Deviations from Covered Interest Rate Parity and the Dollar Funding of Global Banks*

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By developing an equilibrium model of the FX swap market, this paper studies the determinants of deviations from covered interest rate parity (CIP) and investigates how changes in the environment surrounding the FX swap market affect the U.S. dollar funding of global banks. We find that the role of global banks' creditworthiness in determining CIP deviations has been supplanted by global interest rate differentials, which reflect monetary policy divergence among advanced economies. Our model and an empirical analysis suggest that the sensitivity of CIP deviations to variation in global interest rate differentials has risen, as regulatory reforms have increased the marginal cost of global banks' dollar funding. We also show that real money investors have increased their presence as suppliers of U.S. dollars in the FX swap market and their investment behavior has significantly affected CIP deviations and hence the dollar funding of global banks.

JEL Codes: F39, G15, G18.

1. Introduction

The role of U.S. dollar (USD) in the global financial system is as important as ever, and non-U.S. banks play an essential role in

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USD-denominated international financial transactions.[1] Looking at the nationality of banks extending USD-denominated foreign claims, non-U.S. banks overwhelm U.S. banks in terms of market share (figure 1). When non-U.S. banks extend credit in dollars, they have to fund themselves in dollars, and often their on-balance-sheet credit extensions exceed their funding in dollars. This gap in funding is usually covered by foreign exchange (FX) swaps, since banks are typically unwilling to bear FX risk. In an FX swap, the parties to the transaction simultaneously conclude the purchase and sale of two different currencies of equal value on two separate delivery dates in the opposing direction. For example, a Japanese bank would purchase USD against Japanese yen (JPY) in the spot market and JPY against the same amount of USD in the forward market, which is in effect obtaining USD against JPY collateral.

As shown in figure 1, the dependence of non-U.S. banks' USD funding on the FX swap market has been on an increasing trend, but with a sharp decline in times of stress such as the Lehman crisis and the euro-zone sovereign debt crisis. From the perspective of global financial stability, it is very important to understand how the FX swap market functions, because severe strains in wholesale funding markets such as the FX swap market force non-U.S. financial institutions to cut their dollar lending, which may destabilize the global financial system.

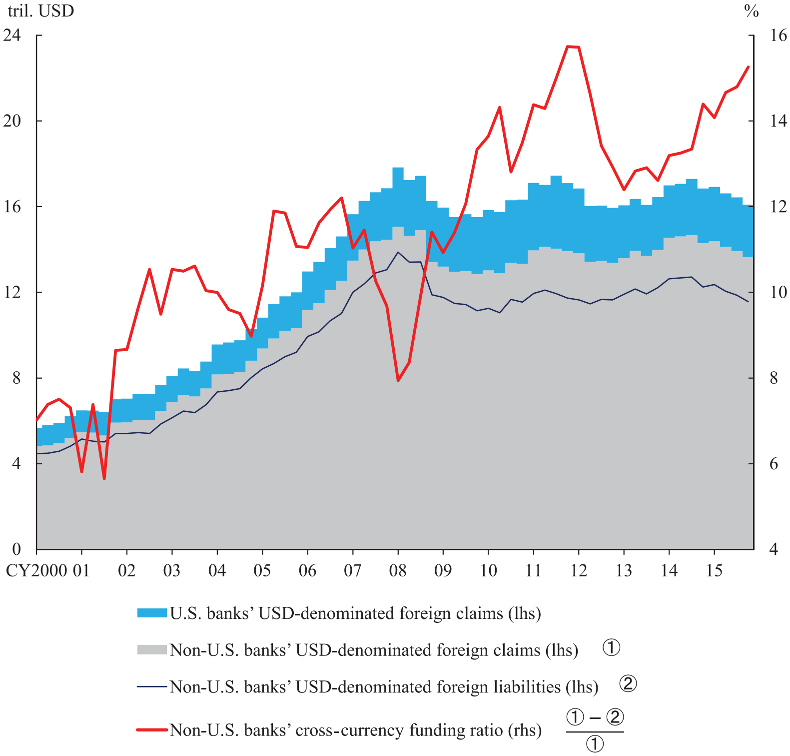
If the FX swap market is frictionless and allows market participants to instantaneously exploit arbitrage trading opportunities, the following condition holds, which is often referred to as the covered interest rate parity (CIP):

$$(1 + r^*) = \frac{X_1}{X_0}(1 + r), \tag{1}$$

where r^* and r are the interest rates in USD and JPY, respectively. X_0 is the FX spot rate between USD and JPY at $t = 0$, and X_1 is the FX forward rate contracted at $t = 0$ for exchange at $t = 1$. In

[1]See Avdjiev and Takats (2016) for the choice of currency made by non-U.S. banks in their cross-border lending. They show that the bulk of international claims are extended in USD.

Figure 1. USD-Denominated Foreign Position of Banks



Source: BIS consolidated banking statistics (immediate borrower basis); BIS locational banking statistics by nationality.

Notes: "Foreign claims" and "foreign liabilities" comprise local claims and liabilities of the bank's offices abroad as well as cross-border claims and liabilities of the bank's offices worldwide. "Non-U.S. banks' USD-denominated foreign claims" and "Non-U.S. banks' USD-denominated foreign liabilities" are calculated as USD-denominated foreign claims and liabilities of all countries minus those of U.S. banks, respectively. "Non-U.S. banks' cross-currency funding" (i.e., FX swap) is defined as "Non-U.S. banks' USD-denominated foreign claims" minus "Non-U.S. banks' USD-denominated foreign liabilities." See McGuire and von Peter (2009) on how to calculate the USD position of banks using BIS international banking statistics.

practice, however, this condition is often violated, and the equality below holds:

$$(1 + r^*) + \Delta = \frac{X_1}{X_0}(1 + r), \qquad (2)$$

where Δ is what is called a "CIP deviation." The right-hand side of equation (2) is often referred to as the "FX swap-implied dollar rate," while $1 + r^*$ is referred to as the "dollar cash rate." A CIP deviation is the premium paid to the USD supplier in the FX swap market.

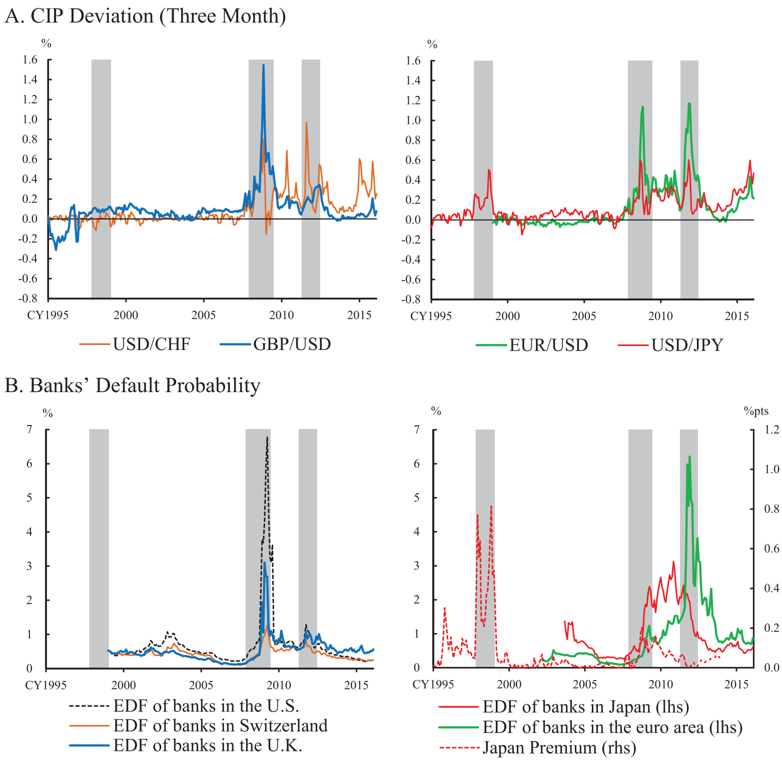
CIP deviations have attracted the attention of policymakers over the last two decades. This is because CIP conditions have been severely violated whenever a banking crisis has occurred. Figure 2 displays the time path of CIP deviations against USD in four major currencies, the euro (EUR), JPY, Swiss franc (CHF), and U.K. pound sterling (GBP), as well as that of banks' default probabilities measured by Moody's expected default frequency (EDF) and the "Japan premium."[2] Three banking crises are shaded in gray: Japan's banking crisis, the Lehman crisis, and the euro-zone sovereign debt crisis. The figure shows that whenever a bank's creditworthiness deteriorated, a CIP deviation that involved the currency of the jurisdiction soared, suggesting that USD suppliers required a larger premium during these periods. During Japan's banking crisis, the CIP deviation in the USD/JPY pair increased, while the deviation in the other currency pairs was minimal. In contrast, during the Lehman crisis and the euro-zone sovereign debt crisis, the increase in the respective CIP deviation of the GBP/USD and EUR/USD pairs was pronounced, compared with the other currency pairs.

This close relationship between CIP deviation and banks' creditworthiness seems to have weakened more recently. Around the time of the Federal Reserve's tapering announcement in December 2013, the CIP deviation in the four currency pairs started to increase. For example, the level of CIP deviation for USD/JPY at the end of 2015 was as high as the level recorded in Japan's banking crisis. However, there has been no clear sign so far of a deterioration in Japanese banks' creditworthiness.

This paper explores the determinants of CIP deviation by building an equilibrium model. The model consists of two types of agents: non-U.S. financial institutions (such as Japanese banks) and arbitrageurs (such as U.S. banks and real money investors). A Japanese

[2]The EDF measures the probability at period t that a bank will default over a horizon of one year starting from the period t, or alternatively that the market value of the bank's assets will fall below its liabilities payable over the period.

Figure 2. CIP Deviation and Banks' Default Probability



Source: Bloomberg; Moody's; Bank of Japan.

Notes: The shaded areas correspond to the period of Japan's financial crisis (November 1997 through January 1999), the global financial crisis (December 2007 through June 2009), and the euro-zone sovereign debt crisis (May 2011 through June 2012). CIP deviation is calculated as FX swap-implied dollar rates minus USD LIBOR. The average of the expected default frequency (EDF) of the G-SIBs, which are headquartered in each country, is used as the measure of banks' default probability. For the euro area, the average of the EDF of the G-SIBs in France, Germany, and Italy is used. "Japan Premium" is calculated as the three-month USD TIBOR minus the three-month USD LIBOR.

bank maximizes its profits by optimally setting its plans for asset investment and funding in the two currencies, JPY and USD. As the interest margin (i.e., the spread between the lending rate and the funding rate) in the United States becomes larger than that in Japan, the Japanese bank increases its investment in USD-denominated assets. When the bank confronts a funding gap in USD, it raises USD funding in the FX swap market. An arbitrageur also optimizes its asset and funding allocation in the two currencies, but acts as the supplier of USD in the FX swap market.

According to the model, CIP deviations arise due to either of the following: (i) a widening in the interest margin differential between U.S. and non-U.S. jurisdictions, (ii) a rise in a non-U.S. bank's default probability or a fall in U.S. arbitrageurs' default probability, or (iii) an increase in banks' liquidity needs or a decrease in the wealth endowment of arbitrageurs. Specifically, a widening in the interest margin differential encourages non-U.S. banks to invest more in USD-denominated assets, which is accompanied by their increased demand for USD through the FX swap market, leading to a higher CIP deviation. A rise in the default probability of a non-U.S. bank makes it more costly to raise dollar funding from the uncollateralized U.S. money market than otherwise, again increasing its demand for USD from FX swap transactions, which also results in a higher CIP deviation. Higher liquidity needs among non-U.S. banks and U.S. arbitrageurs tightens the demand–supply balance of USD in the FX swap market, leading to a higher CIP deviation.

We investigate whether the model's predictions are consistent with the data using monthly series of CIP deviations in EUR/USD, USD/JPY, USD/CHF, and GBP/USD. A series of panel regression analyses, which use a CIP deviation as the dependent variable and the three factors explained above as the independent variables, suggests that the predictions of our model accord with the data. In addition, we provide some evidence that monetary policy divergence between the Federal Reserve and other advanced economies' central banks has contributed to the recent upsurge in CIP deviations. Since monetary policy has a significant impact on the interest margin (or the yield-curve slope), interest margin differentials between U.S. and non-U.S. countries depend on the degree of monetary policy divergence between them.[3] Specifically, we find that CIP deviation rises when the balance sheet of the central bank in a non-U.S. jurisdiction grows at a quicker pace than that in the United States in an unconventional monetary policy regime.

[3]As regards the influence of monetary policy on banks' net interest margins, see Borio, Gambacorta, and Hofmann (2015), for example.

We next demonstrate that the sensitivity of a CIP deviation to its determinant factors is affected by regulatory reforms which increase the marginal cost of global banks' USD funding. When an arbitrageur (e.g., a U.S. bank) faces a widening interest margin differential, it seeks to increase its USD-denominated assets. However, as stricter regulations such as the new leverage ratio framework are imposed on the financial sector, it is more costly for an arbitrageur to expand its balance sheet. The arbitrageur therefore shifts its USD funds away from FX swap transactions toward other dollar-denominated investments, which leads to a decrease in the supply of USD in the FX swap market. Similarly, a non-U.S. bank facing a widening interest margin differential seeks to increase its USD-denominated investments and raise additional dollars. However, as regulatory reforms increase the marginal cost of raising USD from the U.S. money market, a non-U.S. bank shifts its USD funding source toward the FX swap market. This leads to an increase in the demand for USD in the FX swap market. As a result, the widening interest margin differential causes a higher CIP deviation at the equilibrium in the case of stricter financial regulations. To the best of our knowledge, existing studies have not shed light on how regulatory reforms affect the cost structure of global banks and CIP deviations in the FX swap market. Our study is therefore the first to investigate this issue.

Another contribution of this paper is to empirically examine the recent change in market structure of FX swaps. While arbitrage trading activities by banks have declined due to regulatory reforms, real money investors—such as asset management companies, sovereign wealth funds (SWFs), and foreign official reserve managers—have increased their presence as suppliers of USD in the FX swap market. Our equilibrium model suggests that a fall in total assets under management (AUM) of real money investors leads to the reduction in their supply of USD in the FX swap market and hence a rise in CIP deviations. Based on the model's prediction, we offer a novel estimation methodology that serves for identifying the role of real money investors. Because the data on FX swap transactions of real money investors is not available, we estimate the impact of their investment behavior as a supply shock, i.e., a shock that contemporaneously affects CIP deviations and FX swap transaction volume in the opposite direction, by applying a VAR identification scheme with sign restrictions. The estimation result suggests that the identified supply shock contributed to increasing CIP deviation and lowering the FX swap transaction volume from mid-2014. One of the possible factors behind this result is the sharp decline in oil prices in the latter half of 2014. In fact, the estimated shock has recently become more correlated with oil prices, which implies that SWFs of oil-producing countries have reduced the supply of USD in the FX swap market because of the fall in oil prices and hence AUM. The combination of our equilibrium model and the VAR identification with sign restrictions allows us to pin down the role played by real money investors in the FX swap market.

Our study is built upon a small but growing literature on the identification of the sources of CIP deviation. Baba and Packer (2009b) study the EUR/USD FX swap market from 2007 to 2008, and argue that the difference in perceived counterparty risk between European and U.S. financial institutions contributed to a rise in CIP deviation. Ivashina, Scharfstein, and Stein (2015) argue that there is a linkage between CIP deviation and the creditworthiness of euro-zone banks, focusing on the period of the euro-zone sovereign debt crisis in 2011. Terajima, Vikstedt, and Witmer (2010) examine why the CIP deviation in Canadian dollars/USD was minor during the global financial crisis, and argue that economic conditions specific to Canada, such as the presence of a stable U.S. retail deposit base that provides USD, have the potential to mitigate Canadian banks' reliance on the FX swap market. Pinnington and Shamloo (2016) decompose the CIP deviation for a set of currency pairs that involve CHF into three components: foreign exchange market distortion, interbank market distortion, and transaction costs. They argue that the last component was responsible for the CIP deviation of the studied currency pairs during the first half of 2015 when the Swiss National Bank abandoned its minimum exchange rate policy. Our paper is also related to He et al. (2015), which studies the impact of monetary policy in advanced economies on USD-denominated loans extended by non-U.S. banks.

In comparison with existing studies, our paper has two novel features.

First, it develops a model where a CIP deviation is determined as the equilibrium price that clears the FX swap transaction. The model of our study is close to that of Ivashina, Scharfstein, and Stein (2015) in that both models consist of two types of agents, arbitrageurs and non-U.S. banks. We extend their model so that arbitrageurs optimize their asset portfolio allocation between USD-denominated assets and non-USD denominated assets while taking advantage of the difference in funding costs across currencies. In our model, the difference in funding costs affects arbitrageurs' supply of USD in the FX swap market, while Ivashina, Scharfstein, and Stein (2015) do not take into account such an effect. We believe that this point is essential to describe the arbitrageurs' behavior. The existence of dollar funding premiums in the swap market (i.e., CIP deviation) has recently signified an opportunity for suppliers of USD to obtain yen funding at a very low rate. Arbitrageurs that have dollars to spare can invest in Japanese government securities, even if the nominal yields on such paper are zero or negative, and secure yields as good as or higher than U.S. government securities without taking on foreign exchange risk. Our model can describe such behavior of arbitrageurs, which is one of the keys to understanding the FX swap market.

Second, our paper empirically checks our model's prediction regarding CIP deviations and shows that the model is consistent with the data, based on the observation of four currency pairs. By doing this, it provides a comprehensive picture of what has driven CIP deviations from 2007 to 2016. While Pinnington and Shamloo (2016) also document the decomposition of the CIP deviation involving CHF into different driving forces, our paper differs from theirs in highlighting global interest rate differentials as important drivers of CIP deviation. Our paper also differs from Sushko et al. (2016). They estimate the demand for USD of Japanese financial institutions using Bank for International Settlements international banking statistics, and gauge the contribution of their demand and other factors to the CIP deviation for the USD/JPY pair. In contrast, we focus rather on the underlying shocks, such as interest margin differential across jurisdictions, which drive banks' demand for USD. In particular, our study is also unique in using central banks' relative balance sheet growth rates as a proxy for interest margin differential to show explicitly the growing importance of monetary policy divergence in the recent rise in CIP deviation facing major currencies.[4]

[4]Sushko et al. (2016) also point out the growing importance of monetary policy divergence behind movements in CIP deviations in recent years. The key difference between their paper and ours arises from our direct estimation of the

The rest of this paper is organized as follows. The next section provides a simple equilibrium model that explains how a CIP deviation is determined by the economic environment, including interest margin differentials and the creditworthiness of global banks. Section 3 describes our econometric methodologies and the results. Section 4 discusses the impact of regulatory reforms on the FX swap market and the increasing presence of real money investors in the market. Section 5 presents our conclusions.

2. A Theoretical Model of CIP Deviation

The basic setting of our model is borrowed from Ivashina, Scharfstein, and Stein (2015). Based on an optimization problem, we derive the behavior of market participants in the FX swap market, and a CIP deviation is determined as the price that clears the demand and supply of USD in the swap market. In our model, the demand and supply of USD is affected by a richer set of variables: global interest rate differentials and global banks' liquidity needs as well as banks' creditworthiness and arbitrageurs' wealth endowment that are central to the model of Ivashina, Scharfstein, and Stein (2015). In addition, we derive and interpret the comparative statics on the sensitivity of a CIP deviation to its determinant factors, focusing on the cost parameters of global banks which are found in the model of Ivashina, Scharfstein, and Stein (2015).

The model is static. The economy consists of two countries, the United States and a non-U.S. country (e.g., Japan), and two types of financial intermediaries, which we refer to as an arbitrageur and a non-U.S. financial institution, respectively.[5] The former is headquartered in the United States, and the latter is headquartered in a non-U.S. country.

quantitative relationship between the central bank's policy instruments and CIP deviation.

[5]A non-U.S. financial institution in our paper is broadly defined, as it includes non-bank financial institutions such as insurance companies that have recently played an increasingly important role in the market. See, for example, Bank of Japan (2016).

2.1 Demand for USD in the FX Swap Market: The Non-U.S. Bank's Optimization Problem

A non-U.S. financial institution (e.g., a Japanese bank) invests in two types of assets: USD-denominated assets (loans and bonds, etc.) that are issued by borrowers in the United States, and JPY-denominated assets that are issued by borrowers in Japan. We denote the two types of assets by L_{US} and L_{JP}. In addition to the two types of assets, we assume that a non-U.S. bank holds a certain amount of USD in cash to prepare for liquidity needs, which is denoted as M. Our preferred interpretation is that liquidity needs capture a liquidity demand with several motives: a precautionary hoarding of liquid assets in response to an increase in uncertainty, regulatory requirements imposed on banks to hold a liquid asset, and liquidity demand arising from banks' transactions.

We further assume that the minimum size of liquidity needs is exogenously given and denoted by V, and cash delivers zero return. A non-U.S. bank raises dollar funding from the U.S. money market by issuing uninsured certificates of deposit (CDs) and commercial paper (CP), with a funding rate of $1 + r^* + p\alpha$. Here, r^* is the risk-free rate in the United States, α is the size of default risk of a non-U.S. bank, and p is a parameter that takes a positive value. A non-U.S. bank raises funding in JPY from the deposits or the money market in Japan. We assume that the deposits collected in Japan are insured by the government so that the borrowing rate associated with JPY funding is equal to the risk-free rate in Japan, which is denoted as r. We denote the two types of funding by D_{US} and D_{JP}. Figure 3 shows the balance sheet of a non-U.S. bank.

A non-U.S. bank takes no FX 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 raises USD of amount S from the FX swap market to fill the gap. The objective of a non-U.S. bank is to maximize its profits, taking all prices as given, and its optimization problem is given as follows:

$$\max_{L_{US},L_{JP},D_{US},D_{JP},M,\ and\ S} \left\{ \begin{array}{l} g_f\left(L_{US}\right) + g_h\left(L_{JP}\right) - c_f\left(D_{US}\right) \\ -c_h\left(D_{JP}\right) - \left(X_1 \times X_0^{-1} - 1\right) S \end{array} \right\} \qquad (3)$$

subject to

$$\begin{aligned} M &\geqslant V \\ L_{US} + M &= D_{US} + S \\ L_{JP} &= D_{JP} - S, \end{aligned} \tag{4}$$

where

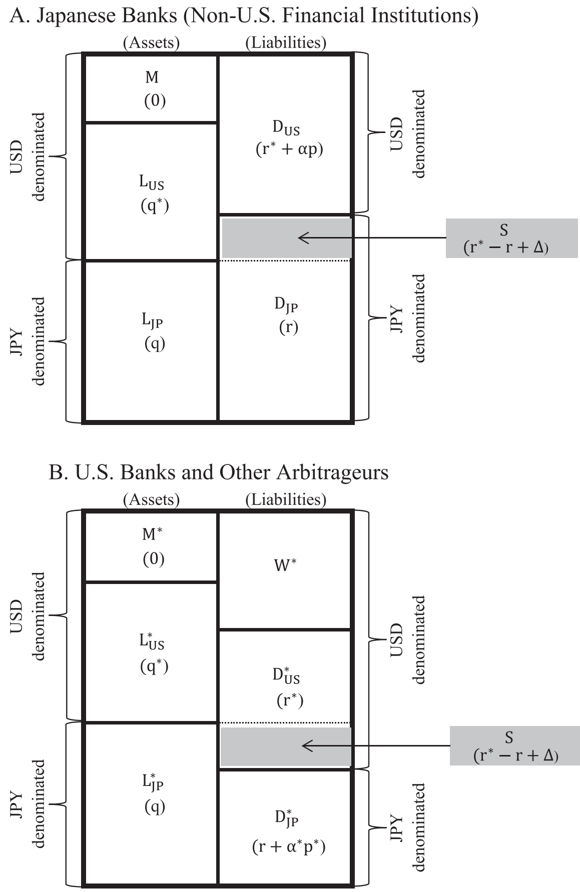
$$\begin{aligned} g_f\left(L_{US}\right) &= \left(1+q^*\right) L_{US} - \frac{\tau^*}{2}\left(L_{US}\right)^2, \\ g_h\left(L_{JP}\right) &= \left(1+q\right) L_{JP} - \frac{\tau}{2}\left(L_{JP}\right)^2, \\ c_f\left(D_{US}\right) &= \left(1+r^*+p\alpha\right) D_{US} + \frac{\eta^*}{2}\left(D_{US}\right)^2,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

Here, q^* and q are the interest rate on USD-denominated assets and on JPY-denominated assets, and X_0 and X_1 are the exchange rate between JPY and USD at spot and forward transactions.[6] The bank earns an expected net return of $g_f(L_{US})$ from USD-denominated assets and $g_h(L_{JP})$ from JPY-denominated assets, where τ^* and τ are parameters that govern the size of credit costs and administrative costs associated with L_{US} and L_{JP}. $c_f(D_{US})$ and $c_h(D_{JP})$ are the cost function of raising funds in USD and JPY, respectively, where η^* and η are parameters that govern the costs associated with changing the size of a bank's balance sheets. We assume that the four parameters (τ^*, τ, η^*, η) always take a positive value, which means that a bank's profit from assets decreases with scale, and its funding cost increases with scale. As discussed later, the impact of regulatory reforms, such as the new leverage ratio framework and the U.S. money market fund reform, is reflected in an increase in the parameters η and η^*.

In equation (3), the first two terms stand for the net earnings of a non-U.S. bank from USD-denominated assets and JPY-denominated

[6]For simplicity, following He et al. (2015) and Ivashina, Scharfstein, and Stein (2015), we assume that there is no interaction between the FX spot rate X_0 and USD-denominated lending. By contrast, Shin (2016) discusses the role of FX rates on USD-denominated lending, and argues that the violation of CIP is a symptom of tighter dollar credit conditions putting a squeeze on accumulated dollar liabilities built up outside the United States during the previous period of easy dollar credit.

Figure 3. Balance Sheets of Global Banks in the Model Economy



Note: The figures in parentheses are the interest applied to each asset or liability.

assets, while the third and fourth terms stand for the net funding cost of USD and JPY. The last term stands for the cost associated with FX swap transactions. Equation (4) specifies the minimum level of liquidity that a non-U.S. bank needs to hold.[7] Note that the cost of borrowing USD from the FX swap market comprises the cost

[7]Because the return from holding cash is dominated by lending returns, this inequality always holds with equality.

associated with FX swap transactions, $X_1 \times X_0^{-1} - 1$, and the cost associated with funding of JPY, which is r. The total cost is therefore collapsed to the FX swap-implied dollar rate.[8]

Taking the first-order condition of a non-U.S. bank's optimization problem and assuming for simplicity that $\eta = \eta^*$ and $\tau = \tau^*$, we can derive a non-U.S. bank's demand function for USD through FX swaps.

$$S = \frac{1}{2\tau}\left\{\left[\left(q^* - r^*\right) - (q - r)\right] - \frac{\tau + \eta}{\eta}\Delta + \frac{\tau p}{\eta}\alpha + \tau V\right\} \quad (5)$$

Here, $q^* - r^*$ is the interest margin in the United States, and $q - r$ is that in Japan. An interest margin differential is defined as the spread between them. The first term in the right-hand side of equation (5) states that the demand for USD increases with the interest margin differential between the two countries.[9] Other things being equal, a widening in the interest margin differential makes an investment in USD-denominated assets more attractive, leading to a higher demand for USD through the FX swap market. The second term states that the demand declines with CIP deviation Δ, as it implies that FX swap becomes more costly than otherwise. The third term states that the demand increases as a non-U.S. bank becomes riskier. A non-U.S. bank cannot make a USD-denominated borrowing at the risk-free rate r^*, but needs to pay the premium $p\alpha$ to lenders in the U.S. money market. With a higher default probability, the bank's funding cost from the U.S. money market rises, which in turn leads the bank to shift its funding source from the U.S. money market to the FX swap market. The interpretation for the last term is straightforward. When more USD needs to be held in cash, the demand for USD thorough the FX swap market increases.

Similarly, the amount of USD-denominated assets held by a non-U.S. bank, i.e., their supply of USD in the U.S. loan and bond market, is given as follows:

$$L_{US} = \frac{1}{\tau + \eta}\left\{\left(1 + \frac{\eta}{2\tau}\right)(q^* - r^*) - \frac{\eta}{2\tau}(q - r) - \frac{\tau + \eta}{2\tau}\Delta - \frac{p}{2}\alpha - \frac{\eta}{2}V\right\}. \quad (6)$$

[8] Using the log-approximated version of expression (2), we obtain the following expression for a CIP deviation: $r^* + \Delta \approx X_1 \times X_0^{-1} - 1 + r$.

[9] We assume that the interest margin differential is sufficiently large so that a non-U.S. bank always raises a positive amount of USD from the FX swap market.

The signs of the coefficients on interest margin and CIP deviation Δ are the same as those that appear in the demand equation (5). By contrast, a bank's default probability 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., higher liquidity needs V), it cuts back on USD-denominated assets.

2.2 Supply of USD in the FX Swap Market: The Arbitrageur's Optimization Problem

We assume that a non-U.S. bank cannot take the supply side in the FX swap market, and that the supplier of USD, which we call the arbitrageur hereafter, maximizes its profit under some constraints. An arbitrageur (e.g., a U.S. bank) raises USD funds with a size D^*_{US} from U.S. markets and JPY funds with a size D^*_{JP} from the Japanese money market. It is assumed that an arbitrageur can collect USD funds such as insured retail deposits at the risk-free rate r^* but cannot raise JPY funds at the risk-free rate r. It needs to pay an additional risk premium $p^*\alpha^*$ to raise JPY funds. Here, α^* is the size of the default risk of an arbitrageur, and p^* is a parameter that takes a positive value. An arbitrageur allocates its funds to investment in USD-denominated assets by the amount of L^*_{US}, and investment in JPY-denominated asset by the amount of L^*_{JP}. Whenever L^*_{JP} is larger than D^*_{JP}, an arbitrageur raises JPY of amount S from the FX swap market to fill the gap. In addition, just like a non-U.S. bank, an arbitrageur holds a certain amount of USD in cash, which we denote by M^*, due to precautionary demand, regulatory requirements, or both. The minimum size of liquidity needs is exogenously given and denoted as V^*. Finally, we assume that an arbitrageur is exogenously given capital or wealth of the amount W^* in USD. The rationale behind this setting is the presence of real money investors, such as asset management companies and SWFs. They participate in the FX swap market together with U.S. banks as USD suppliers. By incorporating a wealth endowment of W^*, we intend to capture the total AUM of these real money investors. Figure 3 shows the balance sheet of an arbitrageur.

The optimization problem of an arbitrageur is then given as follows:

$$\max_{L^*_{US}, L^*_{JP}, D^*_{US}, D^*_{JP}, M^*,\ and\ S} \left\{ \begin{array}{l} h_f\left(L^*_{US}\right) + h_h\left(L^*_{JP}\right) - \kappa_f\left(D^*_{US}\right) \\ -\kappa_h\left(D^*_{JP}\right) + \left(X_1 \times X_0^{-1} - 1\right) S \end{array} \right\} \tag{7}$$

subject to

$$\begin{aligned} M^* &\geqslant V^* \\ L^*_{US} + M^* &= W^* + D^*_{US} - S \\ L^*_{JP} &= D^*_{JP} + S, \end{aligned} \tag{8}$$

where

$$\begin{aligned} h_f\left(L^*_{US}\right) &= \left(1+q^*\right) L^*_{US} - \frac{\gamma^*}{2}\left(L^*_{US}\right)^2, \\ h_h\left(L^*_{JP}\right) &= \left(1+q\right) L^*_{JP} - \frac{\gamma}{2}\left(L^*_{JP}\right)^2, \\ \kappa_f\left(D^*_{US}\right) &= \left(1+r^*\right) D^*_{US} + \frac{\theta^*}{2}\left(D^*_{US}\right)^2, \\ \kappa_h\left(D^*_{JP}\right) &= \left(1+r+p^*\alpha^*\right) D^*_{JP} + \frac{\theta}{2}\left(D^*_{JP}\right)^2. \end{aligned}$$

An arbitrageur earns an expected net return of $h_f\left(L^*_{US}\right)$ from USD-denominated assets and $h_h\left(L^*_{JP}\right)$ from JPY-denominated assets, where γ^* and γ are parameters that govern the size of credit costs and administrative costs associated with L^*_{US} and L^*_{JP}, respectively. $\kappa_f\left(D^*_{US}\right)$ and $\kappa_h(D^*_{JP})$ are the cost function of raising funds in USD and JPY, respectively, where θ^* and θ are parameters that govern the costs associated with changing the size of an arbitrageur's balance sheets. We assume that these four parameters (γ^*, γ, θ^*, θ) always take a positive value, which means that an arbitrageur's profits from financial assets decrease with scale, and its funding cost increases with scale. As discussed later, regulatory reforms contribute to an increase in the parameters θ^* and θ. Equation (8) specifies the minimum level of liquidity that an arbitrageur needs to hold.

Taking the first-order condition of an arbitrager's problem and assuming that $\gamma = \gamma^*$ and $\theta = \theta^*$ for simplicity, we can derive an arbitrageur's supply function of USD through FX swaps.

$$S = \frac{1}{2\gamma}\left\{-\left[\left(q^* - r^*\right) - (q - r)\right] + \frac{(\gamma+\theta)}{\theta}\Delta + \frac{p^*\gamma}{\theta}\alpha^* - \gamma\left(V^* - W^*\right)\right\} \tag{9}$$

In contrast to a non-U.S. bank's decision, the interest margin differential works in the opposite direction in an arbitrageur's decision. When an interest margin differential $(q^* - r^*) - (q - r)$ widens, it is more profitable for an arbitrageur to substitute the supply of USD away from the FX swap transaction to other USD-denominated assets. The supply of USD increases with CIP deviation Δ, because FX swap transactions become more profitable with a higher CIP deviation. It is also important to note that the size of liquidity needs and endowment influences the supply of FX swaps. When liquidity needs V^* increase and/or wealth endowment W^* decreases, there are fewer USD funds left for FX swap transactions.

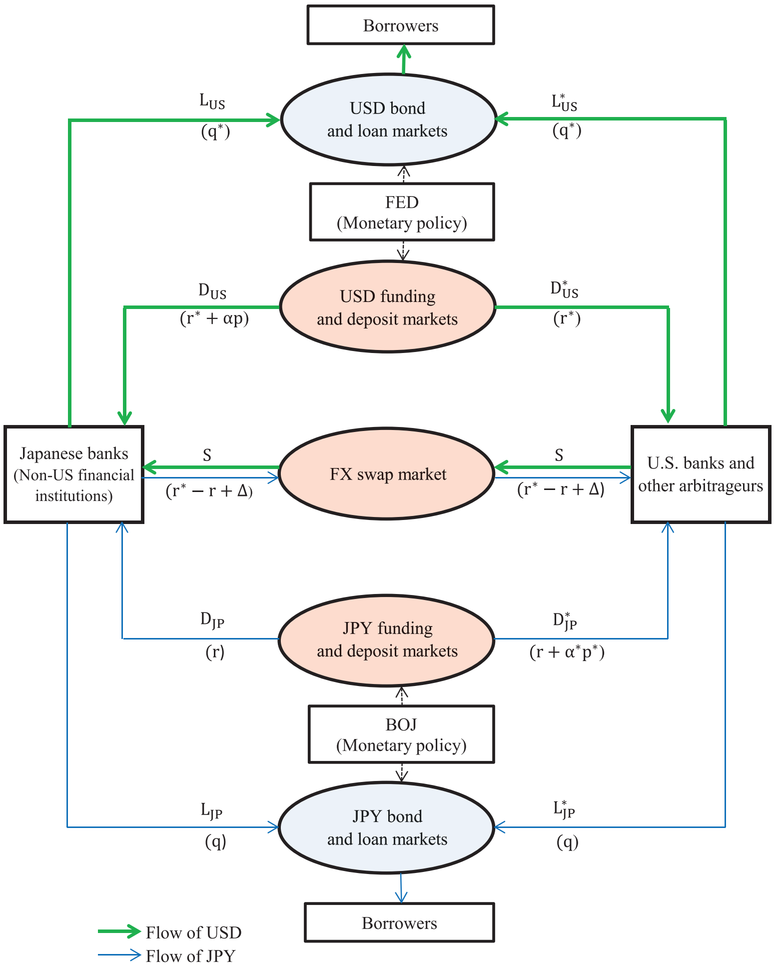
2.3 Equilibrium Condition

The flow of funds of USD and JPY is shown in figure 4. Combining the demand and supply functions (5) and (9), a CIP deviation at the equilibrium is given by the following expression:

$$\Delta = \frac{\eta\theta}{(\tau+\eta)\gamma\theta + (\gamma+\theta)\tau\eta} \times \left\{ \begin{array}{c} (\tau+\gamma)\left[\left(q^* - r^*\right) - (q - r)\right] \\ + \frac{\tau\gamma p}{\eta}\alpha - \frac{\tau\gamma p^*}{\theta}\alpha^* + \tau\gamma(V + V^* - W^*) \end{array} \right\}. \tag{10}$$

According to this equation, CIP deviation Δ is determined by three factors: (i) the interest margin differential, $(q^* - r^*) - (q - r)$, (ii) the default probabilities of a non-U.S. bank and an arbitrageur, α and α^*, and (iii) the liquidity needs of a non-U.S. bank and an arbitrageur, V and V^*, and the wealth endowed to an arbitrageur, W^*. The first factor influences CIP deviation through *investment decisions* made by non-U.S. banks and arbitrageurs. The second factor influences CIP deviation through *funding decisions* made by these two types of agents. For instance, suppose that the default probability of a non-U.S. bank (α) increases, and lenders in U.S. money markets require a higher premium, which in turn leads the bank to raise more USD from the FX swap market, increasing the CIP deviation.

Figure 4. Flow of Funds in the Model Economy



Note: The figures in parentheses are the interest rates applied to each asset or liability.

The higher default probability of an arbitrageur (α^*) affects CIP deviation through a similar mechanism, but in the opposite direction. The third factor influences CIP deviation by directly changing the size of demand and supply for USD that is transacted in the FX swap market.

The volume of the FX swap transaction S at the equilibrium is given by

$$S = \frac{(\tau+\gamma)\,\Omega^{-1}-1}{2\gamma}\left[(q^{*}-r^{*})-(q-r)\right]+\frac{\left(1-\tau\Omega^{-1}\right)p^{*}}{2\theta}\alpha^{*} + \frac{\tau\Omega^{-1}p}{2\eta}\alpha+\frac{\tau\Omega^{-1}}{2}V-\frac{1-\tau\Omega^{-1}}{2}\left(V^{*}-W^{*}\right), \tag{11}$$

where

$$\Omega = \frac{1}{\eta\left(\gamma+\theta\right)}\left[\theta\gamma(\tau+\eta)+\eta\tau(\gamma+\theta)\right] \text{ and } \left(1-\tau\Omega^{-1}\right)>0.$$

Except for the interest margin differential, the sign of the coefficients of all other factors is uniquely determined. Whether a widening interest margin differential $(q^{*}-r^{*})-(q-r)$ leads to an increase in the volume of FX transaction S depends on parameter values, because, as shown in equation (5) and (9), a change in the interest margin differential makes the demand and supply curves for USD shift in the opposite direction. If inequality $\theta\tau<\gamma\eta$ holds, the widening differential affects the transaction volume positively. That is, the impact of the rightward shift of the demand curve is larger than that of the leftward shift of the supply curve. This inequality is satisfied when, for example, the marginal cost of USD funding for non-U.S. banks (η) is sufficiently larger than that for U.S. arbitrageurs (θ).[10]

2.4 The Cost Structure of Global Banks and CIP Deviation

With our theoretical model, we now assess how the cost structure of global banks affects CIP deviation at the equilibrium. For simplification, we continue to assume that for both arbitrageurs and non-U.S. financial institutions, the values of parameters related to marginal return on assets and marginal cost of funding are identical *across currencies* $(\tau=\tau^{*},\eta=\eta^{*},\theta=\theta^{*},\gamma=\gamma^{*})$.

As equation (10) indicates, provided that participating banks are sufficiently creditworthy, CIP deviation collapses to zero in the

[10]As shown later in section 4.2, we empirically observe that swap transaction volume is positively correlated with the interest rate differential (see figure 9, right-side graph of panel B). Therefore, in the following analysis, we assume that $\theta\tau<\gamma\eta$ holds.

case of $\theta = 0$ or $\eta = 0$, which means that an arbitrageur can expand its balance sheet without any constraints, or a non-U.S. bank can borrow funds very easily from the U.S. money market.[11] Indeed, CIP deviations in the 2000s remained almost zero until the global financial crisis occurred and financial regulation was tightened (figure 2).[12] This is probably because unusually easy financial conditions in this period made the value of these parameters negligible.

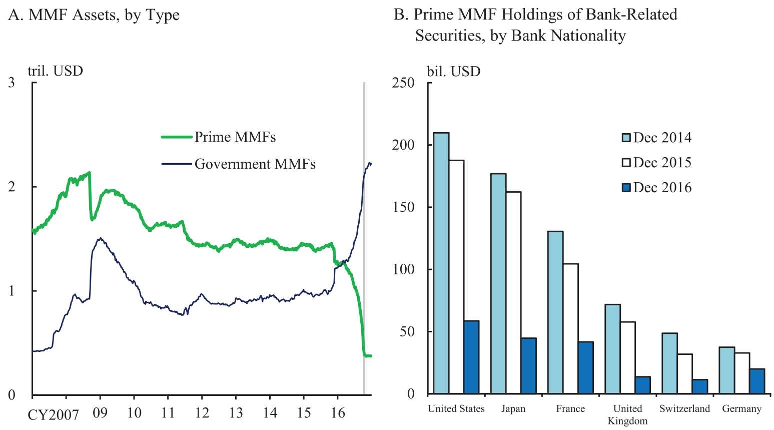
Since the global financial crisis, a good number of regulatory reforms have affected the dollar funding costs of global banks, potentially raising the parameters of cost functions. The U.S. money market fund (MMF) reform is one such example. This reform requires institutional prime MMFs, which principally invest in CDs and CP issued by global banks, to shift from constant net asset value to floating/variable net asset value, while institutional government MMFs are exempt from this rule. The MMF reform rules were published in July 2014 and came into effect in October 2016. Anticipation of the new rules led to a shrinkage of prime funds' assets since around October 2015 (figure 5). Institutional investors switched from prime MMFs to government MMFs, and reduced investment by prime MMFs in CDs and CP lowers the availability of banks' wholesale USD funding. This implies that it costs more for global banks to raise USD in the U.S. money market than in the past. They have to invest in advertising, promotions, and branches, and the more they increase their dollar assets, the greater the marginal costs of dollar funding. In this sense, the U.S. MMF reform increases the parameter η^* of the cost function $c_f\left(D_{US}\right)$ and the parameter θ^* of the cost functions $\kappa_f\left(D^*_{US}\right)$.

The new leverage ratio framework is another example which affects the cost structure of global banks. Specifically, the Basel III leverage ratio framework and the U.S. supplementary leverage ratio (SLR) framework, along with the public disclosure requirements introduced in January 2015, have the effect of increasing capital

[11]According to equation (10), CIP deviation converges to $p\alpha$ as the parameter η approaches zero, while it converges to $-p^*\alpha^*$ as the parameter θ approaches zero. The values therefore take zero when both α and α^* are zero.

[12]See Akram, Rime, and Sarno (2008) for developments in CIP deviations during the pre-crisis period.

Figure 5. Impact of U.S. MMF Reform



Source: Investment Company Institute; U.S. Securities and Exchange Commission.

Notes: For panel A, government MMFs are defined as MMFs that invest 99.5 percent or more of their total assets in cash, government securities, and/or government repurchase agreements. Prime MMFs are defined as MMFs that primarily invest in corporate debt securities. The vertical line in panel A corresponds to the compliance date for amendments related to MMF reforms released by the U.S. Securities and Exchange Commission (October 2016).

requirements for balance sheet expansion relative to the more traditional risk-based capital ratio, which seems to be dampening banks' arbitrage activities. Market participants also suggest that uncertainty remains as to whether short-term USD lending through cross-currency funding markets, with USD funded in the money market, may lead to violation of the Volcker rule, which came into effect in July 2015.[13] This has probably induced U.S. banks to be cautious and avoid arbitrage through FX swap transactions. These stricter financial regulations increase the marginal cost for arbitrageurs (such as U.S. banks) of expanding their balance sheets, and raise the parameter θ of the cost function $\kappa_h\left(D^*_{JP}\right)$ and the parameter θ^* of the cost function $\kappa_f\left(D^*_{US}\right)$.

How does a rise in the parameters $\theta\,(=\theta^*)$ and $\eta\,(=\eta^*)$ caused by regulatory reforms affect CIP deviations? CIP deviations take

[13]See, for example, Arai et al. (2016) and Pozsar (2016).

a positive value when the parameters θ and η are greater than zero. Denoting the coefficient of an interest margin differential $(q^* - r^*) - (q - r)$ in equation (10) to determine CIP deviation by $\partial\Delta/\partial(IMD)$, we can derive the partial derivative of this coefficient with respect to θ and η.

$$\frac{\partial\left(\frac{\partial\Delta}{\partial(IMD)}\right)}{\partial\theta} = \frac{\left(\eta^2\gamma\theta + \tau\gamma\eta^2\right)(\tau+\gamma)}{\left((\tau+\eta)\gamma\theta + \tau(\gamma+\theta)\eta\right)^2} > 0,$$
$$\frac{\partial\left(\frac{\partial\Delta}{\partial(IMD)}\right)}{\partial\eta} = \frac{\left(\eta^2\gamma\theta + \tau\gamma\eta^2\right)\tau\gamma}{\left((\tau+\eta)\gamma\theta + \tau(\gamma+\theta)\eta\right)^2} > 0 \qquad (12)$$

In other words, a rise in the parameters θ and η enhances the sensitivity of a CIP deviation to an interest margin differential. When an arbitrageur (e.g., a U.S. bank) faces a widening interest margin differential, it seeks to increase its USD-denominated assets. With a higher value of θ $(=\theta^*)$, it is more costly for an arbitrageur to expand its balance sheet. Therefore, an arbitrageur shifts its USD funds away from FX swap transactions toward other dollar-denominated investments, which leads to a larger decrease in the supply of USD in the FX swap market (see figures 3 and 4). Similarly, a non-U.S. bank facing a widening interest margin differential seeks to increase its USD-denominated investments. With a higher value of η $(=\eta^*)$, the marginal cost of raising USD from the U.S. money market becomes larger. Therefore, a non-U.S. bank shifts its USD funding source toward the FX swap market, which leads to a larger increase in the demand for USD in the FX swap market (see figures 3 and 4). As a result, a widening interest margin differential causes a higher CIP deviation at the equilibrium as financial regulations become stricter (that is, as the value of parameters θ and η becomes higher).

The relationship regarding how coefficients of liquidity needs (V, V^*) vary with the two parameters is also derived. Denoting these coefficients by $\frac{\partial\Delta}{\partial V}$ and $\frac{\partial\Delta}{\partial V^*}$, respectively, we obtain the following comparative statics:

$$\frac{\partial\left(\frac{\partial\Delta}{\partial V}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial\Delta}{\partial V}\right)}{\partial\eta}, \frac{\partial\left(\frac{\partial\Delta}{\partial V^*}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial\Delta}{\partial V^*}\right)}{\partial\eta} > 0. \qquad (13)$$

Again, these partial derivatives show that CIP deviations react much more to a change in liquidity needs when a tighter regulatory reform is implemented.

Note that the extent to which regulatory reforms influence the effect of banks' default probabilities (α, α^*) on CIP deviation differs across parameters.

$$\frac{\partial\left(\frac{\partial \Delta}{\partial \alpha}\right)}{\partial \theta}, \frac{\partial\left(\frac{\partial \Delta}{\partial \alpha^*}\right)}{\partial \theta} > 0, \quad \text{and} \quad \frac{\partial\left(\frac{\partial \Delta}{\partial \alpha}\right)}{\partial \eta}, \frac{\partial\left(\frac{\partial \Delta}{\partial \alpha^*}\right)}{\partial \eta} < 0 \tag{14}$$

For example, when the default probability of a non-U.S. bank (α) increases, lenders in the U.S. money market require a higher premium, which in turn leads the bank to raise more USD from the FX swap market. With a higher value of θ, an arbitrageur requires a much larger premium to compensate for the higher marginal cost of dollar funding, resulting in an even higher CIP deviation. In contrast, with a higher value of η $(=\eta^*)$, a non-U.S. bank faces a larger marginal cost in raising USD from the U.S. money market, and it reduces dollar lending given an interest margin differential. Therefore, the demand by a non-U.S. bank for USD in the FX swap market is suppressed, resulting in a modest rise in CIP deviation.

Finally, it should be also noted that stricter financial regulations (i.e., higher θ and η in our model) increase the sensitivity of CIP deviations to wealth endowment shocks. The following comparative statics are obtained from equation (10):

$$\frac{\partial\left(\frac{\partial \Delta}{\partial W^*}\right)}{\partial \theta}, \quad \frac{\partial\left(\frac{\partial \Delta}{\partial W^*}\right)}{\partial \eta} < 0. \tag{15}$$

When arbitrageurs such as real money investors face a fall in total AUM (W^*) and reduce the supply of USD in the FX swap market, the demand–supply balance of USD tightens, leading to an increase in CIP deviation. With a higher value of η, a non-U.S. bank faces a higher marginal cost for funding USD from the U.S. money market and becomes less responsive to changes in CIP deviation. That is, the demand curve for USD in the FX swap market becomes steeper, as shown in equation (5). Consequently, the fall in supply of USD is more easily translated into an even higher CIP deviation. Similarly, with a higher value of θ, a U.S. bank requires a much larger premium to compensate for the higher funding costs, which implies that the supply curve of USD in the FX swap market becomes steeper, as shown in equation (9). Again, the leftward shift of the steeper supply curve leads to a much higher CIP deviation. In this sense, an adverse shock to arbitrageurs, such as a fall in the AUM of real money investors, is amplified by stricter financial regulations.

3. Empirical Analysis: Exploring Determinants of CIP Deviation

As indicated in equation (10), our model predicts that a CIP deviation is determined by three factors: (i) an interest margin differential, (ii) default risk of market participants, and (iii) liquidity needs of market participants and wealth endowment of arbitrageurs. In this section, we empirically examine if the model's prediction accords with the data, by regressing CIP deviations on these factors.

3.1 Data

We study the CIP deviation in four currency pairs—EUR/USD, USD/JPY, GBP/USD, and USD/CHF—for the sample period from January 2007 to February 2016, unless otherwise noted.

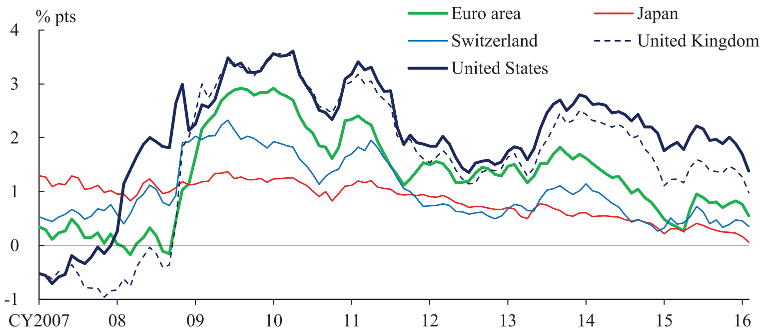
As regards the interest margin $(q^* - r^*, q - r)$, we use the ten-year government bond yield less three-month overnight index swap (OIS) rate, i.e., the slope of the yield curve, for the United States and the four non-U.S. jurisdictions (figure 6). Here, we use the OIS rate as a risk-free rate (r, r^*), because no principal is exchanged in OIS contacts and therefore the counterparty risk associated with them is relatively small.[14]

As for banks' default probabilities (α, α^*), we use the expected default frequency (EDF) series of large banks shown in figure 2.[15] In our model, a bank's default probability affects CIP deviation, as it alters the size of demand and supply of USD in the FX swap market through a change in funding costs in the money market.

[14]The OIS is an interest rate swap in which the floating leg is linked to a publicly available index of daily overnight rates.

[15]Some existing studies, such as Baba and Packer (2009a, 2009b) and He et al. (2015), use credit default swap (CDS) spread as a measure of a bank's default probability. As a robustness check, we estimate the model using CDS spread instead of EDF. We find that the results are indeed little changed.

Figure 6. Interest Margin



Source: Bloomberg.

Note: Interest margin is calculated as the ten-year government bond rate minus the three-month OIS rate.

In addition to this channel, Baba and Packer (2009a, 2009b) argue that a bank's default probability influences CIP deviation through the counterparty credit risk associated with FX swap transactions. They claim that even though FX swap transactions are collateralized, counterparty credit risks are not fully covered by the collateral, because the replacement cost varies over the contract period, due to changes in underlying risk factors—in particular, those associated with exchange rates. When this is the case, counterparty credit risk works in such a way that CIP deviation Δ increases with α and decreases with α^*, reflecting the relative degree of creditworthiness between the two counterparties. While this channel is absent in our theoretical model, it is possible that the empirical exercise conducted below captures this effect as well.

It is difficult to find the data counterpart for liquidity needs of market participants (V, V^*). This is because they are not observable and are driven by different economic factors such as precautionary demand, transaction motive, and financial regulations. Our strategy is to make use of VIX, the Chicago Board Options Exchange (CBOE) Volatility Index, to capture a portion of variations in V and V^*. This index is widely considered as reflecting the sentiments of global investors and arbitrageurs. We use this variable as a proxy of liquidity needs due to precautionary demand originating from market uncertainty. Data on the wealth endowment of arbitrageurs (W^*) are also not available, and we discuss this issue later in section 4.

Following the most common treatment in the existing literature, we use the CIP deviation based on LIBOR as a dependent variable (Δ).[16] Note that the CIP deviation based on LIBOR can be decomposed into two components: (i) the CIP deviation based on the OIS rate, and (ii) the difference in LIBOR-OIS spreads between the currency pair. Since we use the OIS rate as a risk-free rate (r, r^*), the CIP deviation based on the OIS rate corresponds to Δ in equations (2) and (10). Therefore, by using the CIP deviation based on LIBOR as a dependent variable in the panel estimation, we implicitly assume that the contribution of the difference in LIBOR-OIS spreads is captured by independent variables, in particular, the credit risk of market participants (α, α^*).

3.2 Methodology

Our baseline model is a set of regressions that includes a CIP deviation as the dependent variable and its three determinant factors as the independent variables.

(Model 1)

$$\begin{aligned} \Delta_{it} = \delta_1 \left[(q_t^* - r_t^*) - (q_{it} - r_{it}) \right] + \beta_1 \alpha_{it} + \beta_1^* \alpha_t^* \\ + \lambda_1 \, VIX_t + c_{1i} + \varepsilon_{1it} \end{aligned} \tag{16}$$

(Model 2)

$$\begin{aligned} \Delta_{it} = \delta_2^* \left(q_t^* - r_t^* \right) + \delta_2 \left(q_{it} - r_{it} \right) + \beta_2 \alpha_{it} + \beta_2^* \alpha_t^* \\ + \lambda_2 \, VIX_t + c_{2i} + \varepsilon_{2it} \end{aligned} \tag{17}$$

(Model 3)

$$\begin{aligned} \Delta_{it} = \delta_{3i} \left[(q_t^* - r_t^*) - (q_{it} - r_{it}) \right] + \beta_{3i} \alpha_{it} + \beta_{3i}^* \alpha_t^* \\ + \lambda_{3i} \, VIX_t + c_{3i} + \varepsilon_{3it} \end{aligned} \tag{18}$$

[16] See, for example, Baba and Packer (2009a, 2009b), Coffey, Hrung, and Sarkar (2009), and He et al. (2015).

Here, the subscript i stands for jurisdiction (i = the euro area, Japan, Switzerland, and the United Kingdom). The parameters c_{1i}, c_{2i}, and c_{3i} represent the jurisdiction-specific fixed effects, and ε_{1it}, ε_{2it}, and ε_{3it} are error terms. The three models are different from each other regarding how parameter restrictions on the coefficients are imposed. Model 1 corresponds to our theoretical model in which the following assumptions are imposed on technology parameters.

- For both arbitrageurs and non-U.S. financial institutions, parameters related to the marginal return of financial assets and the marginal cost of funding are identical *across currencies* ($\tau = \tau^*, \eta = \eta^*, \theta = \theta^*, \gamma = \gamma^*$).
- For non-U.S. financial institutions, each parameter related to the marginal return of financial assets (τ, τ^*) and the marginal cost of funding (η, η^*) is identical *across jurisdictions*.

Model 2 corresponds to the case where the first assumption is dropped, and model 3 corresponds to the case where the second assumption is dropped, while one other assumption is maintained in both cases.

As discussed in section 2.4, the sensitivity of a CIP deviation to its determinant factors may be time varying due to regulatory reforms, but in this section we assume that the coefficients in models 1–3 are fixed over the sample period. (In section 4.1, we allow the coefficients to be time varying.)

3.3 Estimation Results

Table 1 shows the results of the panel regression.[17] We compute the standard deviation of an estimated coefficient using White period standard errors and covariance, allowing the residuals in each model to be serially correlated.[18] In all three models, the signs of estimated

[17]As for GBP/USD in model 3, we exclude the arbitrageur's default probability α^* from the set of explanatory variables in order to avoid the multicollinearity problem. As shown in figure 2, the EDF of U.K. banks has recently developed in a similar way to the EDF of U.S. banks.

[18]The error terms ε_{1it}, ε_{2it}, and ε_{3it} represent banks' liquidity needs (V, V^*) unexplained by VIX and the wealth endowment of arbitrageurs (W^*). Given our model structure, it is reasonable to assume that these error terms are uncorrelated

coefficients of explanatory variables are consistent with the prediction of our equilibrium model shown in equation (10). A higher interest margin in the United States ($q^* - r^*$), or a lower interest margin in non-U.S. jurisdictions ($q - r$), or both, tightens the demand–supply balance of USD in the FX swap market, resulting in a larger positive CIP deviation. The estimated coefficients of non-U.S. banks' default risk (α) are positive, and those of U.S. arbitrageurs' default risk (α^*) are negative and statistically significant. This observation is consistent with the substitution effect captured in the second and third terms in equation (10) and/or the credit risk channel emphasized in Baba and Packer (2009a, 2009b).[19] The coefficients of VIX are positive and statistically significant, suggesting that heightened market uncertainty increases precautionary demand by both non-U.S. banks and arbitrageurs, pushing up CIP deviations.

3.4 Sensitivity Analysis: Use of Alternative Variables

3.4.1 CIP Deviation Based on Alternative Terms

In our baseline estimation, we focus on CIP deviations measured by the three-month FX swap-implied dollar rate. Here, we examine whether the estimated results are robust to a choice of terms. To do this, we employ model 1 with the dependent variable replaced by CIP deviations measured by the six-month and one-year FX swap-implied dollar rate, respectively. Table 2 shows the results based on these alternative estimation settings. Estimation results are little changed from those reported in table 1.[20]

with explanatory variables. As a robustness check, we estimate the three models using the lagged value of the explanatory variables in order to avoid possible correlation between error terms and explanatory variables. The results are little changed from those reported in table 1.

[19] Baba and Packer (2009a) report that during the Lehman crisis even U.S. banks participated in the FX swap market to raise USD. They examine how the CDS spreads of U.S. financial institutions are correlated with CIP deviation. Similar to our finding, they find that CDS spreads of U.S. financial institutions are negatively correlated with CIP deviation.

[20] Although not reported, we conduct the estimation exercise using alternative terms based on model 2 and model 3 as well. The results are little changed.

Table 1. Panel Regressions of CIP Deviations (3M)

			Model 3			
	Model 1	**Model 2**	**EUR/USD**	**USD/JPY**	**USD/CHF**	**GBP/USD**
Interest Margin^{US} – Interest Margin$^{non\text{-}US}$	0.0469***		0.0452***	0.0578***	0.0567***	0.0763***
	(6.23)		(2.86)	(5.72)	(3.37)	(2.74)
Interest Margin^{US}		0.436***				
		(5.84)				
Interest Margin$^{non\text{-}US}$		−0.0595***				
		(−5.55)				
EDF^{US}	−0.0558***	−0.0511***	−0.0525***	−0.0689***	−0.1316***	
	(−3.84)	(−3.39)	(−3.01)	(−3.87)	(−5.02)	
EDF$^{non\text{-}US}$	0.0865***	0.0908***	0.1206***	0.0014	0.2615*	0.0854**
	(6.72)	(6.87)	(8.57)	(0.07)	(1.90)	(1.99)
VIX	0.0148***	0.0146***	0.0207***	0.0096***	0.0146***	0.0169***
	(7.33)	(7.19)	(7.73)	(3.28)	(5.02)	(7.56)
Constant	−0.1621***	−0.1426***	−0.1827***			
	(−4.86)	(−4.18)	(−8.09)			
Fixed Effects	Yes	Yes	Yes			
R-squared	0.49	0.49	0.65			
RMSE	0.15	0.15	0.06	0.05	0.07	0.05
No. of Observations	440	440	440			

Notes: Sample period: 2007:M1–2016:M2. Figures in parentheses are t-statistics. Standard errors are calculated based on period weights (PCSE) method. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Table 2. Panel Regressions of CIP Deviations of Different Terms

	Dependent Variable		
	CIP Deviation (3M)	**CIP Deviation (6M)**	**CIP Deviation (1Y)**
Interest Margin^{US} – Interest Margin$^{non\text{-}US}$	0.0469***	0.0510***	0.0736***
	(6.23)	(6.54)	(8.42)
EDF^{US}	−0.0558***	−0.1093***	−0.1163***
	(−3.84)	(−7.60)	(−8.62)
EDF$^{non\text{-}US}$	0.0865***	0.1353***	0.1386***
	(6.72)	(11.17)	(9.78)
VIX	0.0148***	0.0147***	0.0158***
	(7.33)	(6.06)	(5.56)
Constant	−0.1621***	−0.1976***	−0.2389***
	(−4.86)	(−4.93)	(−5.07)
Fixed Effects	Yes	Yes	Yes
R-squared	0.49	0.50	0.48
RMSE	0.15	0.16	0.18
No. of Observations	440	440	440

Notes: Sample period: 2007:M1–2016:M2. Figures in parentheses are *t*-statistics. Standard errors are calculated based on period weights (PCSE) method. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent level, respectively.

3.4.2 CIP Deviation Based on OIS

Following the most common treatment in the existing literature, we use the CIP deviation based on LIBOR as the dependent variable (Δ) in the baseline estimation. Theoretically, however, the CIP deviation based on the risk-free rate is more compatible with our model, because interest rates r and r^* are the risk-free rates in the model. We repeat the regression exercises for model 1, with the dependent variable replaced by the three-month CIP deviation based on the OIS rate. Table 3 shows the estimation result. With the exception that the coefficient of a default probability of non-U.S. banks (α) is statistically insignificant with an opposite sign, all other coefficients are significant with correct signs. When CDS spread is used

Table 3. Panel Regressions of CIP Deviations (3M) Based on OIS

	α, α^* : EDF	α, α^* : CDS
Interest Margin$^{\text{US}}$ – Interest Margin$^{\text{non-US}}$	0.0729***	0.0819***
	(5.71)	(5.33)
Default Probability of U.S. Banks (α^*)	−0.0897***	−0.0009***
	(−4.65)	(−3.62)
Default Probability of Non-U.S. Banks (α)	−0.0156	0.0003**
	(−0.92)	(2.17)
VIX	0.0292***	0.0277***
	(7.55)	(6.53)
Constant	−0.2930***	−0.2614***
	(−4.77)	(−4.50)
Fixed Effects	Yes	Yes
R-squared	0.60	0.58
RMSE	0.20	0.21
No. of Observations	440	440

Notes: Sample period: 2007:M1–2016:M2. Figures in parentheses are t-statistics. Standard errors are calculated based on period weights (PCSE) method. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent level, respectively. The coefficients are estimated based on the estimation model 1, equation (16).

as an alternative measure of default probability, the coefficients on the default probability of both U.S. arbitrageurs and non-U.S. banks are statistically significant with correct signs.

Summing up the results of tables 1–3, using different measures of CIP deviations as dependent variables does not change our main finding that interest margin differential, banks' creditworthiness, and their liquidity needs are determinant factors of CIP deviations.

3.4.3 Interest Margin Differential and Monetary Policy Divergence

In tables 1–3, we use the ten-year government bond yield less three-month OIS rate as the interest margin ($q^* - r^*, q - r$). However, in practice, arbitrageurs and non-U.S. financial institutions invest in a broader class of assets other than government bonds. Because monetary policy affects returns of broad asset classes, a policy variable may be a good proxy for the interest margin. Indeed, existing studies agree that monetary policy significantly influences banks' net interest margins, which implies that interest margin differentials between U.S. and non-U.S. countries depend on the degree of monetary policy divergence between them. There is also considerable empirical evidence that unconventional monetary policies such as quantitative easing have the effect of lowering medium- to long-term bond yields and term premiums, which is closely related to the interest margin in our model.[21] In addition, unconventional monetary policies affect the return of risky assets as well as safe assets (e.g., government bonds). For example, the Bank of Japan has purchased exchange-traded funds (ETFs), Japanese real estate investment trusts (J-REITs), commercial paper, and corporate bonds in order to lower risk premium of assets prices.

Here, we therefore explicitly include a monetary policy instrument itself in our regression models as a proxy of interest margin. In most of the sampled jurisdictions during our sample periods, the policy instrument has changed from the short-term interest rate to quantitative measures. Therefore, as regards our model estimation, we move forward the starting period of the sample period from January 2007 to December 2008, the month after quantitative easing (QE) was first launched by the Federal Reserve, and use the size of the central bank's balance sheet as the policy instrument. This approach is consistent with existing studies such as Gambacorta, Hofmann, and Peersman (2014) and He et al. (2015). Specifically, we estimate models 1–3 by replacing interest margin with the size of the central bank's balance sheet.

(Model 1)

$$\Delta_{it} = \delta_1 \left[CB_t^* - CB_{it} \right] + \beta_1 \alpha_{it} + \beta_1^* \alpha_t^* + \lambda_1 \, VIX_t + \phi_1 \xi_{it} + c_{1i} + \epsilon_{1it} \tag{19}$$

(Model 2)

$$\Delta_{it} = \delta_2^* \, CB_t^* + \delta_2 \, CB_{it} + \beta_2 \alpha_{it} + \beta_2^* \alpha_t^* + \lambda_2 \, VIX_t + \phi_2 \xi_{it} + c_{2i} + \epsilon_{2it} \tag{20}$$

[21]See, for instance, Rogers, Scotti, and Wright (2014) and Kimura and Nakajima (2016).

(Model 3)

$$\Delta_{it} = \delta_{3i}\left[CB_t^* - CB_{it}\right] + \beta_3\alpha_{it} + \beta_3^*\alpha_t^* + \lambda_{3i}VIX_t + \phi_3\xi_{it} + c_{3i} + \epsilon_{3it} \quad (21)$$

Here, CB_t^* and CB_{it} are the monthly growth rate of the seasonally adjusted size of the balance sheet of the Federal Reserve and that of the central bank in the non-U.S. jurisdiction i, respectively. Note that the expected sign for the difference in growth rate of central banks' balance sheets (i.e., $CB_t^* - CB_{it}$) is negative rather than positive. When the growth rate of the central bank's balance sheet in the non-U.S. jurisdiction outpaces that in the United States, the interest margin differential is expected to widen, which brings about a higher CIP deviation. The parameters c_{1i}, c_{2i}, and c_{3i} represent the jurisdiction-specific fixed effects, and ϵ_{1it}, ϵ_{2it}, and ϵ_{3it} are residuals. ξ_{it} is the vector of control variables that serves for extracting policy shocks from the change in the growth rates of the central bank's balance sheet, which consists of the CPI inflation rate and capacity utilization of the manufacturing sector in jurisdiction i.[22]

As shown in table 4, the estimation results indicate that the impact of monetary policy divergence on CIP deviations is statistically significant with the correct sign. That is, CIP deviations rise when the growth rate of the central bank's balance sheet in the non-U.S. jurisdiction outpaces that in the United States. This is because such diverging monetary stances encourage non-U.S. financial institutions to "search for yield" on USD-denominated assets and lead to an increase in demand for USD through the FX swap market. The signs of the estimated coefficients of banks' default probabilities and VIX are unaffected by replacing the interest margin with the central bank's balance sheet in the regression equation.

3.5 Economic Significance of Explanatory Variables

In tables 1–4, we confirm that each explanatory variable is statistically significant. We next empirically examine an economic significance of explanatory variables as the determinant factors of CIP

[22] As a sensitivity analysis, we estimate the models without the control variables. The results are little changed from those reported in table 4.

Table 4. Impact of Monetary Policy Divergence on CIP Deviations: Panel Analysis

	Model 1	Model 2	Model 3			
			EUR/USD	USD/JPY	USD/CHF	GBP/USD
BS (Monthly Growth Rate)^{US} – BS (Monthly Growth Rate)$^{non\text{-}US}$	−2.8470***		−2.8276***	−3.8069***	−2.1985***	−1.6965***
	(−9.36)		(−6.15)	(−4.05)	(−5.45)	(−3.03)
BS (Monthly Growth Rate)^{US}		−2.5289***				
		(−4.34)				
BS (Monthly Growth Rate)$^{non\text{-}US}$		3.0476***				
		(8.51)				
EDF^{US}	−0.0334*	−0.0332*	0.0298	−0.0645***	−0.1369***	
	(−1.74)	(−1.74)	(0.87)	(−2.64)	(−4.14)	
EDF$^{non\text{-}US}$	0.0730***	0.0733***	0.1010***	0.0224	0.0933	0.0857*
	(5.60)	(5.63)	(6.82)	(1.28)	(0.64)	(1.68)
VIX	0.0112***	0.0108***	0.0126***	0.0141***	0.0141***	0.0120***
	(5.05)	(5.51)	(3.14)	(3.95)	(3.91)	(4.18)
Constant	−0.0469	−0.0460	−0.0806***			
	(−1.54)	(−1.58)	(−3.09)			
Fixed Effects	Yes	Yes	Yes			
R-squared	0.56	0.56	0.72			
RMSE	0.12	0.12	0.05	0.04	0.06	0.04
No. of Observations	348	348	348			

Notes: Sample period: 2008:M12–2016:M2. Figures in parentheses are t-statistics. Standard errors are calculated based on period weights (PCSE) method. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent level, respectively.

deviations. Specifically, based on the estimation result of equation (21) as an example, we compute the contribution of the explanatory variables to CIP deviations and see how the relative significance of each variable to movements in CIP deviation has changed over time.[23]

Figure 7 shows the result. Several observations are particularly noteworthy. First and most importantly, the differential in growth rates of the central bank's balance sheet has contributed to a rise in CIP deviation, in particular since 2014. Its positive contribution is pronounced in two currency pairs, EUR/USD and USD/JPY. Second, banks' liquidity needs proxied by VIX have not recently affected CIP deviations, while they contributed to increasing CIP deviations in the Lehman crisis. Third, banks' default probabilities played the key role in increasing CIP deviations for the currency pair EUR/USD during the euro-zone sovereign debt crisis, possibly through the substitution of funding source that is highlighted in Ivashina, Scharfstein, and Stein (2015). It is also notable that, for pairs USD/JPY and USD/CHF, banks' default probabilities resulted in a net lowering of CIP deviation during the Lehman crisis. This reflects the fact that the decline in banks' creditworthiness at that time was disproportionately larger in the United States than in Japan and Switzerland, leading to a smaller premium for USD supply. A similar finding is also reported in Baba and Packer (2009a). In recent years, however, the contribution of banks' default probabilities has been very minor.

4. Discussion

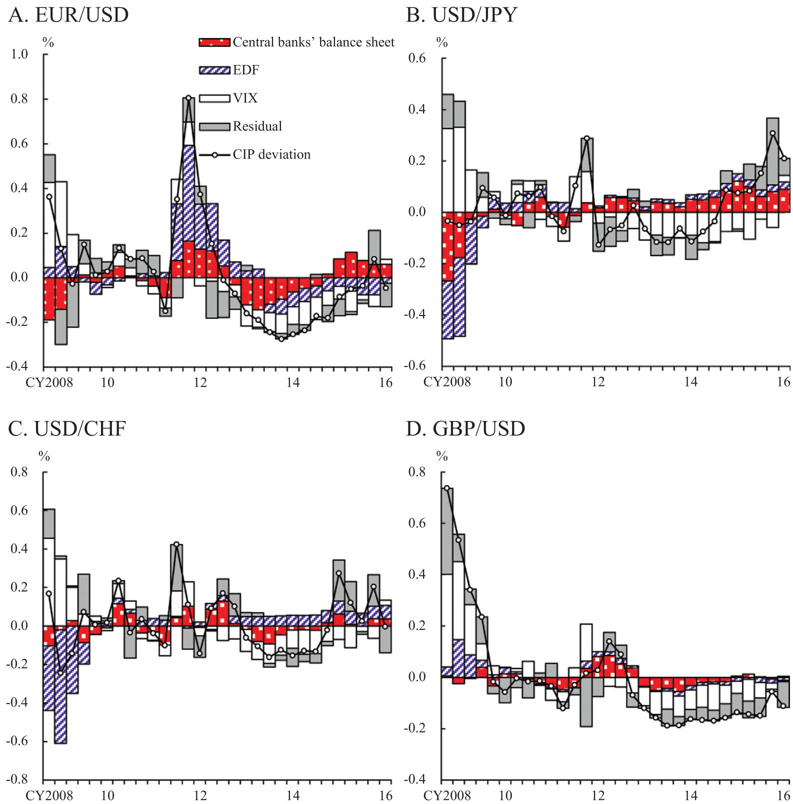
In this section, we extend the analysis of the CIP deviation by turning our attention to the impact of regulatory reforms (section 4.1) and the increasing presence of alternative arbitrageurs (section 4.2).

4.1 The Impact of Regulatory Reforms

As explained in section 2.4, the sensitivity of a CIP deviation to its determinant factors is affected by regulatory reforms which change

[23]Using the estimation results based on other equations does not affect the main implications suggested by figure 7.

Figure 7. Decomposition of CIP Deviation



Notes: Each panel shows the quarterly average of the decomposition of CIP deviation based on the regression results of model 3 shown in table 4. Contributions of constant terms are not depicted. "Central banks' balance sheet" in each panel is the contribution of the difference in growth rates of the central banks' balance sheets. "EDF" in each panel is the sum of the contribution of EDF in the non-U.S. jurisdiction and EDF in the United States, indicating the net effect of banks' default probabilities. Residuals in each panel include the contribution of control variables.

the cost structure of global banks. We empirically examine whether the effect of regulatory reforms is reflected in the change in coefficients of the model. To this end, we estimate model 1 in equation (16), using the same monthly series but with different sample periods for the four currency pairs, and see how the estimated coefficients vary depending on the sample period. We set the starting period of the sample period to January 2007 and allow the ending point to differ across examples. Note that the effect of new regulatory reforms is expected to appear in the later stages of the sample period. Specifically, against the backdrop of the U.S. MMF reform, institutional investors have been switching from prime MMFs to government MMFs since fall 2015 (figure 5). The Volcker rule took effect in July 2015. As for the Basel III leverage ratio framework, public disclosure of the leverage ratio started effective January 2015 based on the standards published in January 2014. As for the U.S. SLR framework, U.S. banking agencies finalized the enhanced SLR standards in April 2014, and advanced approaches firms (including the eight U.S. global systemically important banks, or G-SIBs) began making detailed pillar 3 public disclosure regarding the SLR in January 2015.[24]

The upper four graphs in figure 8 show the result. The x-axis represents the end of the sample period. The y-axis represents the estimated coefficient of each explanatory variable. The coefficient of the interest margin differential increases gradually as the ending point of the sample period is extended forward. This observation is consistent with the model's prediction in equation (12). That is, the sensitivity of CIP deviations to interest margin differentials increases with stricter financial regulation (i.e., higher θ and η). In contrast, the estimated coefficients of banks' default probabilities (α, α^*) are stable across the sample periods. This is probably because a rise in the value of parameters θ and η has the opposite effect on the sensitivity of a CIP deviation to banks' default probabilities, as shown in equation (14).[25]

[24]The effects of the new leverage ratio framework are typically observed in the quarter-end spikes of USD funding costs, as follows: (i) Since around 2014, U.S. banks have deleveraged due partly to the U.S. SLR (in which a higher ratio than international rules is required, and is calculated on the basis of daily averaged assets); (ii) non-U.S. banks, European banks in particular, which previously had increased positions in the U.S. money market, have started to shrink their balance sheets at quarter-ends since the middle of 2014, partly to hold down the leverage ratio at quarter-ends (in many countries, although not in the United States, banks report only the leverage ratio at quarter-ends); (iii) at quarter-ends, U.S. banks increase market-making and arbitrage-trading activities in the money market at higher rates, inclusive of higher costs posed by regulation.

[25]The estimated coefficient of VIX is also stable, although equation (13) suggests that the sensitivity of a CIP deviation to liquidity needs (V, V^*) rises with

In order to examine whether the change in the coefficient of the interest margin differential is statistically significant, we estimate model 1 with a dummy variable (DUM_t^T), which takes zero from January 2007 to a point before the period T and takes unity from period T to February 2016. Using this variable, we estimate the following panel equation for $i =$ the euro area, Japan, Switzerland, and the United Kingdom.

$$\Delta_{it} = (\delta_T + \delta_T^D \times DUM_t^T)[(q_t^* - r_t^*) - (q_{it} - r_{it})] + \beta_T \alpha_{it} + \beta_T^* \alpha_t^* + \lambda_T VIX_t + c_{Ti} + \varepsilon_{Tit}, \tag{22}$$

$$\text{where } DUM_t^T = \begin{cases} 0, & t < T \\ 1, & T \leqslant t \end{cases}$$

The lower two graphs in figure 8 show the estimation result. The y-axis stands for estimated coefficients δ_T and δ_T^D, and the x-axis stands for the period T. Both of the parameters are positive and statistically significant. While the estimated coefficient δ_T is stable, δ_T^D rises as the period T is extended forward. Specifically, the estimation result suggests that the sensitivity of CIP deviations to interest margin differentials becomes higher from around 2014, which corresponds to the period when the effect of new regulatory reforms related to the parameters θ and η is expected to appear. The sensitivity of CIP deviations in 2015 is about two times higher than before.

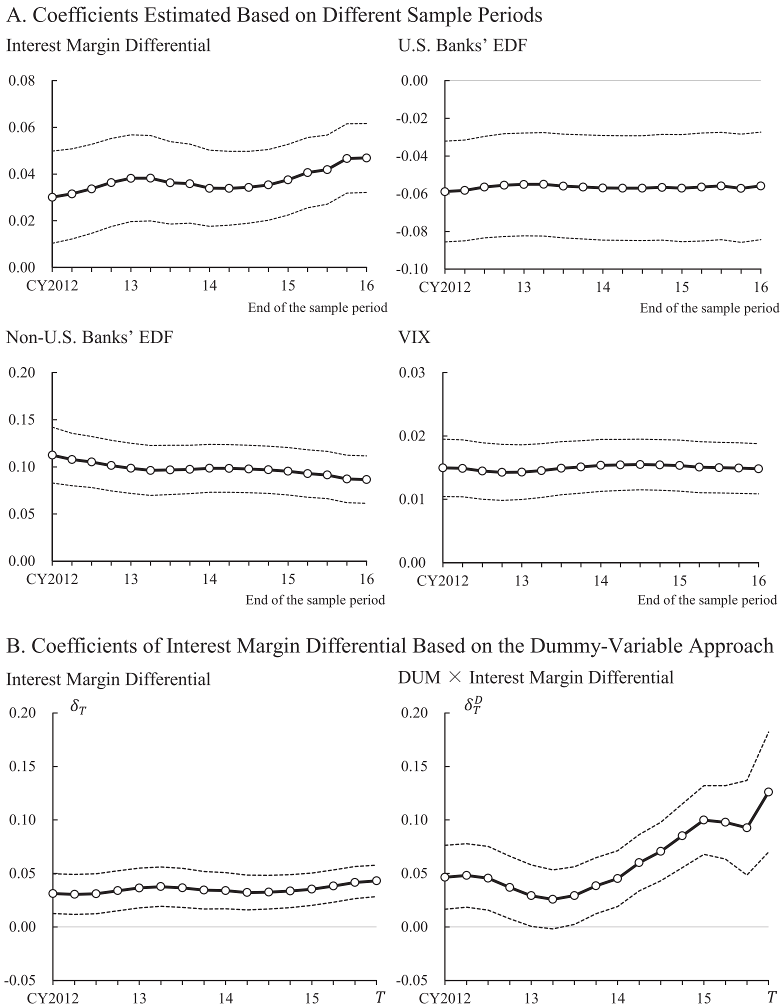
4.2 Real Money Investors as Alternative Arbitrageurs

While arbitrage trading activities by banks have declined due to regulatory reforms, real money investors, such as asset management companies, SWFs, and foreign official reserve managers, have increased their presence as suppliers of USD in the FX swap market.[26] The existence of dollar funding premiums in the swap market signifies an opportunity for suppliers of USD to obtain yen funding

higher θ and η. This may be related to the fact that VIX is an imperfect measure of liquidity needs, as we have discussed.

[26]See Arai et al. (2016) and Nakaso (2017) for details.

Figure 8. Impact of Regulatory Reforms on CIP Deviations



Notes: For panel A, the x-axis denotes the end of the sample period used to estimate the coefficient of the variable which is depicted in the y-axis. Dotted lines indicate 95 percent confidence intervals. For panel B, the x-axis denotes the starting period from which the dummy variable takes unity. Dotted lines indicate 95 percent confidence intervals.

at a very low rate. As a result, real money investors that have dollars to spare can invest in Japanese government securities, even if the nominal yields on such paper are zero or negative, and secure yields as good as or higher than U.S. government securities without taking on foreign exchange risk.[27] Indeed, the proportion of foreign holders of Japanese T-bills has increased from about 30 percent in 2014 to 50 percent in 2016. In the following, we empirically assess the role of real money investors in the FX swap market, by assuming that their total AUM is captured by the wealth endowment of arbitrageurs (W^*) in our model.

4.2.1 Methodology

Based on equations (10) and (11), we first estimate the following equations for USD/JPY:[28]

$$\Delta_t = \delta_1^* \left(q_t^* - r_t^*\right) + \delta_1 \left(q_t - r_t\right) + \beta_1 \alpha_t + \beta_1^* \alpha_t^* + \lambda_1 \, VIX_t + c_1 + v_{1t} \tag{23}$$

$$S_t = \delta_2^* \left(q_t^* - r_t^*\right) + \delta_2 \left(q_t - r_t\right) + \beta_2 \alpha_t + \beta_2^* \alpha_t^* + \lambda_2 \, VIX_t + c_2 + v_{2t}. \tag{24}$$

Here, v_{1t} and v_{2t} are error terms, which represent banks' liquidity needs (V, V^*) unexplained by VIX and the wealth endowment of arbitrageurs (W^*). We next decompose these error terms (v_{1t}, v_{2t})

[27] For example, the Reserve Bank of Australia puts more than half of its foreign reserves into yen and then swaps most of them back into Australian dollars and American dollars. Reserve Bank of Australia (2016) explains as follows: "As has been the case for some years, when the costs of hedging currency risk are taken into account, yields on short-dated Japanese investments have generally exceeded those available in the other currencies in the Reserve Bank's portfolio. Reflecting this, the bulk of the foreign currency the Bank obtains from swaps against Australian dollars is Japanese yen. For the same reason, the Bank also swaps other currencies in its reserves portfolio against the yen to enhance returns. As a consequence, while the Bank's exposure to changes in the value of the yen remains small (consistent with the yen's 5 per cent allocation in the Bank's benchmark), around 58 per cent of the Bank's foreign exchange reserves were invested in yen-denominated assets at the end of June 2016."

[28] The monthly volume of FX swap transaction (S) is available only for USD/JPY. We use the daily average turnover of FX swaps traded by foreign exchange brokers in Tokyo in each month.

into two components: (i) *demand shocks* related to non-U.S. banks' liquidity needs, and (ii) *supply shocks* related to arbitrageurs' liquidity needs and wealth endowment.

As equation (5) suggests, an increase in non-U.S. banks' liquidity needs (V) causes a rightward shift of the demand curve for USD in the FX swap market. This leads to an increase in both CIP deviation (Δ) and the transaction volume of FX swap (S), as indicated by equations (10) and (11). In contrast, as equation (9) suggests, an increase in arbitrageurs' liquidity needs (V^*) or a decrease in their wealth endowment (W^*) causes a leftward shift in the supply curve for USD in the FX swap market, which leads to an increase in CIP deviation (Δ) and a decrease in the transaction volume of FX swap (S).

By making use of these characteristics and applying the VAR identification scheme with sign restrictions, we extract demand and supply shocks from residual series v_{1t} and v_{2t}. Specifically, we first formulate the vector autoregression (VAR) that consists of these two residual series, and then identify demand and supply shocks from error terms of this VAR by imposing two restrictions. The first restriction is that a positive demand shock contemporaneously increases v_{1t} and v_{2t}, and the second restriction is that a positive supply shock contemporaneously increases v_{1t} and decreases v_{2t}. That is, we assume that the error terms v_{1t} and v_{2t} are expressed by a linear combination of two structural shocks in the VAR model, and identify demand shocks and supply shocks by making use of sign restrictions.[29]

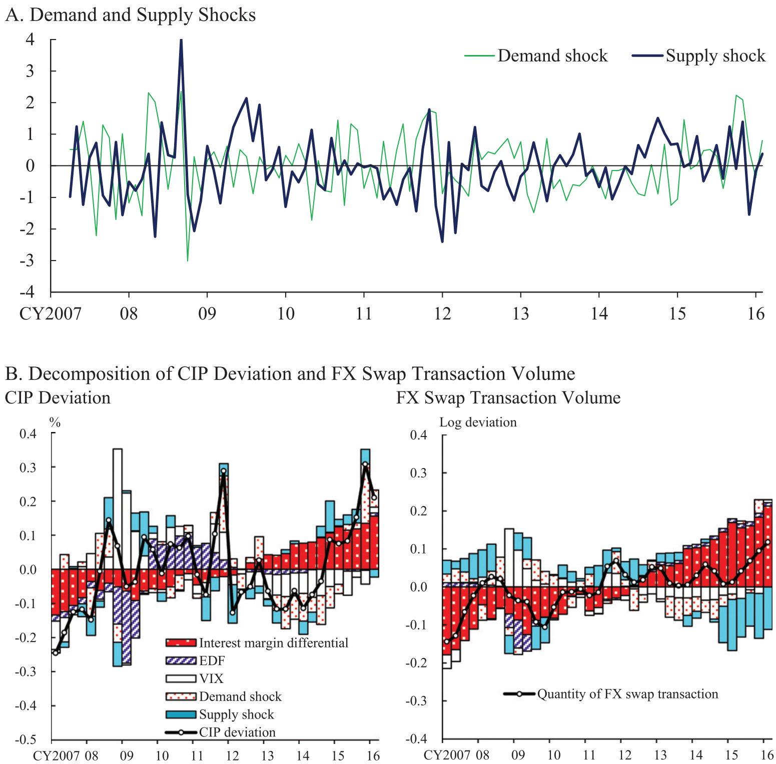
4.2.2 Estimation Results

The upper graph in figure 9 shows the time paths of two estimated structural shocks for USD/JPY. The lower two graphs show the decomposition of the CIP deviation and the FX swap transaction volume into interest margin differential, banks' EDFs, VIX, and two structural shocks.[30] Both demand and supply shocks have been an important source of variations in CIP deviation (Δ) and the FX

[29]See Uhlig (2005) for details of VAR identification with sign restrictions.

[30]The contribution of demand shocks and supply shocks can be obtained as the linear combination of a sequence of these shocks based on the VAR model.

Figure 9. Decomposition of CIP Deviation and FX Swap Transaction Volume (USD/JPY)



Source: Authors' calculations.

Notes: The size of demand and supply shocks is normalized so that its variance is unity. Panel B shows the quarterly average of the decomposition of CIP deviation and FX swap transaction based on the estimation results. Note that contributions of constant terms are not depicted. "Interest margin differential" and "EDF" in each panel are the sum of the contribution of interest margin in Japan and in the United States, and the sum of the contribution of EDF in Japan and the United States, respectively. "FX swap transaction volume" is the log deviation of the volume from its average in 2006.

swap transaction volume (S). Demand shocks contributed to lowering CIP deviation (Δ) and the transaction volume (S) in 2013 and 2014, but increasing them in 2015 and beyond. While supply shocks lowered CIP deviation (Δ) and boosted the FX swap transaction volume (S) in 2012 and 2013, the sign of the shocks' impacts was flipped in the middle of 2014, increasing CIP deviation (Δ) and lowering the transaction volume (S).

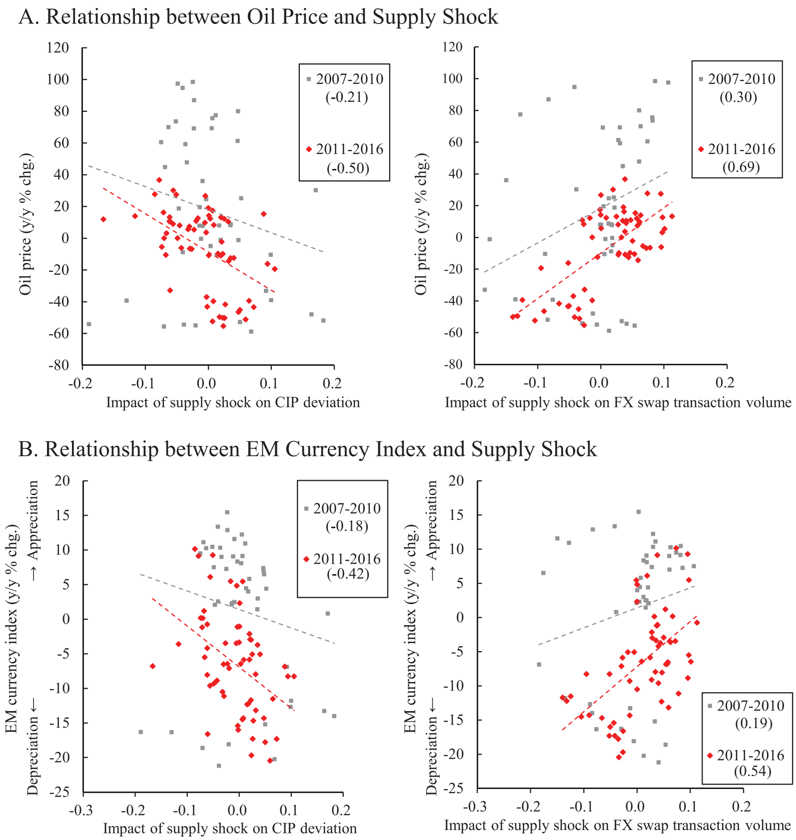
As regards supply shocks, we are unable to disentangle the contributions of V^* and W^*, and are only able to evaluate the combined role played by liquidity needs of arbitrageurs and their wealth endowment. However, what we observe from the upper two graphs in figure 10 is a growing presence of SWFs of oil-producing countries in the FX swap market. These graphs show that the correlation with oil price is negative for the impact of supply shocks on CIP deviation and positive for that on the FX swap transaction volume. In addition, for both CIP deviation and the FX swap transaction volume, the absolute values of the correlation coefficients become recently larger than before, indicating that the relationship between supply shocks and oil price has become tighter.

Market contacts indicate that SWFs in oil-producing countries have supplied USD in the FX swap market.[31] This seems to hold true especially in the period from 2011 to the middle of 2014 when oil prices were fairly high, which implies an increase in the wealth endowment (W^*) of SWFs and hence the rightward shift of the supply curve of USD in the FX swap market. Indeed, in this period, supply shocks tend to be negative (figure 9A), and they contribute to a decline in CIP deviation and an increase in the FX swap transaction volume (figure 9B). Market contacts also say that since oil prices plummeted in the second half of 2014, the SWFs that had formerly allocated their oil money in USD to the FX swap market have started to withdraw from the market. Such a development should appear as a negative shock in W^*, which would cause a leftward shift in the supply curve of USD in the FX swap market. Indeed, from mid-2014, supply shocks tend to be positive (figure 9A), and they contribute to an increase in CIP deviation and a decline in the FX swap transaction volume (figure 9B).

Because statistics are not available on the portfolio of real money investors, such as SWFs and foreign official reserves, we cannot show direct evidence of their impact on the FX swap market. However, other market contacts indicate that during the period of emerging

[31] See, for example, Arai et al. (2016).

Figure 10. Arbitrageurs' Wealth Endowment and FX Swap Market



Source: Bloomberg; J.P. Morgan; authors' calculations.

Notes: Figures in parentheses are correlation coefficients. In panel A, WTI (West Texas Intermediate) is used as the measure of oil price. In panel B, the emerging markets (EM) currency index is calculated by J.P. Morgan.

market currency depreciation in mid-2015, official reserve managers shifted their USD-denominated assets from less liquid cross-currency funding markets to U.S. Treasury bills, driven by their increased need to intervene in the FX markets to support their home currency. U.S. Department of the Treasury (2016) also points out that in the latter half of 2015, many emerging market central banks responded to capital outflows by intervening in FX markets to defend their currencies, and the intervention caused central banks to dip into their stocks of foreign exchange reserves. Such a behavior of emerging market central banks (reserve managers) is reflected in the supply shock in our model, i.e., a decline in arbitrageurs' wealth endowment (W^*).

The lower two graphs in figure 10 imply a growing presence of emerging market FX reserves as a USD supplier in the FX swap market. These graphs show that the correlation with the emerging markets currency index is negative for the impact of supply shocks on CIP deviation and positive for that on FX swap transaction volume. In addition, for both CIP deviation and the FX swap transaction volume, the absolute values of the correlation coefficients become recently larger than before, indicating that the relationship between supply shock and emerging market currencies has become tighter through the reserve managers' behavior.

5. Conclusion

This paper theoretically and empirically shows that CIP deviation is driven by several factors: global interest rate differentials, banks' default probabilities, banks' liquidity needs, and the wealth endowment of arbitrageurs. We find that in recent years the key driver of CIP deviation has changed from banks' default probabilities to global interest rate differentials. The sensitivity of CIP deviations to variation in global interest rate differentials has risen due to regulatory reforms which increase the marginal cost of global banks' dollar funding.

To conclude, we would like to note the implications of our model for financial stability. While arbitrage trading by banks has declined due to regulatory reforms, real money investors have come to play a greater role in the supply of USD in the FX swap market. However, as in 2015 when emerging market currencies depreciated and oil prices declined, real money investors such as foreign official reserve managers and SWFs are not stable or reliable USD liquidity providers. When a severely adverse shock occurs in the global financial system, real money investors may sell off their USD-denominated assets and reduce the supply of USD to non-U.S. financial institutions in the FX swap market. This then induces non-U.S. financial institutions to cut their USD-denominated assets, which may amplify the sale of financial assets by real money investors. In addition, such an adverse shock to real money investors is amplified by stricter financial regulations, which increase the marginal cost of banks' dollar funding. Since they make the demand and supply curves of USD in the FX swap market steeper, the leftward shift of the supply curve due to a fall in the AUM of real money investors is more easily translated into an even higher CIP deviation, which results in a larger cut in non-U.S. banks' USD-denominated assets. Although an economic significance of such amplification mechanism needs to be empirically examined, our theoretical model suggests that the potential vulnerabilities related to the financial regulations are hidden in the FX swap market.[32]

Appendix. FX Swap Market and Global Financial Stability

Differentiating equations (6) and (10) with respect to non-U.S. banks' default probability (α) yields the following comparative statics:

$$\frac{\partial \Delta}{\partial \alpha} > 0, \quad \frac{\partial L_{US}}{\partial \alpha} < 0. \tag{25}$$

Indeed, historically, non-U.S. bank's creditworthiness significantly affected their overseas dollar lending through variations in CIP deviation. During both Japan's banking crisis in the late 1990s and the euro-zone sovereign debt crisis in 2011, an increase in CIP deviation brought about by a worsening of non-U.S. banks' creditworthiness was followed by a cut in their dollar lending. In the former crisis, as Peek and Rosengren (2001, 2002) document, because of the deterioration in Japanese banks' balance sheets and an increase in the dollar funding premium (the so-called Japan premium), they cut lending—in particular, wholesale lending to the United States. As for the latter crisis, Ivashina, Scharfstein, and Stein (2015) document that euro-zone banks cut their dollar lending more than their euro lending.

Our empirical analysis suggests, however, that the linkage between banks' creditworthiness and CIP deviation has been weakened in recent years. As explained in section 3.5, the role of banks'

[32]See the appendix for details.

creditworthiness in determining CIP deviations has been supplanted by global interest rate differentials, which reflect monetary policy divergence among advanced economies. This then begs the question, how does monetary policy divergence, especially resulting from changes in the Federal Reserve's policy stance, affect non-U.S. banks' dollar lending? Although a rise in the U.S. interest margin $(q^* - r^*)$ encourages non-U.S. banks to "search for yield" on USD-denominated assets (i.e., $\frac{\partial L_{US}}{\partial (q^* - r^*)} > 0$), regulatory reforms limit the impact of U.S. monetary policy on their activities, as the following comparative statics show:[33]

$$\frac{\partial \left(\frac{\partial L_{US}}{\partial (q^* - r^*)} \right)}{\partial \theta}, \frac{\partial \left(\frac{\partial L_{US}}{\partial (q^* - r^*)} \right)}{\partial \eta} < 0. \tag{26}$$

Because regulatory reforms (i.e., higher θ and η in our model) raise the marginal costs of USD funding and increase the sensitivity of CIP deviations to interest margin differentials (see equation (12)), such reforms dampen the impact of a rise in the U.S. interest margin $(q^* - r^*)$ on non-U.S. banks' lending and investments (L_{US}) and prevent them from engaging in excessive "search for yield" activities.

It should be noted, however, that the regulatory reforms bring about dual impacts on the global financial system. Although stricter regulations (i.e., higher θ and η in our model) limit the impact of monetary policy divergence on non-U.S. financial institutions' "search for yield" activities, they amplify the impact of liquidity shortage of banks and an adverse wealth shock to arbitrageurs. Specifically, the following comparative statics are obtained from equations (6) and (10):

$$\begin{aligned}
&\frac{\partial \left(\frac{\partial L_{US}}{\partial V} \right)}{\partial \theta}, \frac{\partial \left(\frac{\partial L_{US}}{\partial V} \right)}{\partial \eta}, \frac{\partial \left(\frac{\partial L_{US}}{\partial V^*} \right)}{\partial \theta}, \frac{\partial \left(\frac{\partial L_{US}}{\partial V^*} \right)}{\partial \eta} < 0, \text{ and} \\
&\frac{\partial \left(\frac{\partial L_{US}}{\partial W^*} \right)}{\partial \theta}, \frac{\partial \left(\frac{\partial L_{US}}{\partial W^*} \right)}{\partial \eta} > 0.
\end{aligned} \tag{27}$$

[33]Unlike CIP deviation Δ in equation (10), USD-denominated loan L_{US} in equation (6) cannot be expressed as a function of an interest margin differential. We therefore derive a change in USD-denominated loans L_{US} only with respect to a change in interest margin in USD. It should also be noted that similar to the discussion in section 2, we maintain the assumption that $\gamma\eta > \theta\tau$ here.

An increase in banks' liquidity needs and a decline in the total AUM of arbitrageurs lead to a tightening of demand–supply balance of USD in the FX swap market and a higher CIP deviation, which then induces non-U.S. banks to cut their USD-denominated assets. This effect is amplified by stricter regulations which increase the marginal costs of banks' USD funding, because they make the demand and supply curves of USD in the FX swap market steeper. The leftward shift of the steeper supply curve and the rightward shift of the steeper demand curve lead to a much higher CIP deviation and hence a further decrease in non-U.S. banks' USD-denominated assets. If their lending and investments are cut rapidly and on a large scale, this may destabilize the global financial system.

Data Appendix

CIP Deviation (Figure 2, Tables 1–4)

CIP deviation (Δ) is calculated from equation (2). For the forward discount rate (X_1/X_0) of each currency pair (EUR/USD, USD/JPY, USD/CHF, and GBP/USD), we use FX spot (middle rates) and forward rates (middle rates). For interest rates (r^*, r), LIBOR (offered rates) is used in figure 2 and tables 1, 2, and 4, while OIS (middle rates) is used in table 3. All the data are taken from Bloomberg. We take the monthly average from the daily closing price data to construct the monthly series.

Interest Margin (Figure 6 and Tables 1–3)

Interest margin is calculated as the ten-year government bond yield less the three-month OIS rate. For the government bond yield in the euro area, we use the German bond yield so as to avoid the possibility that country-specific sovereign risks are reflected in the yield. We use bid rates for the government bond yield of Japan and Switzerland, and middle rates for others. We take the monthly average of the daily closing price data to construct the monthly series. All the data are taken from Bloomberg.

EDF (Figure 2 and Tables 1–4)

As for the default risk (α_i) of banks that are headquartered in jurisdiction i, we use the average of the EDF of all G-SIBs in jurisdiction

i. For the euro area, the average of the EDF of all G-SIBs in France, Germany, and Italy is used. As for the default risk of an arbitrageur (α^*), we use the average of the EDF of all G-SIBs in the United States. We use the one-year EDF of each bank, which is calculated by Moody's. We take the monthly average of the daily data to construct the monthly series.

CDS (Table 3)

Similar to the treatment of the EDF series, we use the average of the CDS of G-SIBs in each jurisdiction. For the euro area, we use the data for France, Germany, and Italy. We use the five-year fair-value CDS of each bank, which is calculated by Moody's. We take the monthly average of the daily data to construct the monthly series.

VIX (Tables 1–4)

We use the CBOE Volatility Index as VIX. The data are taken from Bloomberg. We take the monthly average of the daily data to construct the monthly series.

Monthly Growth Rate of the Central Bank's Balance Sheet Size (Table 4)

The data of the balance sheet of the Bank of England and the Swiss National Bank are taken from the websites of these banks, and those of the other central banks are taken from the Federal Reserve Economic Data (FRED) database. The figures are as of the end of each month. We apply seasonal adjustments to these series by the X12-ARIMA.

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