of CIP deviation. Section 4 provides a static equilibrium model that explains how a CIP deviation can be decomposed to economic environments, including credit spread differentials, bank's default premium and liquidity needs of global banks. Section 5 describes the empirical methodologies and the results. Section 6 concludes.

2 Related Literature

Since 2008, there has been an increasing number of literature trying to explain the CIP deviations, and they can be broadly divided into two strands. They stress that CIP deviations are predominantly driven by constraints on the *supply* of dollars available for FX swaps, and by the *demand* for dollar funding by cross-border banks, respectively. On the supply side, Baba and Packer (2009) is one of the earliest works to explain the deviations from rising counterparty risk during the financial crisis. Avdjiev et al. (2019) explore the strengthening of the dollar in limiting risk bearing capacity. Du et al. (2018) emphasizes the rising balance sheet costs and regulatory requirements limiting arbitrage capital among many others (Anderson et al., 2019; Cenedese et al., 2020; Correa et al., 2020; Liao, 2020). They also propose that the short-term (3-month) CIP deviations show significant rises at quarter-ends as banks off-load their holdings of short-term swap. Similarly, Cenedese et al. (2020) use micro-level evidence to show that the more leveraged dealers are more sensitive to structural imbalances in the FX swap market, hence price significantly higher forward premia, and CIP deviations.

The second strand focuses on demand side factors for dollar funding in the FX swap market. This includes the impact of monetary policies (Bahaj and Reis, 2018; Borio et al., 2016; Bräuning and Ivashina, 2020; Du et al., 2018; Iida et al., 2018), shocks to dollar funding for European banks during the sovereign debt crisis (Ivashina et al., 2015), and differences in funding costs across currencies (Liao, 2020; Rime et al., 2019; Syrstad, 2020). My paper connects the supply and demand side of global dollar funding in the FX swap market by extending the theoretical model of CIP deviation developed by Ivashina et al. (2015) and He et al. (2015), and discusses the determinants of CIP deviations.

My paper also speaks to a recent literature of modeling CIP deviations. Their models mostly focus on increasing limits or adding restrictions on arbitrage. Ivashina et al. (2015) imposes an outside cost of capital, Vayanos and Vila (2009) and Gourinchas et al. (2019) introduce the segmented market, and many others achieve it by tightening balance sheet constraint of arbitrageurs supplying USD in the FX swap market (Avdjiev et al., 2019; Borio et al., 2018; Fang and Liu, 2019; Gabaix and Maggiori, 2015; Liao and Zhang, 2020; Liao, 2020).

3 CIP Condition and Measuring CIP Deviations

In this section, we review the CIP conditon and define the measure of deviation from the CIP condition, the cross-currency basis. We then empirically document the persistent deviation from the CIP condition.

3.1 Covered Interest Rate Parity

Let $y_{t,t+n}$ and $y^{\$}_{t,t+n}$ respectively denote the continuously compounded n-year annualized risk-free interest rates at time t in home currency and U.S. dollars. S_t is the spot exchange rate between home currency and U.S. dollars, which is expressed in units of home currency per USD and an increase in S_t hence implies an appreciation in of USD and a depreciation of the home currency. $F_{t,t+n}$ is the forward exchange rate at time t in home currency per USD. With these notations, the CIP condition can be written as

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

The intuition behind the CIP condition is that an investor should be indifferent between the following two strategies: (i) an investor with one USD at time t can invest in USD and would have $e^{ny^{\$}_{t,t+n}}$ USD at time $t+n$. (ii) The investor may alternatively exchange her one USD for S_t units of home currency at time t, invest in home currency and would have $S_t e^{ny_{t,t+n}}$ units of home currency n years from time t. At time t, the investor also signed a currency forward contract to lock into a $t+n$ forward exchange rate $F_{t,t+n}$ that converts the home currency proceeds into USD, which equals $\frac{S_t}{F_{t,t+n}} e^{ny_{t,t+n}}$. Therefore, the return of the two investment strategies should be the same under the CIP condition. These two strategies are shown in Figure 1. As illustrated, the CIP condition is thus a non-arbitrage condition.

[Figure 1 is here]

3.2 Measuring CIP Deviations

When there are deviations from CIP, Equation (1) does not hold, suggesting that one investment strategy now generates a higher return than the other. The difference between the two payoffs is know as the cross-currency basis, $x_{t,t+n}$. We can write the the continuously compounded cross-currency basis as the deviation from the CIP condition:

$$e^{ny^{\$}_{t,t+n}} = \frac{S_t}{F_{t,t+n}} e^{ny_{t,t+n} + nx_{t,t+n}} \tag{2}$$

In logs, we can write that the forward premium, $\rho_{t,t+n}$, based on Equation (1) is equal to the interest rate difference between the two markets:

$$\rho_{t,t+n} \equiv \frac{1}{n}(f_{t,t+n} - s_t) = y_{t,t+n} - y^{\$}_{t,t+n} \tag{3}$$

Then equivalently in log, the cross-currency basis can be written as

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

Here we further denote the synthetic U.S. dollar return, $y_{t,t+n} - \rho_{t,t+n}$, as $y^{\$,syn}_{t,t+n}$. The cross-currency basis thus measures the difference between direct USD return $y^{\$}_{t,t+n}$ and the synthetic dollar return $y^{\$,syn}_{t,t+n}$, which is obtained by transferring the home interest rate into USD via currency forward contracts. One can see that when CIP condition holds, the equalization of Equation (1) and (2) obviously indicates that the cross-currency basis, $x_{t,t+n}$, is zero.

A negative (positive) cross-currency basis implies that direct USD interest rate is lower (higher) than the synthetic dollar interest rate. The arbitrageur can profit by following the procedure: borrowing USD (home currency) directly from the money market, exchanging the dollars (home currency) into home currency (dollars) at spot exchange rate, lending in home currency (dollars) while signing a forward contract locking the forward exchange rate that converts the home currency (dollars) payoff proceeds back to dollars (home currency). The arbitrageur's profit would be the dollars (home currency) proceeds received from the forward contract net of the dollar (home currency) payment she borrowed in the money market. The profit value in annualized return is just the absolute value of the cross-currency basis.

3.3 Libor-Based Cross-Currency Basis

The tests of CIP condition mostly use Libor rates as the benchmark. In this section, I present the Libor-based cross-currency basis at short and long maturities for seven currencies after 2000. The computation method of the cross-currency basis closely follows the method of Du et al. (2018), and I therefore describe it only briefly here.

3.3.1 Short-Term Libor Cross-Currency Basis

CIP deviations at short maturities, less than one year, can be computed using Libor rates and currency forward and spot rates. Specifically, the short-term Libor basis is defined as

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

where the interest rates for dollar and home currency are now the corresponding Libor rates. The daily spot exchange rates, forward points and daily Libor interbank rates are obtained from Bloomberg. Figure 2 shows the three-month Libor basis from January 2000 to April 2021 for seven major currencies against U.S. dollar: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British pound (GBP), Japanese yen (JPY), and New Zealand dollar (NZD).

As presented in Figure 2, the CIP condition holds quite well with the short-term Libor-based CIP deviations closely fluctuating around the level of zero for all currencies before the Global Financial Crisis (GFC). Since the onset of the GFC, the CIP condition was violated drastically with some bases distorted to almost -200 bps. However, the non-zero Libor-based basis did not disappear as the crisis began to ebb. For most currencies, the three-month Libor basis has remained different from zero persistently. The left panel of Table 1 reports the summary statistics of the three-month CIP deviations with the sample period divided into three periods: pre-GFC (2000-2006), during GFC (2007-2009) and post-GFC (2010-2020). The summary table shows that the cross-currency basis was close around zero pre-crisis but became significantly different from zero during the GFC, and the basis widened further after the GFC for most currencies. Over the whole sample period, while AUD and NZD have averaged a positive basis from 7 to 12 bps, bases for other currencies are all negative, with the JPY on average has a basis below -20 bps.

[Figure 2 is here]

[Table 1 is here]

3.3.2 Long-Term Libor Cross-Currency Basis

At maturities of longer than 3 months, the predominant risk hedging instrument in foreign exchange market is a cross-currency basis swap. The cross-currency basis swap rate thus measures deviations from the CIP condition where interest rates are Libor interest rate swap rates. Daily cross-currency basis swaps data are obtained from Bloomberg. Figure 3 plots the five-year Libor basis from January 2000 to December 2020 for the seven currencies.

[Figure 3 is here]

Similar to the fact in short-term Libor basis, all bases were fluctuating very close to zero before 2007, with slightly positive basis for Australian, Canadian, and New Zealand dollars and negative for all others. After 2007, the long-term Libor bases started to diverge significantly from zero. Though the bases narrowed right after the crisis, the deviations enlarged again and reach their peaks in 2012 during the European deb crisis and again in 2016. The right panel of Table 1 reports the mean and standard deviations in the three sub-periods. After the GFC, AUD and NZD have the most positive bases with mean of 24 and 30 bps, respectively. JPY, CHF and EUR exhibit the most negative one with -59, -34 and -27 bps on average.

In sum, the CIP condition holds quite well before the GFC but has been systematically and persistently violated since the GFC for most major currencies at both short and long maturities. In post-crisis time, the CIP deviations remain compelling and it's puzzling that these significant arbitrage opportunities in currency and fixed income markets exist long after the crisis.

4 A Model of CIP Deviations

This section provides a simple equilibrium model connecting the money market and the foreign exchange market to explain the economic determinants to CIP deviations. I borrow the model setting from Ivashina et al. (2015) and He et al. (2015). In the model, an equilibrium level of CIP deviation is determined as the price that clears the demand and supply of dollar funding. In addition to the impact of banks's creditworthiness, our model features the impact of the credit spread differentials between U.S. and non-U.S. markets, regulatory requirements and liquidity shocks.

The static model consists the U.S. and a non-U.S. country and two financial intermediaries, a U.S. based arbitrageur and a non-U.S. financial institution respectively.

4.1 USD demand in the FX swap market: the non-U.S. bank

I assume a non-U.S. financial institution is a Japanese bank that have its assets on the balance sheet denominated in two currencies: JPY denominated assets and USD-denominated assets, including loans and bonds, etc. The two types of assets are denoted by L_{US} and L_{JP}. L_{US} and L_{JP} deliver the rate of return $r^* + l^*$ and $r + l$, respectively, where r^* and

r are the risk-free rates, l^* and l are the credit spreads on top of the risk-free rates in the U.S. and Japan. In addition to the assets holding, the Japanese bank also holds some liquid USD-denominated assets M, which is assumed to generate zero return.

A Japanese bank holds M in response to different kinds of constraints, as discussed in Aoki et al. (2013). On one hand the bank need to meet the explicit regulatory requirements, and on the other hand that bank also holds the liquidity assets to comply its own risk management rules, such as the stress testing constraints. We assume the that the minimum size of liquidity needs is endogenously given by V.

For the liability of the Japanese bank, it raises dollar funding (D_{US}) from the U.S. money market by issuing uninsured certificates of deposit (CDs) and commercial papers (CP) at the funding cost of $1 + r^* + \alpha$, where α is the additional default premium imposed on the non-U.S. bank when financing in dollars. A Japanese bank raises JPY funding (D_{JP}) from the government-insured deposits or the money market in Japan, so that the funding cost of JPY liability is equal to r, the risk-free rate in Japan.

Given a bank takes no foreign exchange risk, whenever a non-U.S. bank's USD-denominated assets, which is the sum of M and L_{US}, is larger than the amount of USD funding D_{US}, the bank would raise USD from the FX swap market to fill the gap. The size of the swap position is denoted by S. Here to be consistent with the empirics that USD/JPY basis is negative for most of the post-crisis time, we take the cross-currency basis equals the opposite of x, the basis defined in equation (4), to make the basis positive and more intuitive given the fact that Japanese bank pays the basis as the premium to the USD supplier in the foreign exchange swap market. Then the USD funding cost from the FX swap market is equal to $r^* - r + x$, the risk-free rate differential between the U.S. and Japan with the addition of CIP basis between USD and JPY. Figure 4 shows the balance sheet of a non-U.S. bank.

[Figure 4 is here]

The objective of a Japanese bank is to maximize its profits, taking all prices as given. A Japanese bank's optimization problem is given as follows:

$$\max_{\{L_{US}, L_{JP}, D_{US}, D_{JP}, M, S\}} \left[g_f(L_{US}) + g_h(L_{JP}) - c_f(D_{US}) - c_h(D_{JP}) - (r^* - r + x)S \right] \quad (6)$$

subject to

$$
\begin{aligned}
M &\geq V \\
L_{US} + M &= D_{US} + S \\
L_{JP} &= D_{JP} - S
\end{aligned}
$$

where

$$
\begin{aligned}
g_f(L_{US}) &= (1 + r^* + l^*)L_{US} - \frac{\tau^*}{2}(L_{US})^2 \\
g_h(L_{JP}) &= (1 + r + l)L_{JP} - \frac{\tau}{2}(L_{JP})^2 \\
c_f(D_{US}) &= (1 + r^* + \alpha)D_{US} + \frac{\eta^*}{2}(D_{US})^2 \\
c_h(D_{JP}) &= (1 + r)D_{JP} + \frac{\eta}{2}(D_{JP})^2
\end{aligned}
$$

Here, $g_f(L_{US})$ and $g_f(L_{JP})$ are the net return functions for USD-denominated assets and JPY-denominated assets, where τ^* and τ are parameters that capture the size of credit and administrative costs associated with L_{US} and L_{JP}. $c_f(L_{US})$ and $c_f(L_{JP})$ are the cost function of raising funds in USD and JPY respectively, where η^* and η are parameters that capture the costs associated with the liability size of a bank's balance sheets. I further assume that the four parameters (τ^*, τ, η^*, η) always take a positive value, implying a bank's profit from assets decreases with scale, and its funding cost increases with scale. The last term in equation (6) is the funding cost associated with the FX swap transactions. The first constraint specifies the minimum level of liquidity M that a bank needs to hold. The following two constraints state the no currency mismatch assumption of a bank's balance sheet.

Take the first order condition of a non-U.S. bank's optimization problem after assuming for simplicity that $\tau^* = \tau$ and $\eta^* = \eta$, we can derive a non-U.S. bank's demand for USD in the FX swap market:

$$
S = \frac{1}{2\tau}\Big[(l^* - l) - \frac{\eta + \tau}{\tau}x + \frac{\tau}{\eta}\alpha + \tau V\Big] \tag{7}
$$

The first term $(l^* - l)$ is the credit spread differential between U.S. and Japan, and it states that the demand for USD increases with the interest credit spread differential between the two countries, as a widening in the credit differential makes an investment in USD-denominated assets more attractive, relative to JPY-denominated ones. The increased demand for USD would be fulfilled at least partly in FX swap market. The second term states that the USD demand in FX swap market declines with CIP deviation x, as it implies that FX swap becomes more costly than otherwise. The third term represents a substitution effect between the U.S. money market and FX market. With a higher default premium α being charged, a non-U.S. bank's funding cost from the U.S. money market rises, which makes a bank in turn shift its funding source to the FX market. The interpretation for the last term is straightforward. When more USD liquidity needs to be held in cash, the demand for USD through the FX swap market increases.

We can also derive the amount of USD-denominated assets held by a non-U.S. bank as follows.

$$L_{US} = \frac{1}{\tau + \eta}\Big[(1 + \frac{\eta}{2\tau})l^* - \frac{\eta}{2\tau}l - \frac{\tau + \eta}{2\tau}x - \frac{1}{2}\alpha - \frac{1}{2}\eta V\Big] \tag{8}$$

The signs of the coefficients of credit spread differential and CIP deviation x are the same as those in equation (7), with the similar interpretation. In contrast to that, a bank's default premium α affects the amount of USD-denominated assets in the opposite direction, as a higher funding cost from the U.S. money market increases the total cost of dollar funding, reducing investment in USD-denominated assets. Similarly, when a non-U.S. bank faces a liquidity shortage (i.e., a higher USD liquidity needs V), it cuts back on USD-denominated assets.

4.2 USD supply in the FX swap market: the U.S. bank

We assume that a U.S. bank takes the supply side in the FX swap market as the supplier of USD, and maximizes its profit under some constraints. A U.S. bank allocates its funds to investment in USD-denominated assets (L^*_{US}) and JPY-denominated assets (L^*_{JP}), L^*_{US} and L^*_{JP} deliver the rate of $r^* + l^*$ and $r + l$ respectively. Like a non-U.S. bank, a U.S. bank also holds a certain amount USD in cash as liquid assets which we denote by M^*. The minimum size of liquidity needs for a U.S. bank is exogenously given and denoted as V^*. A U.S. bank raises USD funds with a size of D^*_{US} from the U.S. money market, and JPY funds with a size of D^*_{JP} from the Japanese money market. U.S. bank can collect USD funds such as government-insured retail deposits at the risk-free rate r, but needs to pay an additional risk premium α^* to raise JPY funds. By the assumption of no currency mismatch on the balance sheet, a U.S. bank supplies USD of amount S^* in the FX swap market to fill the gap, whenever the USD funds D^*_{JP} is larger than the bank's USD-denominated assets, which is the sum of M^* and L^*_{US}, and the return of the funding from the FX swap market is equal to $r^* - r + x$, paid by its non-U.S. counterparty. Figure 4 shows the balance sheet of a U.S. bank.

The objective of a U.S. bank is to maximize its profits, taking all prices as given. A U.S. bank's optimization problem is given as follows:

$$\max_{\{L^*_{US}, L^*_{JP}, D^*_{US}, D^*_{JP}, M^*, S^*\}} \left[g^*_f(L^*_{US}) + g^*_h(L^*_{JP}) - c^*_f(D^*_{US}) - c^*_h(D^*_{JP}) + (r^* - r + x)S^* \right] \quad (9)$$

subject to

$$\begin{aligned} M^* &\geq V^* \\ L^*_{US} + M^* &= D^*_{US} - S^* \\ L^*_{JP} &= D^*_{JP} + S^* \end{aligned}$$

where

$$\begin{aligned} g^*_f(L^*_{US}) &= (1 + r^* + l^*)L^*_{US} - \frac{\gamma^*}{2}(L^*_{US})^2 \\ g^*_h(L^*_{JP}) &= (1 + r + l)L^*_{JP} - \frac{\gamma}{2}(L^*_{JP})^2 \\ c^*_f(D^*_{US}) &= (1 + r^*)D^*_{US} + \frac{\theta^*}{2}(D^*_{US})^2 \\ c^*_h(D^*_{JP}) &= (1 + r + \alpha^*)D^*_{JP} + \frac{\theta}{2}(D^*_{JP})^2 \end{aligned}$$

Here, $g^*_f(L_{US})$ and $g^*_f(L_{JP})$ are the net return functions for USD-denominated assets and JPY-denominated assets, where γ^* and γ are parameters that capture the size of credit and administrative costs associated with L^*_{US} and L^*_{JP}. $c^*_f(L_{US})$ and $c^*_f(L_{JP})$ are the cost function of raising funds in USD and JPY respectively, where θ^* and θ are parameters that capture the costs associated with the liability size of a bank's balance sheets. The four parameters (γ^*, γ, θ^*, θ) always take a positive value, implying that a bank's profit from assets decreases with scale, and its funding cost increases with scale. The last term in equation (9) is the funding cost associated with the FX swap transactions. The first constraint specifies the minimum level of liquidity M^* that a bank needs to hold. The following two constraints state the no currency mismatch assumption of a bank's balance sheet.

Take the first order condition of a non-U.S. bank's optimization problem after assuming for simplicity that $\gamma^* = \gamma$ and $\theta^* = \theta$, we can derive a U.S. bank's supply for USD in the FX swap market.

$$S^* = \frac{1}{2\gamma}\Big[-(l^* - l) + \frac{\gamma + \theta}{\theta}x + \frac{\gamma}{\theta}\alpha^* - \gamma V^* \Big] \tag{10}$$

In contrast to a non-U.S. bank's swap position, the credit spread differential term works in the opposite direction in U.S. bank's decision. When the credit spread differential between U.S. and the non-U.S. economy widens, it is more profitable for a U.S. bank to substitute the supply of USD away from the FX swap market to other USD-denominated assets. The supply of USD in FX swap market increases with CIP deviation x, as it implies that FX swap becomes more profitable than otherwise. The third term now represents a substitution effect between the Japanese money market and FX swap market. With a higher default premium α^* being charged on JPY funds, a U.S. bank's JPY funding cost from the Japanese money market rises, making it in turn shift its funding source to, and hence supply more USD to the FX swap market. The last term shows the influences of the size of liquidity needs on the supply of FX swaps.

4.3 Equilibrium CIP Condition

Combining the FX swap demand and supply functions (7) and (10), a CIP deviation at the equilibrium is given by the following expression.

$$x = \frac{\eta\theta}{(\tau + \eta)\gamma\theta + (\gamma + \theta)\tau\eta}\Big[\underbrace{(\tau + \gamma)(l^* - l)}_{\text{credit-spread differential}} + \underbrace{\tau\gamma(\frac{\alpha}{\eta} - \frac{\alpha^*}{\theta})}_{\text{default premium}} + \underbrace{\tau\gamma(V + V^*)}_{\text{liquidity needs}} \Big] \tag{11}$$

According to the equilibrium condition, CIP deviation can be decomposed into three factors: (i) the credit spread differential $(l^* - l)$ influences the relative attraction of USD- and JPY-denominated assets, hence the CIP deviations through investment decisions made by U.S. and non-U.S. banks; (ii) the default premium influences the relative funding cost between money market and FX swap market, hence the CIP deviations through funding decisions by the two banks; (iii) last term states that when more USD liquidity is desired, the demand for USD through the FX swap market increases and will drive up the CIP deviations.

5 Empirical Analysis

Our model suggests that a CIP deviation is determined by three components: credit spread differential between two economies, default premium, and liquidity needs for U.S. and non-U.S. banks. In this section, I empirically test if the data is consistent with the model predictions, by studying the CIP deviations for four currency pairs: AUD/USD, EUR/USD, GBP/USD, and JPY/USD.

5.1 Data

My sample starts from January 2003 to December 2020. For credit spread l^* and l, I use the difference between 10-year government bond yield and corresponding OIS rate for the U.S. and the non-U.S. economies. The choice of the measure of credit spread is to ensure comparability of the measures across economies.For default premium, I use the sovereign credit default swaps (CDS) spreads as a proxy in each of the three jurisdictions. The empirical data for liquidity needs (V, V^*) of market participants is difficult to find, since they are unobservable and driven by various economic factors such as precautionary demand, transaction motive, and financial regulatory requirements. My strategy is to use VIX, the Chicago Board Options Exchange (CBOE) Volatility Index, to capture at least a portion of variations in V and V^*. VIX is widely considered as reflecting the sentiments of global investors and arbitrageurs, so we use this index as a proxy of liquidity needs due to precautionary demand originating from aggregate market uncertainty. Liquidity needs cannot be captured by VIX are included in error terms. Following what is commonly used in the existing literature, we use the CIP deviation based on Libor rates as a dependent variable.

5.2 Cross-Currency Basis and Credit Spread Differential

The time path of measures for credit spread in the four economies and the U.S are presented in Figure 5. The credit spread measure continued to fall before the GFC and reached the sample trough since the onset of the crisis. The spread in the euro area and U.K. co-move closely with that in the U.S., they rebounded quickly to the peak after the crisis and then started the downward trend, with a noticeable bounce back during the European sovereign debt crisis. The spread in Japan instead falls steadily since the GFC and hit the zero level until recent years and fluctuated around zero since then.

[Figure 5 is here]

I further find that CIP deviations are highly positively correlated with credit spread differentials between U.S. and a non-U.S. economy in the cross section, which is consistent with the model prediction. In Figure 6, I plot the positive relationship between the four currencies' sample period average credit spread measure and the period average Libor based cross-currency bases. Countries with narrower credit spread exhibit more negative cross-currency bases, which is true for both short-term (3-month) and long-term (5-year) horizon. The positive correlation is even stronger if we adjust the sample to more recent period. The finding is similar to that in Du et al. (2018).

[Figure 6 is here]

5.3 Basic regression analysis using Libor-based CIP deviations

Our baseline regressions focus on the short-term 3-month CIP deviations, and the three determinants described above as the independent variables. Specifically, our first model specification is

$$x_{it} = \beta l_{it} + \beta^* l_{it}^* + \lambda \alpha_{it} + \lambda^* \alpha_{it}^* + \delta VIX_t + c_i + \varepsilon_{it} \tag{12}$$

where subscript i stands for a country and takes a value $i =$ Australia, the Euro Area, U.K, and Japan. c_i is the country-specific fixed effects. Greek letters β, λ and δ are the coefficients to be estimated, and ε's are error terms. Samples are split into pre-crisis (2003-2006), crisis (2007-2009), and post-crisis periods (2010-2020).

We start with the pre-crisis period, in which the 3-month Libor-based cross-currency dollar basis is generally close to zero for all currency pairs (see Figure 2). Panel (a) in Table 2 presents the results of time-series regressions for individual currency pairs, as well as a panel regression with currency fixed effects. In the panel regression, the estimated signs of coefficients for explanatory variables except the liquidity needs are consistent with the model's prediction shown in equation (11) . A higher credit spread in the U.S. or a lower credit spread in non-U.S. country, or both, tightens the demand-supply balance of USD in the FX swap market, resulting in a widening CIP deviation. The estimated coefficients of non-U.S. banks' default risk α are positive, and those of U.S. banks' default risk α^* are negative and statistically significant. This observation is consistent with the substitution effect captured in the second term in equation (11) or the credit risk channel emphasized in Baba and Packer (2009). As the parity held closely before the crisis, the default premium and risk sentiment VIX do not capture much of the effect on cross-currency basis for some currency pairs. Also the coefficients of VIX are negative, contradicting with our model prediction.

Since the onset of the GFC starting from 2007, CIP broke down significantly, the cross-currency dollar basis started to widen and showed abnormal movements during the crisis. Panel (b) in Table 2 presents the results of the sample focusing on the peak crisis period, 2007-2009. Compared with panel (a), almost all coefficients on default premium are with the expected signs and statistically significant, indicating that the widening cross-currency basis are better tracked by the credit risk during the crisis than in the pre-crisis period. The effect of the VIX index in the panel regression also turns consistent with the model prediction during the crisis period.

Finally, we move to the post-crisis period, 2010-2020, as the results reported in Panel (c) in Table 2. Credit spreads, both U.S. and non-U.S. ones, and VIX are not only significant in the panel regression, but also in most of the time-series regressions for individual currencies. The coefficients of VIX index for AUD, EUR and GBP are now as expected and significant, possibly suggesting the higher hedging demand of those currencies following rising volatilities and uncertainties after the crisis.

[Table 2 is here]

To sum up, the results for the three sample periods are stable in terms of the panel regression. The expected sign of significant coefficients on the three determinants confirm our model prediction. The results are similar if we alternatively replace the CIP deviations with the 5-year horizon Libor-based cross-currency basis.

5.4 Dynamics of CIP Deviation Determinants

In this section, we focusing on the dynamics of three determinants of the CIP deviations. To focus on the impact of the credit spread difference between U.S. and the other economy, we adopt the following model specification which takes the assumptions that (i) for both U.S. and non-U.S. banks, parameters of the marginal return of financial assets and the marginal cost of funding are identical across countries (i.e. $\tau^* = \tau$, $\eta^* = \eta$, $\theta^* = \theta$, $\gamma^* = \gamma$); (ii) for non-U.S. banks, each parameter of the marginal return of financial assets (τ^*, τ) and the marginal cost of funding (η^*, η) is identical across countries.

$$x_{it} = \beta(l_{it}^* - l_{it}) + \lambda\alpha_{it} + \lambda^*\alpha_{it}^* + \delta VIX_t + c_{1i} + \varepsilon_{it} \tag{13}$$

Based on the estimation results of model in equation (13), I estimate the contribution of the three components to explore the dynamics of each variable's relative significance to movements in CIP deviation over time.

Figure 7 and Figure 8 shows the time path of this decomposition for the four currency pairs. The first important observation is that banks' default premium played the key role in driving up the CIP deviations, particularly during the global financial crisis for all four currency pairs and during the eurozone sovereign debt crisis for USD/EUR. Secondly, the credit spread differential has contributed in rising CIP deviations, which is pronounced in USD/AUD and USD/JPY. While default premium was the dominant part contributing the CIP deviations, the impact of credit spreads has gained more relative significance in the post-crisis times for some currency pairs. It is also noteworthy that the effect of VIX varies for different currency basis, while the VIX effect contributing to a considerable amount in the pairs of USD/AUD and USD/JPY, its effect has been very minor for USD/EUR and USD/GBP.

[Figure 7 and Figure 8 are here]

5.5 CIP Deviations with Alternative Tenors

We focus only on the 3-month CIP deviations in the baseline model. To test whether the estimated results are robust to different horizons, I apply the model specification of equation (13) to CIP deviations with different tenors ranging from short-term of 3-month to long-term of 10-year, respectively. Table 3 presents the results of these alternative tenors.

[Table 3 is here]

Estimation results are consistent with the model expectation, and are similar to those panel regression results reported in Table 2. One noticeable observation is that the CIP deviations show stronger positive correlation with the credit spread differential between U.S. and the other country.

5.6 Effect of Other Countries on CIP Deviations

Our model in section 4 assumes that the swap transactions between one currency pair in foreign exchange market is independent from transactions of other currency pairs. In this section, we extend our model to allow the FX swap transactions of one currency against USD to be affected by those of other currencies. Specifically, for instance, an U.S. bank who arbitrage the CIP deviation can choose its trading counterparty by comparing the opportunity cost of supplying USD to different trading partners, but not limited to partners from one country. We can further assume that there are two non-U.S. banks, one in Japan and one in the euro area, under the similar economic environment described in our baseline model. Then similar to the case of a Japanese bank, a euro area bank's demand of USD/EUR swap in the FX market is given by

$$S' = \frac{1}{2\tau'}\Big[(l^* - l') - \frac{\eta' + \tau'}{\tau'}x' + \frac{\tau'}{\eta'}\alpha' + \tau' V'\Big] \tag{14}$$

where the variable or parameter A for the euro zone bank is denoted by A'.

The profit maximization question for the U.S. arbitrageur would be slightly different given that there are now two non-U.S. banks as the counter-party in the FX market. A U.S. bank's optimization problem is updated as follows:

$$\max_{\{L^*_{US}, L^*_{JP}, L^*_{EU}, D^*_{US}, D^*_{JP}, D^*_{EU}, M^*, S^*, S'^*\}} \Big[g^*_f(L^*_{US}) + g^*_h(L^*_{JP}) + g^{*\prime}_h(L^*_{EU}) - c^*_f(D^*_{US}) - c^*_h(D^*_{JP}) \\ - c^{*\prime}_h(D^*_{EU}) + (r^* - r + x)S^* + (r^* - r' + x')S^{\prime *}\Big] \tag{15}$$

subject to

$$M^* \geq V^*$$

$$L^*_{US} + M^* = D^*_{US} - S^* - S'^*$$

$$L^*_{JP} = D^*_{JP} + S^*$$

$$L^*_{EU} = D^*_{EU} + S'^*$$

Follow the previous process to take the first order condition of an U.S. arbitrageur's profit maximization problem above, we can solve the USD supply in the FX market for both currency pairs USD/JPY and USD/EUR.

$$S^* = \Omega_{l^*} l^* + \Omega_l l + \Omega_{l'} l' + \Omega_x x + \Omega_{x'} x' + \Omega_{\alpha^*} \alpha^* + \Omega_{V^*} V^* \tag{16}$$

and

$$S'^* = \Pi_{l^*} l^* + \Pi_l l + \Pi_{l'} l' + \Pi_x x + \Pi_{x'} x' + \Pi_{\alpha^*} \alpha^* + \Pi_{V^*} V^* \tag{17}$$

Combining the solution of supply and demand for USD in FX market, the equilibrium level of CIP deviation for the currency pair USD/JPY can be expressed as

$$x = \Phi_{l^*} l^* + \Phi_l l + \Phi_{l'} l' + \Phi_{\alpha^*} \alpha^* + \Phi_\alpha \alpha + \Phi_{\alpha'} \alpha' + \Phi_{V^*} V^* + \Phi_V V + \Phi_{V'} V' \tag{18}$$

where the coefficients Φ's are expressions of parameters in profit and cost functions described in our baseline model. Following our assumptions of symmetric parameter values, we can again determine the signs of the corresponding coefficients, such that $\Phi_{l^*}, \Phi_{\alpha}, \Phi_{\alpha'}, \Phi_{V^*}, \Phi_{V}, \Phi_{V'}$ are positive, while $\Phi_{l}, \Phi_{l'}, \Phi_{\alpha^*}$ are negative.

With the extension of our model such that swap transactions between one currency pair in foreign exchange market is not independent from transactions of other currency pairs, we can see from equation (18) that the cross-currency basis for one currency against USD is not only determined by the credit spreads and default premium of the home country and the U.S., but also influenced by those corresponding variables of another country, who also plays a role in the FX market.

The intuition is again threefold, as discussed before: (i) the credit spread of the euro area influences the relative attraction of EUR- and JPY-denominated assets for U.S. banks, hence the CIP deviations for USD/JPY pair through investment decisions made by U.S. banks; (ii) the default premium in the euro area influences the relative funding cost for between money market in U.S., Japan, and EA, and FX swap market; (iii) last terms of liquidity needs state that when more USD liquidity is desired among three markets including the euro area, the demand for USD through the FX swap market increases and will drive up the USD/JPY CIP deviations.

6 Conclusion

In the era following the GFC, prices in exchange rate markets have exhibited unusual patterns that are contradictory to the classical textbook theories. One of the most fundamental international finance principles, CIP condition has been persistently violated at both short and long horizons. I use a model of dollar funding of global banks in FX swap market, and decompose the CIP deviation into three variables: credit spread differential between U.S. and non-U.S. economies, bank's default premium, and the liquidity needs of global banks. Then through empirical examination, I find the data generally accords with the model predictions and two noteworthy observations. First, the relative significance of credit spread differential has been relatively more important contributing to a rise in CIP deviation for some currencies, particularly after the GFC. Second, banks' default premium played the key role in increasing CIP deviations after the crisis, however, its contribution has been relatively minor. I also show that the CIP dollar basis for one currency is affected by the financial conditions in other countries, who may also participate swap transactions of USD in the FX market.

Figures

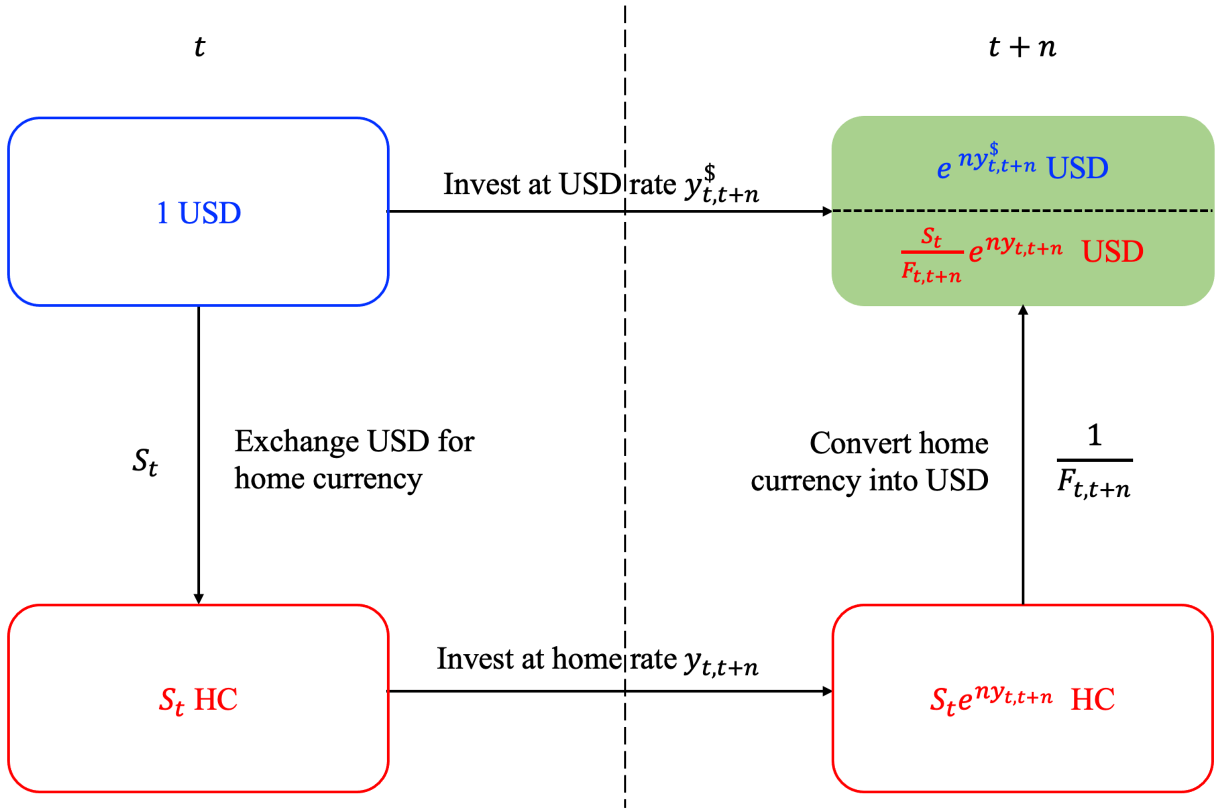


Figure 1: Illustration of Covered Interest Rate Parity (CIP)

This figure shows an illustration of the CIP condition. An investor should be indifferent between the following two investment strategies. The first strategy is highlighted in blue in the figure: an investor with one USD at time t can invest in USD at the continuously compounded rate $y^{\$}_{t,t+n}$ and would obtain $e^{ny^{\$}_{t,t+n}}$ USD at time $t+n$. The second strategy is highlighted in red: at time t, the investor may alternatively exchange her one USD for home currency (HC) at the spot exchange rate S_t units home currency per USD. The investor then invests in home currency at the continuously compounded rate $y_{t,t+n}$ and would have $S_t e^{ny_{t,t+n}}$ units of home currency at time $t+n$. The $t+n$ exchange rate at which the investor can lock into at time t is given by the forward rate $F_{t,t+n}$ units home currency per USD. Using the exchange rate $F_{t,t+n}$ to convert the home currency proceeds into USD, gives $\frac{S_t}{F_{t,t+n}} e^{ny_{t,t+n}}$. CIP implies that, as of time t, locking into a $t+n$ forward exchange rate to convert home currency return into USD, should generate the same amount of USD if these USD were invested directly. Hence under CIP, the return of the two strategies are the same: $e^{ny^{\$}_{t,t+n}} = \frac{S_t}{F_{t,t+n}} e^{ny_{t,t+n}}$.

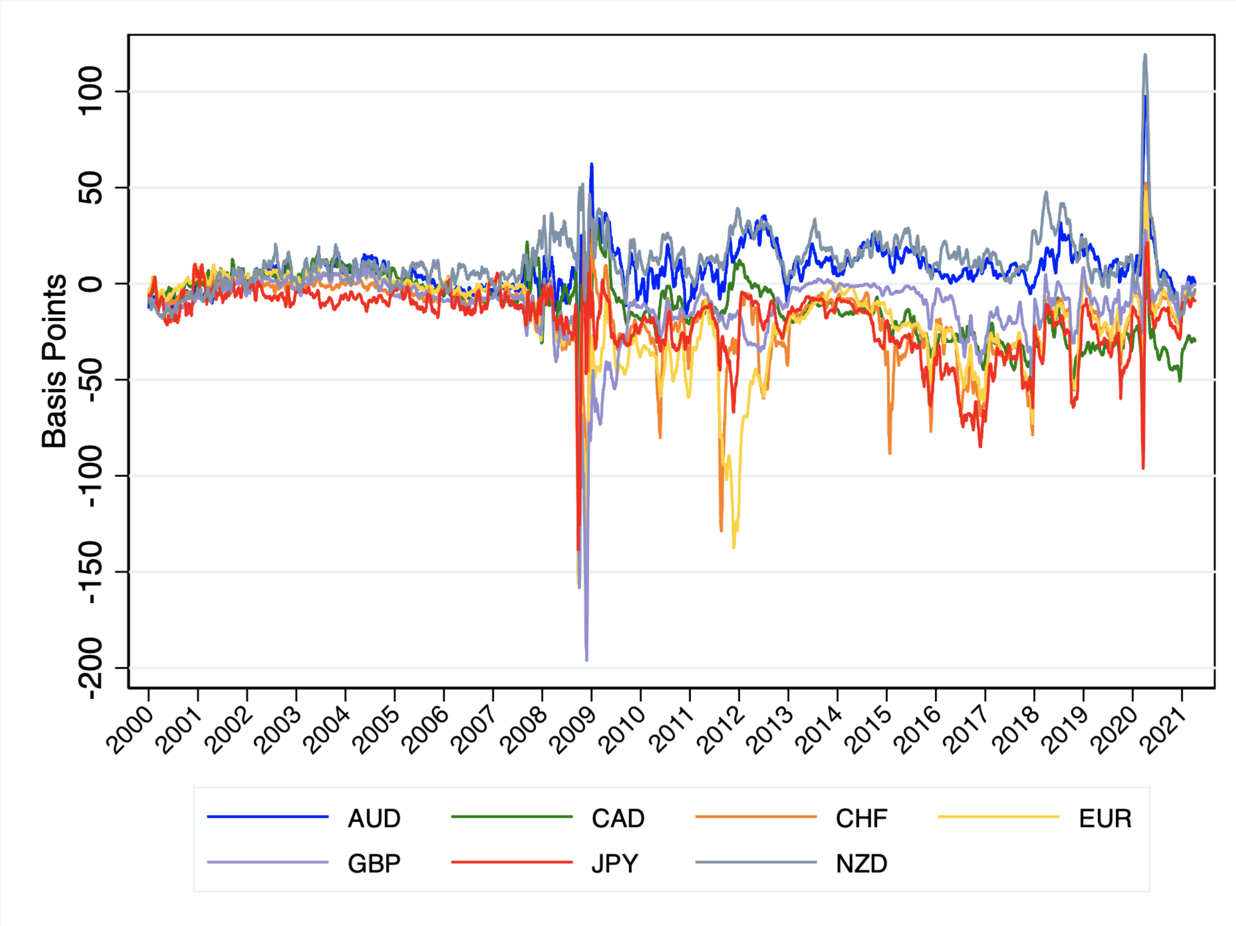


Figure 2: Short-term (3M) Libor-based CIP Deviations

This figure presents the 7-day moving average of the three-month Libor-based cross-currency basis in bps for seven major currencies against U.S. dollar: Australian Dollar (AUD), Canadian Dollar (CAD), Swiss Franc (CHF), Euro (EUR), British Pound (GBP), Japanese Yen (JPY), and New Zealand Dollar (NZD). The three-month Libor basis is equal to $x_{t,t+n}^{Libor} \equiv y_{t,t+n}^{\$,Libor} - (y_{t,t+n}^{Libor} - \rho_{t,t+n})$, where$y_{t,t+n}^{\$,Libor}$ and $y_{t,t+n}^{Libor}$ denote the U.S. and home country three-month Libor rates, and $\rho_{t,t+n}$ denotes the forward premium. $n =$ three months.

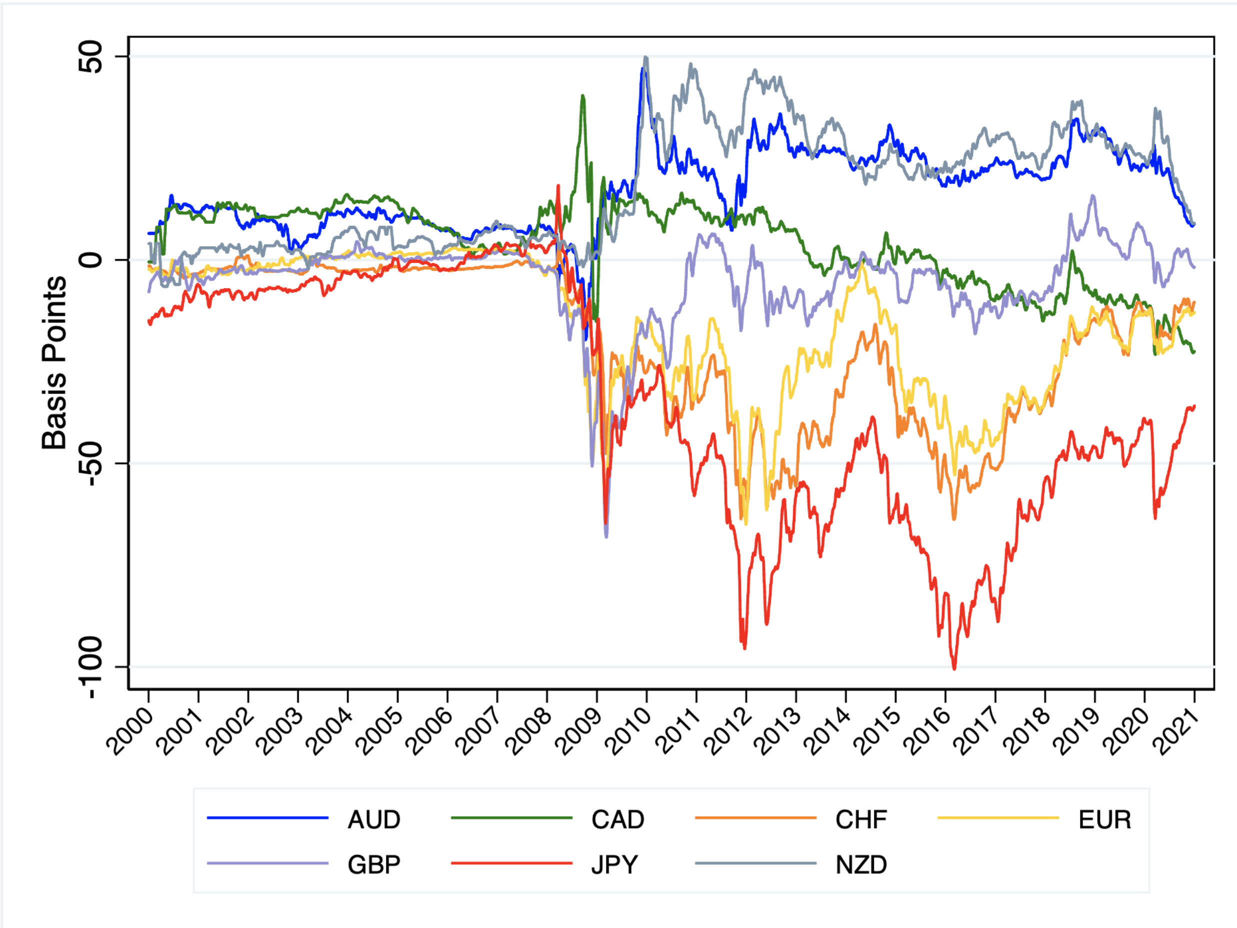


Figure 3: Long-term (5Y) Libor-based CIP Deviations

This figure presents the 7-day moving average of the five-year Libor-based cross-currency basis in bps for the aforementioned seven major currencies against U.S. dollar. The five-year Libor basis directly given by the spread on the five-year cross-currency basis swap.

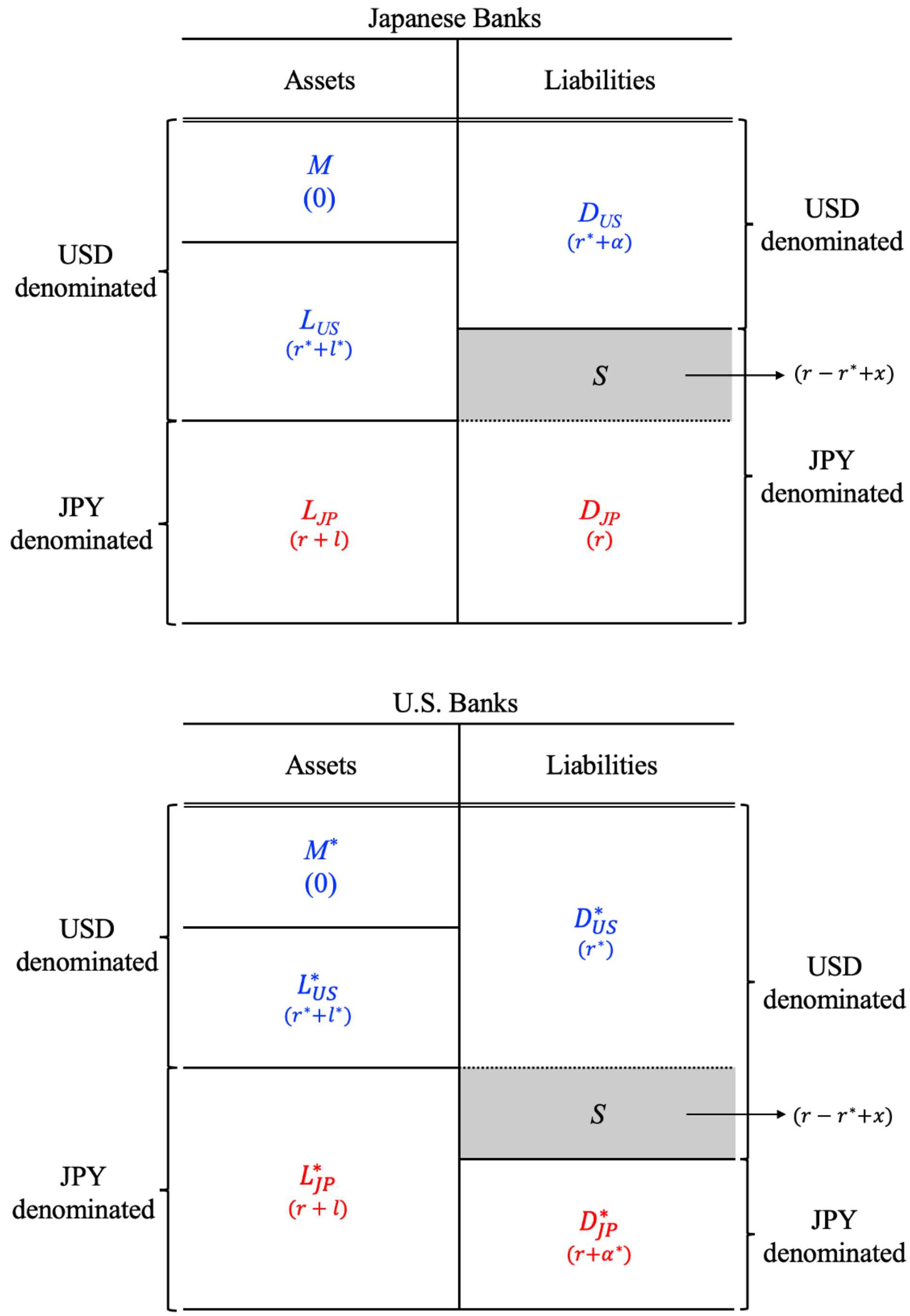


Figure 4: Balance Sheets of Global Banks

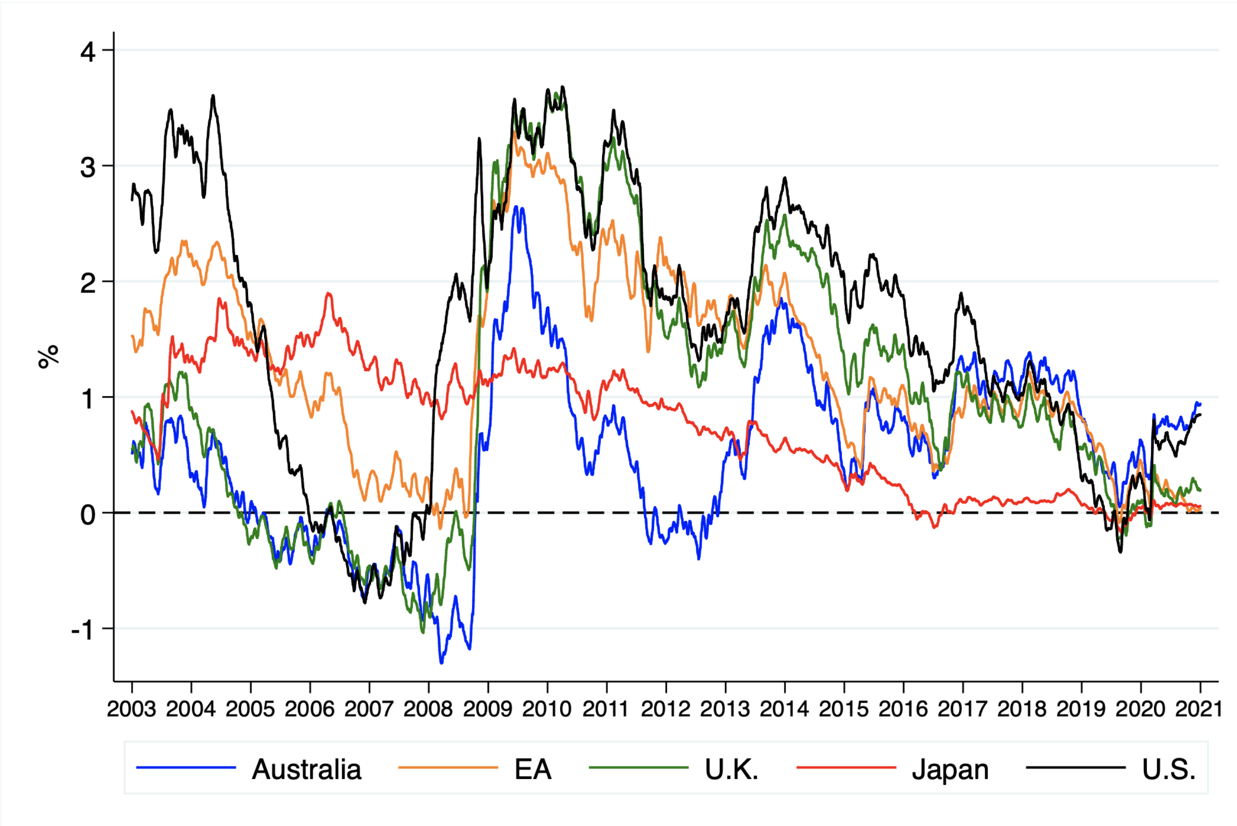


Figure 5: Credit Spread

Credit spread is calculated as the difference between 10-year government bond yield minus 3-month OIS rate. Data are obtained from Bloomberg and based on author's calculations.

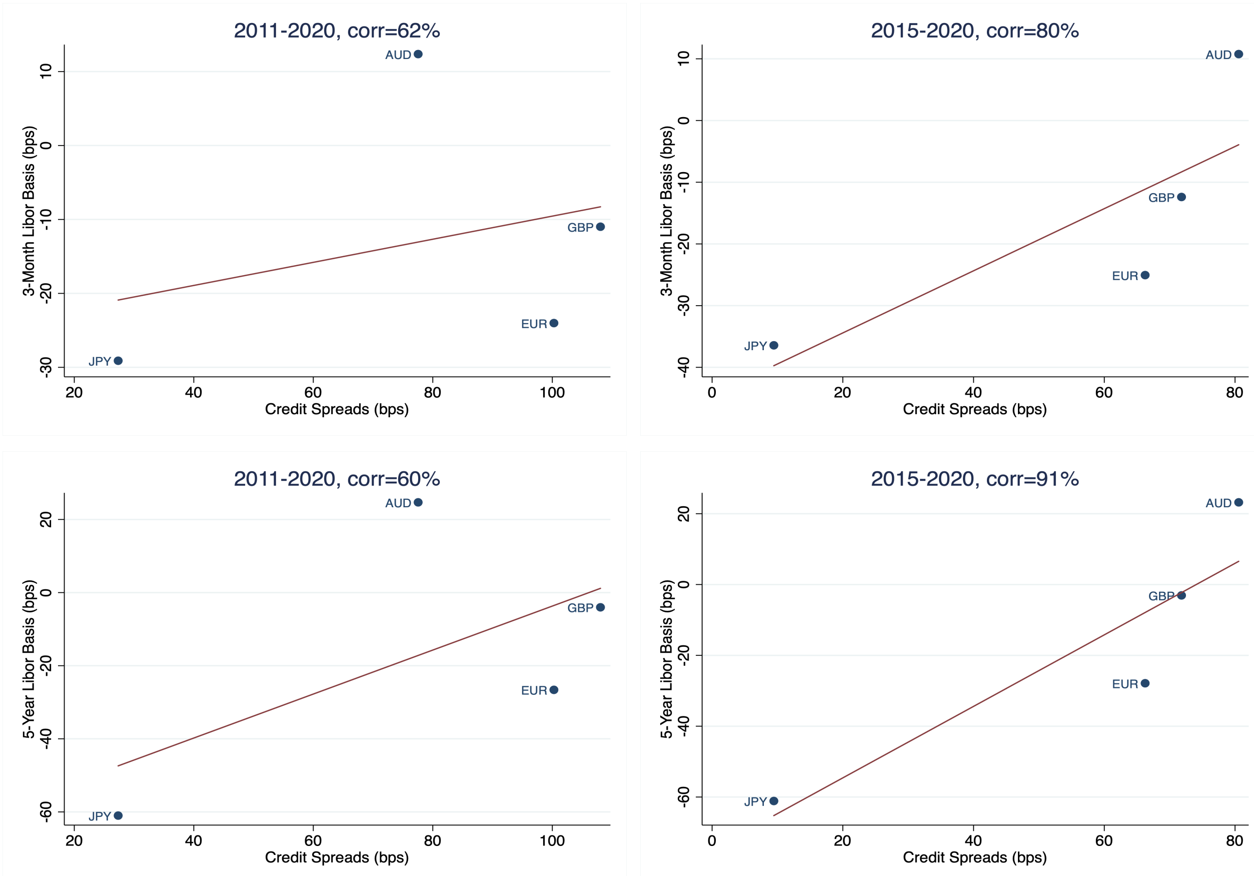
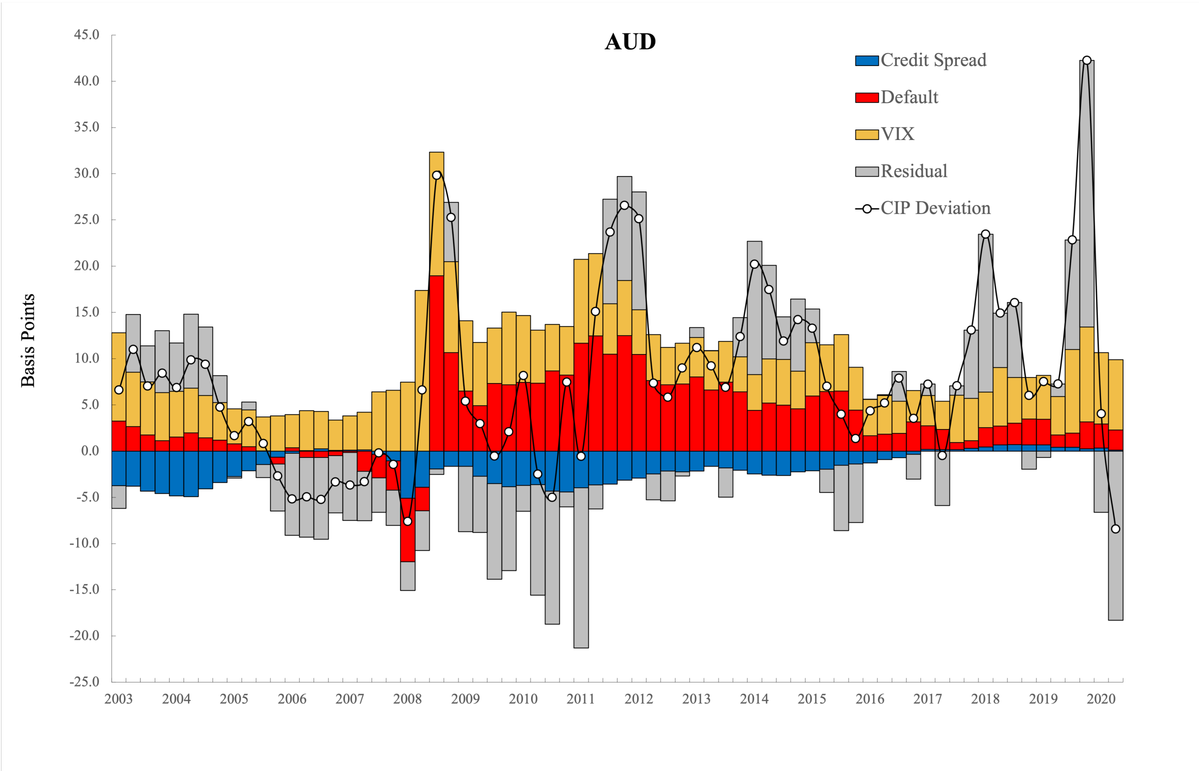


Figure 6: Cross-sectional variation in 3-Month and 5-Year cross-currency basis

This figure presents the positive correlation between various cross-currency bases (y-axis) and credit spread differentials against U.S. (x-axis). The top panels shows the relationship for three-month bases and the bottom one shows the relationship for five-year bases, with two sample periods 2011-2020 and 2015-2020.



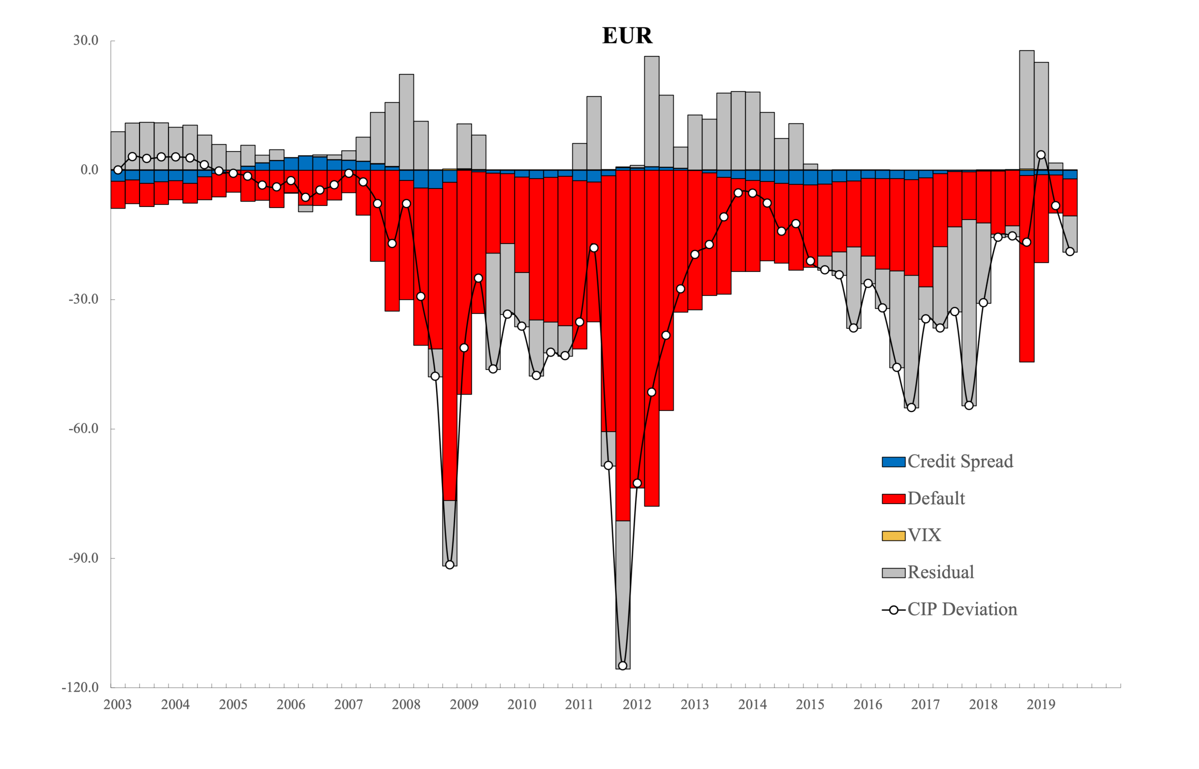
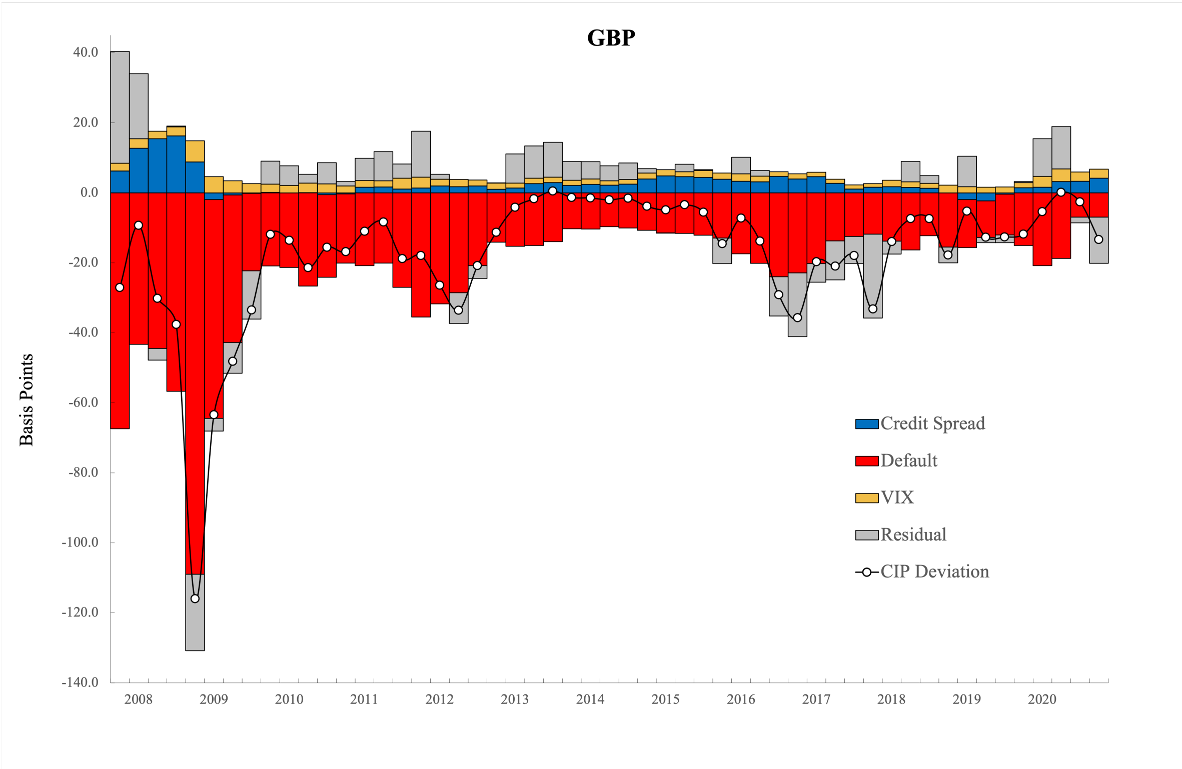


Figure 7: Decomposition of CIP deviation - AUD & EUR



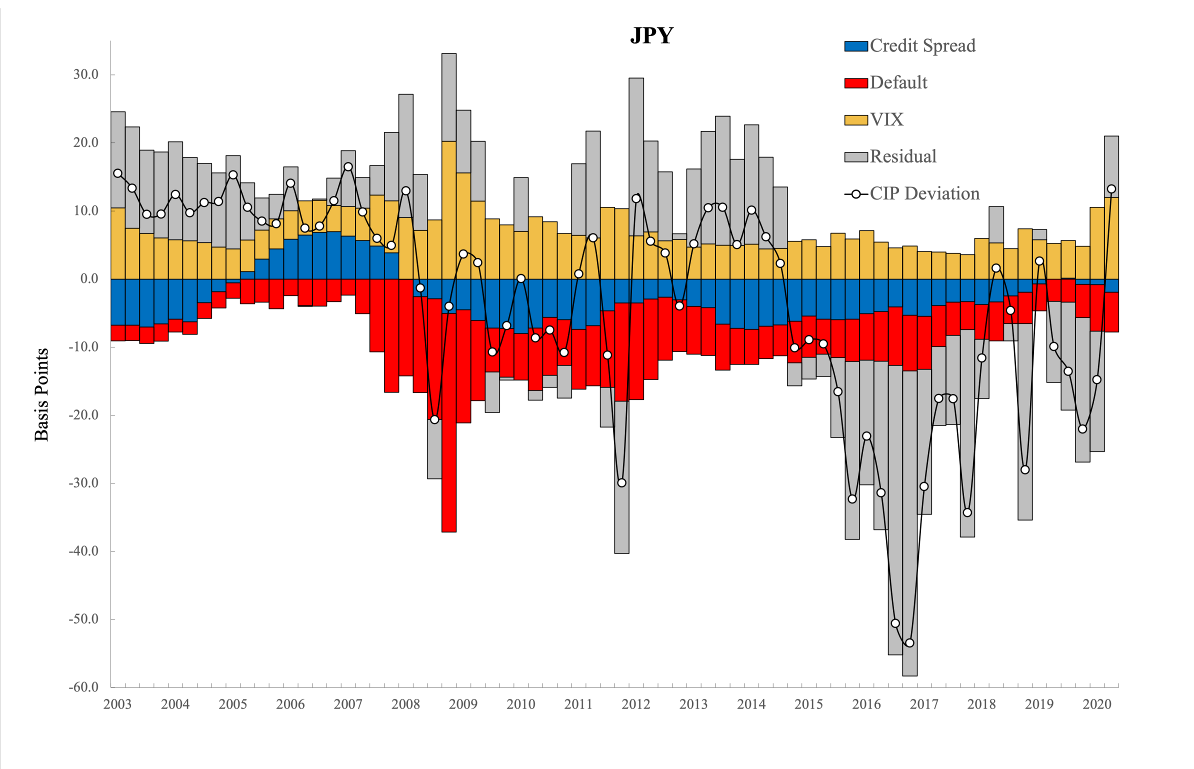


Figure 8: Decomposition of CIP deviation - GBP & JPY

Tables

Table 1. Summary Statistics of CIP Deviations

	Three-Month								Five-Year							
	2000-2006		2007-2009		2010-2020		All		2000-2006		2007-2009		2010-2020		All	
Currency	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
AUD	1.60	7.37	5.17	19.41	10.92	12.43	7.00	13.08	9.47	2.84	9.27	11.84	24.17	5.51	17.14	9.64
CAD	1.60	6.76	-4.41	16.62	-21.98	12.96	-11.61	16.26	10.43	3.98	10.95	9.35	-1.56	9.37	4.22	10.03
CHF	-2.49	5.18	-19.01	27.01	-26.15	20.60	-17.25	21.21	-2.20	0.96	-12.77	12.79	-33.91	14.31	-20.33	18.58
EUR	1.49	4.49	-27.27	31.51	-28.59	23.27	-18.38	25.10	-0.13	2.11	-14.81	16.20	-26.81	12.50	-16.21	16.31
GBP	-3.43	5.98	-32.24	36.59	-11.65	11.11	-11.86	18.74	-1.07	2.39	-17.08	18.06	-4.50	7.46	-5.15	10.19
JPY	-7.31	6.79	-18.17	23.11	-28.70	18.31	-20.07	19.00	-5.27	4.25	-13.51	20.10	-58.86	16.25	-34.52	29.34
NZD	2.94	8.98	15.94	15.62	16.63	14.53	11.97	14.60	3.22	3.17	7.88	8.69	29.73	7.49	17.77	14.25
Average	-0.80	7.49	-11.43	30.12	-12.79	24.36	-8.60	22.13	0.54	5.88	-8.21	20.50	-14.02	29.73	-8.34	24.04

Table 2. Time Series and Panel Regressions of Short-term (3-month) CIP Deviations

(a) Pre-crisis (2003-2006)

x	AUD	EUR	GBP	JPY	Panel
Credit Spread	-3.116***	-5.735***	-7.134***	-7.376***	-3.245***
	(0.857)	(0.593)	(1.419)	(0.954)	(0.333)
Credit Spread_US	3.067***	4.321***	2.444	0.288	0.704***
	(0.304)	(0.283)	(1.664)	(0.196)	(0.142)
CDS	1.052***	0.197	-0.160***	-0.364***	0.504***
	(0.0980)	(0.123)	(0.032)	(0.0938)	(0.0546)
CDS_US	0.00454	-0.00879	-0.339***	-0.0650***	-0.0449***
	(0.0195)	(0.0117)	(0.016)	(0.0235)	(0.0124)
VIX	-0.0492	-0.127***	-0.481***	0.0582	-0.199***
	(0.0681)	(0.0431)	(0.0867)	(0.0639)	(0.0377)
Observations	846	894	894	1,040	2,780
R-squared	0.667	0.621	0.621	0.095	0.294

(b) Crisis (2007-2009)

x	AUD	EUR	GBP	JPY	Panel
Credit Spread	0.812	-11.36***	-4.171*	-3.325	-6.085***
	(1.306)	(1.740)	(2.130)	(6.792)	(0.680)
Credit Spread_US	0.431	3.604***	4.903*	8.160***	1.629***
	(0.897)	(1.230)	(2.631)	(0.824)	(0.522)
CDS	0.309***	0.299***	-0.118**	0.125**	0.155***
	(0.0272)	(0.0791)	(0.0545)	(0.0546)	(0.0247)
CDS_US	-0.0557***	-0.237***	-0.280***	-0.136***	-0.154***
	(0.0161)	(0.0191)	(0.0265)	(0.0179)	(0.0109)
VIX	-0.0701	-0.443***	-0.878***	0.549***	0.290***
	(0.115)	(0.146)	(0.173)	(0.117)	(0.0807)
Observations	644	677	528	784	2,633
R-squared	0.363	0.622	0.676	0.218	0.252

(c) Post-risis (2010-2020)

x	AUD	EUR	GBP	JPY	Panel
Credit Spread	-2.786***	-0.763	-7.561***	41.69***	-1.980***
	(0.664)	(1.235)	(0.932)	(2.017)	(0.341)
Credit Spread_US	3.572***	3.762***	3.244***	8.056***	4.433***
	(0.401)	(0.958)	(0.853)	(0.606)	(0.256)
CDS	0.131***	-0.406***	-0.315***	-0.159***	-0.205***
	(0.0224)	(0.0153)	(0.0130)	(0.0202)	(0.00706)
CDS_US	0.308***	-0.217***	-0.111***	-0.286***	-0.110***
	(0.0148)	(0.0264)	(0.0138)	(0.0238)	(0.0111)
VIX	0.122***	0.224***	0.459***	-0.0584	0.311***
	(0.0316)	(0.0546)	(0.0286)	(0.0461)	(0.0231)
Observations	2,825	2,432	2,870	2,870	10,997
R-squared	0.240	0.427	0.241	0.294	0.106

This table reports the results of time-series and panel regressions of Libor-based CIP deviations on different components. Samples are split to pre-crisis, crisis, and post-crisis periods. Standard errors in parentheses. ***, **, and * respectively indicate significance at the 1%, 5%, and 10% level.

Table 3. CIP Deviations of Alternative Tenors

x	3-Month	6-Month	1-Year	5-Year	10-Year
Credit Spread_diff	0.543***	0.694***	4.479***	4.736***	5.581***
	(0.169)	(0.172)	(0.132)	(0.145)	(0.154)
CDS	0.222***	0.223***	0.295***	0.324***	0.260***
	(0.00544)	(0.00555)	(0.00427)	(0.00468)	(0.00495)
CDS_US	-0.156***	-0.0792***	-0.0746***	-0.0285***	-0.00561
	(0.00415)	(0.00423)	(0.00326)	(0.00357)	(0.00378)
VIX	0.243***	0.242***	-0.0892***	0.237***	0.192***
	(0.0215)	(0.0219)	(0.0168)	(0.0184)	(0.0195)
Country FE			Yes		
Observations	16,410	16,410	16,410	16,410	16,410
R-squared	0.185	0.109	0.397	0.317	0.247

This table reports the results of panel regressions of Libor-based CIP deviations with different tenors on the determinants. Standard errors in parentheses. ***, **, and * respectively indicate significance at the 1%, 5%, and 10% level.

References

Anderson, A., W. Du, and B. Schlusche (2019). Arbitrage capital of global banks. Technical report, Working paper.

Aoki, K., N. Sudo, et al. (2013). Bank's regulation, asset portfolio choice of banks, and macroeconomic dynamics. Technical report, Center for Advanced Research in Finance, The University of Tokyo.

Avdjiev, S., W. Du, C. Koch, and H. S. Shin (2019). The dollar, bank leverage, and deviations from covered interest parity. *American Economic Review: Insights 1*(2), 193–208.

Baba, N. and F. Packer (2009). From turmoil to crisis: dislocations in the fx swap market before and after the failure of lehman brothers. *Journal of International Money and Finance 28*(8), 1350–1374.

Bahaj, S. and R. Reis (2018). Central bank swap lines.

BIS (2019). Triennial central bank survey of foreign exchange and over-the-counter derivatives markets in 2019. *Bank for International Settlements*.

Borio, C. E., M. Iqbal, R. N. McCauley, P. McGuire, and V. Sushko (2018). The failure of covered interest parity: Fx hedging demand and costly balance sheets.

Borio, C. E., R. N. McCauley, P. McGuire, and V. Sushko (2016). Covered interest parity lost: understanding the cross-currency basis. *BIS Quarterly Review September*.

Bräuning, F. and V. Ivashina (2020). Monetary policy and global banking. *The Journal of Finance 75*(6), 3055–3095.

Cenedese, G., P. Della Corte, and T. Wang (2020). Currency mispricing and dealer balance sheets.

Correa, R., W. Du, and G. Y. Liao (2020). Us banks and global liquidity. Technical report, National Bureau of Economic Research.

Du, W., A. Tepper, and A. Verdelhan (2018). Deviations from covered interest rate parity. *The Journal of Finance 73*(3), 915–957.

Fang, X. and Y. Liu (2019). Volatility, intermediaries and exchange rates. *Available at SSRN 2872904*.

Gabaix, X. and M. Maggiori (2015). International liquidity and exchange rate dynamics. *The Quarterly Journal of Economics 130*(3), 1369–1420.

Gourinchas, P.-O., W. Ray, and D. Vayanos (2019). A preferred-habitat model of term premia and currency risk. Technical report, mimeo.

He, D., T. Wong, A. Tsang, and K. Ho (2015). Asynchronous monetary policies and international dollar credit.

Iida, T., T. Kimura, and N. Sudo (2018). Deviations from covered interest rate parity and the dollar funding of global banks. *International Journal of Central Banking*.

Ivashina, V., D. S. Scharfstein, and J. C. Stein (2015). Dollar funding and the lending behavior of global banks. *The Quarterly Journal of Economics 130*(3), 1241–1281.

Liao, G. and T. Zhang (2020). The hedging channel of exchange rate determination. *FRB International Finance Discussion Paper* (1283).

Liao, G. Y. (2020). Credit migration and covered interest rate parity. *Journal of Financial Economics 138*(2), 504–525.

Rime, D., A. Schrimpf, and O. Syrstad (2019). Covered interest parity arbitrage. *Available at SSRN 2879904*.

Syrstad, O. (2020). Does covered interest parity hold in long-dated securities? *Available at SSRN 3611635*.

Vayanos, D. and J.-L. Vila (2009). A preferred-habitat model of the term structure of interest rates. Technical report, National Bureau of Economic Research.