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Regulatory Reforms and the Dollar Funding of Global Banks: Evidence from the Impact of Monetary Policy Divergence

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Abstract

Deviations from the covered interest rate parity (CIP), the premium paid to the U.S. dollar (USD) supplier in the foreign exchange swap market, have long attracted the attention of policy makers, since they often accompany a banking crisis. In this paper, we document the emergence of the new drivers of CIP deviations taking the place of banks' creditworthiness and assess their roles. We first provide theoretical evidence to show that monetary policy divergence between the Federal Reserve and other central banks widens CIP deviations, and that regulatory reforms such as stricter leverage ratios raise the sensitivity of CIP deviations to monetary policy divergence by increasing the marginal cost of global banks' USD funding. We then empirically examine whether the data accords with our theory, and find that monetary policy divergence has recently emerged as an important driver that boosts CIP deviation. We also show that regulatory reforms have brought about dual impacts on the global financial system. By increasing the sensitivity of CIP deviations to various shocks, the stricter financial regulations have limited banks' excessive "search for yield" activities resulting from monetary policy divergence, and have thereby contributed to financial stability. However, the impact of severely adverse shocks in the asset management sector is amplified by the stricter financial regulations and is transmitted to the FX swap market and beyond, inducing non-U.S. banks to cut back on their USD-denominated lending.

JEL classification: F39; G15; G18

Keywords: FX swap market; Monetary policy divergence; Regulatory reform; Financial stability

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1. Introduction

Non-U.S. banks have continued to play an important role in U.S. dollar (USD) denominated international financial transactions. The amount of USD-denominated foreign claims extended by these banks, which is much larger than that of U.S. banks, has maintained pre-Lehman crisis period levels (Figure 1).[1] Transactions in USD, however, come at a cost for non-U.S. banks, because of the gap that often arises between the amount of lending in USD and the amount of funding in USD.[2] Non-U.S. banks try to fill this gap since they are typically unwilling to bear a foreign exchange (FX) risk. They do this by collecting deposits and issuing bonds denominated in USD, or by participating in cross-currency markets. In the FX swap market, for example, banks can raise dollar funding without being exposed to FX risk. Suppose that a bank needs USD today, but it only has Japanese yen (JPY) in its hands; it can raise USD by exchanging JPY for USD on the spot market and simultaneously promising to exchange USD back for JPY on the forward market.

As shown in Figure 1, the dependence of non-U.S. banks' USD funding on cross-currency markets has been on an increasing trend, but with a sharp decline in times of stress such as the Lehman crisis and the eurozone sovereign debt crisis. From a macroprudential perspective, it is very important to understand how cross-currency markets function, because severe strains in wholesale funding markets, including FX swap transactions, 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);

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[1] "Foreign claims" in Figure 1 is defined as claims on residents of countries other than the country where the controlling parent is located, i.e., claims of domestic banks on non-residents of the reporting country. Foreign claims comprise local claims of the bank's offices abroad as well as cross-border claims of the bank's offices worldwide.

[2] See McGuire and von Peter (2009) for the size of USD gap for the banking sector in major countries. See also Avdjiev and Takats (2016) for the choice of currency made by non-U.S. banks in their cross-border lending. They show, based on BIS international banking statistics, that the bulk of international claims are extended in USD.

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

where r^* and r are the interest rates applied to the same entity from a period $t = 0$ to $t = 1$ 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 practice, however, this condition is often violated, and the equality below holds;

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

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 policy makers 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".[3] Three banking crises are shaded in gray: Japan's banking crisis, the Lehman crisis, and the eurozone 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 was minimal in the other currency pairs. In contrast, during the Lehman crisis and the eurozone 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

[3] The EDF is released by Moody's Analytics, and it 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.

to have weakened more recently. Around the time of the Federal Reserve's tapering announcement in May 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 banks' creditworthiness in Japan's banking sector.

In this paper, we explore the determinants of the premium attached to USD in the FX swap market, by specifically focusing on the impact of monetary policy divergence and regulatory reforms. We first extend the theoretical model of CIP deviation developed by Ivashina et al. (2015) and He et al. (2015) and discuss what drives CIP deviation. The model consists of two types of agents: non-U.S. financial institutions (such as Japanese banks and insurance companies) and arbitrageurs (such as U.S. banks and real money investors). A Japanese 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 difference between the interest rate on lending and that on borrowing) in the U.S. 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. arbitrageur's 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, from January 2007 to February 2016. We conduct a series of panel regression analyses that use a CIP deviation as the dependent variable and the three factors discussed above as the independent variables, and we find that the predictions of our model accord with the data. We also find that monetary policy divergence between the Fed and other advanced economies' central banks has contributed to the recent upsurge in CIP deviations. As suggested in previous literature, monetary policy has a significant effect on financial institutions' net interest margins, which suggests that interest margin differentials between U.S. and non-U.S. countries depend on the degree of monetary policy divergence between them.[4] In other words, 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 U.S. in an unconventional monetary policy regime.

We next discuss how regulatory reforms such as stricter leverage ratios affect the sensitivity of CIP deviations to interest margin differentials. When an arbitrageur (e.g., a U.S. bank) faces a widening interest margin differential, it seeks to increase its USD-denominated assets. As stricter regulations 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. As regulations become stricter, it shifts its USD funding source toward the FX swap market because of the higher marginal cost of raising USD from the U.S. money 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

[4] As regards the influence of monetary policy on banks' net interest margins, see Borio et al (2015), for example.

regulations. Because higher CIP deviations limit global banks' excessive "search for yield" activities resulting from monetary policy divergence, regulatory reforms which increase the marginal cost of USD funding are expected to contribute to financial stability.

However, it should also be noted that stricter financial regulations may amplify the impact on the global financial system of adverse shocks in the asset management sector.[5] While arbitrage trading activities by banks have declined due to regulatory reforms, real money investors, such as asset management companies, sovereign wealth funds and foreign official reserve managers, have increased their supply of USD in the FX swap market. In this market environment, when real money investors face a fall in total assets under management (AUM) and reduce the supply of USD in the FX swap market, the demand-supply of USD becomes tightened. Because stricter financial regulations raise the marginal cost of banks' dollar funding, the impact of such an adverse shock is amplified in the FX swap market, leading to an even higher CIP deviation and hence a larger cutback in USD-denominated assets by non-U.S. banks. This then feeds back into the asset management sector by driving down asset prices, thereby having a further negative impact on the real money investors' AUM.

Our study is built upon a small but growing literature on the identification of the sources of CIP deviation. Baba and Packer (2009a) 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 et al. (2015) argue that there is a linkage between CIP deviation and the creditworthiness of eurozone banks, focusing on the period of the eurozone 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'

[5] Following FSB (2016), throughout the current paper, we broadly refer to the sector that conducts various asset management activities, including those of sovereign wealth funds and pension funds, as the "asset management sector."

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 constructs an equilibrium model that gives a theory of what determines a CIP deviation. While this approach is close to the one taken by Ivashina et al. (2015), our paper sharply contrasts with theirs in explicitly taking into account the role played by monetary policy divergence and tightening of financial regulation in addition to bank's creditworthiness. 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 macroeconomic factors as important drivers of CIP deviation. Our paper also differs from Borio et al. (2016). They estimate the demand for USD of Japanese financial institutions using BIS international banking statistics, and gauge the contribution of this demand and other factors to the CIP deviation for the USD/JPY pair. In contrast, we focus rather on the underlying shocks that drive banks' demand for USD. In particular, our study is unique in using central banks' balance sheet data to show explicitly the growing importance of monetary policy divergence in the recent rise in CIP deviation facing major currencies.[6] In addition, we discuss the possibility of changes in the market structure of FX swaps, such as the

[6] Borio 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 quantitative relationship between the central bank's policy instruments and CIP deviation.

emergence of real money investors as new arbitrageurs, and the effect of regulatory reforms on market liquidity in FX swaps. As far as we know, our paper is the first to examine the impact of regulatory reforms on the FX swap market in both theoretical and empirical terms.

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 monetary policy divergence and regulatory reforms on the FX swap market in terms of financial stability. Section 5 presents our conclusions.

2. A theoretical model of CIP deviation

The basic setting of our model is borrowed from Ivashina et al. (2015) and He et al. (2015). In our model, a borrower and a lender in the FX swap market are explicitly modelled, and a CIP deviation is determined as the price that clears the demand and supply of USD. Our setting, however, deviates from these two studies as it highlights the impact of interest margin differentials between U.S. and non-U.S. economies, regulatory reforms and liquidity shocks facing market participants, as well as the impact of banks' creditworthiness that is central to their studies.

The model is static. The economy consists of two countries, the U.S. 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.[7] The former is headquartered in the U.S., and the latter is headquartered in a non-U.S. country.

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

[7] 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, BOJ (2016).

assets: USD-denominated assets (loans and bonds, etc.) that are issued by borrowers in the U.S., 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. financial institution holds a certain amount of USD in cash to prepare for liquidity needs, which we denote by 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.[8]

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 $1 + r^* + p\alpha$. Here, r^* is the risk-free rate in the U.S., 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 we denote by 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:

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

subject to

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[8] Similar to Aoki and Sudo (2013), we assume that a bank faces two classes of constraint, one that originates from regulatory requirements that are explicitly stated, and one that originates from the bank's own risk management policy, such as value at risk constraints conducted for the bank's own sake, and that only the tighter of the two binds the bank's activities.

$$M \geq V \tag{4}$$

$$L_{US} + M = D_{US} + S$$

$$L_{JP} = D_{JP} - S,$$

where

$$g_f(L_{US}) = (1 + q^*)L_{US} - \frac{\tau^*}{2}(L_{US})^2,$$

$$g_h(L_{JP}) = (1 + q)L_{JP} - \frac{\tau}{2}(L_{JP})^2,$$

$$c_f(D_{US}) = (1 + r^* + p\alpha)D_{US} + \frac{\eta^*}{2}(D_{US})^2,$$

$$c_h(D_{JP}) = (1 + r)D_{JP} + \frac{\eta}{2}(D_{JP})^2.$$

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 transaction.[9] 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 (or stricter) leverage ratios and money market reforms, 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 assets, while the third and fourth terms stand for the net funding cost of USD and JPY. The last term stands for the cost

[9] For simplicity, following Ivashina et al. (2015) and He et al. (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. He points out that when the USD depreciates, global banks lend more in USD to borrowers outside the U.S., and when it appreciates, they reduce their USD lending. He further 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 U.S. during the previous period of easy dollar credit.

associated with FX swap transactions. Equation (4) specifies the minimum level of liquidity that a non-U.S. bank needs to hold.[10] Note that the cost of borrowing USD from the FX swap market is comprised of the cost 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.[11]

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 for USD through the FX swap market.

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

Here, $q^* - r^*$ is the interest margin in the U.S., 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.[12] 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.,

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

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

[12] 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.

their supply of USD in the U.S. loan and bond market, is given as follows.

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

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 US 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 sovereign wealth funds (SWFs). They participate in 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.

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

subject to

$$\begin{gathered} M^* \geq V^* \\ L_{US}^* + M^* = W^* + D_{US}^* - S \\ L_{JP}^* = D_{JP}^* + S, \end{gathered} \tag{8}$$

where

$$h_f(L_{US}^*) = (1 + q^*)L_{US}^* - \frac{\gamma^*}{2}(L_{US}^*)^2,$$

$$h_h(L_{JP}^*) = (1 + q)L_{JP}^* - \frac{\gamma}{2}(L_{JP}^*)^2,$$

$$\kappa_f(D_{US}^*) = (1 + r^*)D_{US}^* + \frac{\theta^*}{2}(D_{US}^*)^2,$$

$$\kappa_h(D_{JP}^*) = (1 + r + p^*\alpha^*)D_{JP}^* + \frac{\theta}{2}(D_{JP}^*)^2.$$

An arbitrageur earns an expected net return of $h_f(L_{US}^*)$ from USD-denominated assets and $h_h(L_{JP}^*)$ 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. $\kappa_f(D_{US}^*)$ 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 decreases with scale, and its funding cost increases with scale. As discussed later, regulatory reforms, such as the new (or stricter) leverage ratios and the Volcker rule, 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 for USD through the FX swap market.

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

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 less 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.

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

According to this equation, CIP deviation Δ is determined by three factors: (i) the interest margin differential, $(q^* - r^*) - (q - r)$, (ii) the default probability 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, which is the sum of 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, 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. The higher default probability of an arbitrager (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

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

where

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

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).[13]

3. Empirical analysis

3.1 Exploring determinants of CIP deviation

Data

Our model predicts that, as shown in equation (10), a CIP deviation is determined

[13] As shown later in Section 4.3, we empirically observe that swap transaction volume is positively correlated with the interest rate differential (see Figure 10 (2-b)). Therefore, in the following analysis, we assume that $\theta\tau < \gamma\eta$ holds.

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. 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 $(q^* - r^*)$ and $(q - r)$, we use the 10-year government bond yield less OIS rate for the U.S. and the four non-U.S. jurisdictions.[14] The time path of measures for interest margin differential is shown in Figure 5.

As for banks' default probabilities α and 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. In addition to this channel, Baba and Packer (2009a,b) 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.[16] 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

[14] Admittedly, in practice, non-U.S. financial institutions and U.S. arbitrageurs invest in a broader class of assets other than government bonds. We choose this measure, however, so as to ensure comparability of the measures across jurisdictions.

[15] Because we focus on financial transactions made by large globally active banks, we construct our measure of default risk α_i of a bank that is headquartered in a country i by an average of the EDF of all GSIBs that are headquartered in the country i. For the euro area, the average of the EDF of the GSIBs in France, Germany, and Italy is used. We similarly construct the measure of default risk of an arbitrageur α^* by taking the average value of the EDF of all GSIBs in the U.S. Some existing studies, such as Baba and Packer (2009a, b) and He et al. (2015), use CDS spread as a measure of a bank's default probability. As a robustness check, we construct a similar series for large banks from CDS spread, and estimate the model using CDS spread instead of EDF. We find that the results are indeed little changed.

[16] Baba and Packer (2009a, b) and Baba et al. (2008) empirically show that CIP deviation is affected by the default risk of the counterparties involved in an FX swap transaction.

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 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. Components unexplained by VIX are included in error terms. Data on the wealth endowment of arbitrageurs (W^*) is 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).[17] Note that the CIP deviation based on LIBOR can be decomposed into two components: (1) the CIP deviation based on the OIS (Overnight-Index Swap) rate, and (2) the difference in LIBOR-OIS spreads between USD and other currencies. 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).[18] Therefore, using the CIP deviation based on LIBOR as a dependent variable in our estimation implies that the contribution of the differential between LIBOR-OIS spreads is captured by independent variables, in particular, the credit risk of market participants $(\alpha,\ \alpha^*)$.

Methodology

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

(Model 1)

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

[18] The OIS is an interest rate swap in which the floating leg is linked to a publicly available index of daily overnight rates. The counterparty risk associated with OIS contracts is relatively small because no principal is exchanged.

$$\Delta_{it} = \delta_1[(q_t^* - r_t^*) - (q_{it} - r_{it})] + \beta_1\alpha_{it} + \beta_1^*\alpha_t^* + \lambda_1 VIX_t + c_{1i} + \varepsilon_{1it} \quad (12)$$

(Model 2)

$$\Delta_{it} = \delta_2^*(q_t^* - r_t^*) + \delta_2(q_{it} - r_{it}) + \beta_2\alpha_{it} + \beta_2^*\alpha_t^* + \lambda_2 VIX_t + c_{2i} + \varepsilon_{2it} \quad (13)$$

(Model 3)

$$\Delta_{it} = \delta_{3i}[(q_t^* - r_t^*) - (q_{it} - r_{it})] + \beta_{3i}\alpha_{it} + \beta_{3i}^*\alpha_t^* + \lambda_{3i} VIX_t + c_{3i} + \varepsilon_{3it} \quad (14)$$

Here, the subscript i stands for a currency, interest margin, or banks' default probability in a jurisdiction i, for i= the euro area, Japan, Switzerland, and the U.K. $c_{1i}, c_{2i},$ and c_{3i} are the country-specific fixed effects. Greek letters are the coefficients to be estimated, and $\varepsilon_{1it}, \varepsilon_{2it},$ 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 two assumptions are imposed on technology parameters.

· For both non-U.S. financial institutions and U.S. arbitrageurs, 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.

Results

Table 1 shows the results of the panel regression.[19] We compute the standard deviation of an estimated coefficient using White period standard errors & covariance, allowing the residuals in each model to be serially correlated.[20] In all the three models,

[19] 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 suggested in Figure 2, the EDF of U.K. banks has recently developed in a similar way to the EDF of U.S. banks.

[20] The error terms $\varepsilon_{1it}, \varepsilon_{2it},$ 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 with explanatory variables. As a robustness check, we

the estimated signs of coefficients of explanatory variables are consistent with the model's prediction shown in equation (10). A higher interest margin in the U.S. $(q^* - r^*)$, 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,b).[21] 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.

3.2 Sensitivity analysis

Use of 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.[22]

CIP deviation based on OIS

Following the most common treatment in the existing literature, we use the CIP

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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.

[21] Baba and Packer (2009b) 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.

[22] 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.

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 CIP deviation based on the OIS rate. As shown in Table 3, estimation results are little changed from those reported in Table 1, although the estimated coefficient on a default probability of non-U.S. banks (α) is statistically insignificant with an opposite sign. When CDS spread is used as an alternative measure of default probability, the estimated coefficients on the default probability of both U.S. arbitrageurs and non-U.S. banks are statistically significant with the correct sign.

A model with a third-country effect

In the baseline model, we implicitly assume that FX swap transactions of USD/JPY are independent from those of EUR/USD. We now relax this assumption, allowing an arbitrageur to choose its trading partner by looking at the opportunity cost of supplying USD to one counterparty instead of the other. We assume that there are two types of non-U.S. banks, one headquartered in Japan and the other in the euro area, and both types of bank are subject to an economic environment similar to that described in Section 2. In this economy, the CIP deviation for USD/JPY is given as follows.

$$\Delta = \rho_{q^*-r^*}(q^* - r^*) + \rho_{q-r}(q - r) + \rho_{\tilde{q}-\tilde{r}}(\tilde{q} - \tilde{r}) + \rho_{\alpha^*}\alpha^* + \rho_{\alpha}\alpha + \rho_{\tilde{\alpha}}\tilde{\alpha} + \rho_{V^*}V^* + \rho_V V + \rho_{\tilde{V}}\tilde{V} + \rho_{W^*}W^*, \quad (15)$$

where ρ_{q-r}, $\rho_{\tilde{q}-\tilde{r}}$, ρ_{α^*}, $\rho_{W^*} < 0$ and $\rho_{q^*-r^*}$, ρ_{α}, $\rho_{\tilde{\alpha}}$, ρ_{V^*}, ρ_V, $\rho_{\tilde{V}} > 0$ under simplifying assumptions about parameter values.[23] We denote a variable Z in the euro area by $\tilde{Z}$, and the coefficient of a variable Z by ρ_Z. Each of the coefficients ρ_Z is given by the combination of parameters related to the marginal return of financial assets and marginal cost of funding ($\tau, \tau^*, \tilde{\tau}, \eta, \eta^*, \tilde{\eta}, \theta, \theta^*, \tilde{\theta}, \gamma, \gamma^*, \tilde{\gamma}$) in the three jurisdictions. As discussed in the Appendix, variables in the euro area affect the CIP deviation for USD/JPY. A widening interest margin in the euro area ($\tilde{q} - \tilde{r}$) reduces the demand for

[23] See Appendix for details of the setting.

USD by eurozone banks, which then increases USD available for Japanese banks in the FX swap market. Consequently, the CIP deviation for USD/JPY falls. A rise in eurozone banks' default probability $\tilde{\alpha}$ and liquidity needs $\tilde{V}$ pushes up the CIP deviation for USD/JPY, because eurozone banks' demand for USD through the FX swap market increases, which leads to a decrease in the USD available to Japanese banks.

In order to empirically assess the third-country effect, we run the following panel regression in which variables in the third country are explicitly included in the explanatory variables.

$$\begin{aligned}\Delta_{it} = \delta^*(q_t^* - r_t^*) + \delta(q_{it} - r_{it}) + \tilde{\delta}(\tilde{q}_{it} - \tilde{r}_{it}) + \beta^*\alpha_t^* + \beta\alpha_{it} + \tilde{\beta}\tilde{\alpha}_{it} \\ +\lambda VIX_t + c_i + \varepsilon_{it}\end{aligned}, \tag{16}$$

where c_i is the country-specific fixed effect. Greek letters are the coefficients to be estimated, and ε_{it} is residual. We construct the interest margin $(\tilde{q}_{it} - \tilde{r}_{it})$ and a bank's default probability $(\tilde{\alpha}_{it})$ in the third country in the estimation equation of a jurisdiction i using the weighted average of the corresponding variables in the other three jurisdictions.[24] Table 4 shows the estimation result. Although the third country effect through a bank's default probability $\tilde{\alpha}$ is not statistically significant, the effect through the interest margin has a statistically significant explanatory power on CIP deviation. That is, the coefficient for the interest margin $\tilde{q}_{it} - \tilde{r}_{it}$ takes a negative value at a statistically significant level. This indicates that a widening in the interest margin in the third country reduces the demand for USD by banks in that country, which then leads arbitrageurs to supply more USD to banks in jurisdiction *i*, lowering the CIP deviation of the pair that includes the currency of jurisdiction *i*. However, it should be noted that including third-country variables has little quantitative impact of on the explanatory power of the estimation model. Compared with Model 1 or Model 2 in Table 1, the adjusted R^2 only increases from 0.49 to 0.50. In the analysis below, therefore, we use a model that abstracts from the third-country effects as our baseline.

[24] In the equation of CIP deviation for USD/JPY, for instance, variables in the third country are the average of the variables in the euro area, the U.K., and Switzerland. As for the weight, we use the total amount of USD-denominated cross-border claims extended by banks in each jurisdiction as given in the BIS locational banking statistics by nationality (LBSN).

4. Discussion

In this section, we extend the analysis conducted above by turning our attention to (i) monetary policy divergence, (ii) regulatory reforms, and (iii) the emergence of alternative arbitrageurs. We then consider the policy implications of our analysis for financial stability.

4.1. The impact of monetary policy divergence

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 divergence in monetary policy stance between them. In addition, there is 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.[25]

Methodology

We provide an empirical study of how monetary policy affects CIP deviation by explicitly including a monetary policy instrument in our regression models. 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 et al. (2014) and He et al. (2015). More precisely, we estimate Models 1, 2, and 3 by replacing interest margin with the size of the central bank's balance sheet.

(Model 1)

$$\Delta_{it} = \delta_1[CB_t^* - CB_{it}] + \beta_1\alpha_{it} + \beta_1^*\alpha_t^* + \lambda_1 VIX_t + \phi_1\xi_{it} + c_{1i} + \epsilon_{1it} \tag{17}$$

(Model 2)

[25] See, for instance, Rogers et al. (2014) and Nakajima and Kimura (2016).

$$\Delta_{it} = \delta_2^* CB_t^* + \delta_2 CB_{it} + \beta_2 \alpha_{it} + \beta_2^* \alpha_t^* + \lambda_2 VIX_t + \phi_2 \xi_{it} + c_{2i} + \epsilon_{2it} \tag{18}$$

(Model 3)

$$\Delta_{it} = \delta_{3i}[CB_t^* - CB_{it}] + \beta_3 \alpha_{it} + \beta_3^* \alpha_t^* + \lambda_{3i} VIX_t + \phi_3 \xi_{it} + c_{3i} + \epsilon_{3it} \tag{19}$$

Here, CB_t^* and CB_{it} are the monthly growth rate of the seasonally adjusted size of the balance sheet of the Fed and that of the central bank in the non-U.S. jurisdiction i, respectively. Since financial institutions invest in a broader class of assets whose returns are affected by central banks' actions through the portfolio-rebalancing channel, the size of the central bank's balance sheet may be a good proxy for interest margin in the unconventional monetary policy regime. 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 U.S., the interest margin differential is expected to widen, which bring about a higher CIP deviation. $c_{1i}, c_{2i},$ and c_{3i} are the country-specific fixed effects. Greek letters are the coefficients to be estimated, 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.[26]

Results

As shown in Table 5, 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 U.S. 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

[26] As a sensitivity analysis, we estimate the models without the control variables. The results are little changed from those reported in Table 5.

sheet in the regression equation.

Based on the estimation results of Model 3, 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. Figure 6 shows the time path of this decomposition. Two 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 after 2014. Its positive contribution is pronounced in two currency pairs, EUR/USD and USD/JPY. Second, banks' default probabilities played the key role in increasing CIP deviations for the currency pair EUR/USD during the eurozone sovereign debt crisis, possibly through the substitution of funding source that is highlighted in Ivashina et al. (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 U.S. than in Japan and Switzerland, leading to a smaller premium for USD supply. A similar finding is also reported in Baba and Packer (2009b). In recent years, however, the contribution of banks' default probabilities has been very minor.

4.2. The impact of regulatory reforms

Expected impact on the cost structure of banks

Since the global financial crisis, a good number of regulatory reforms have already been introduced or are expected to be implemented in order to strengthen the financial system. Under these frameworks, restrictions have typically been imposed on the size or composition of banks' balance sheets, potentially affecting the supply of USD in the FX swap market. In our theoretical model, a tightening of regulatory frameworks alters the liquidity position and funding structure of banks in the following three ways.

First, the size of the liquidity needs of both non-U.S. banks and U.S. arbitrageurs increases. For example, the LCR, which came into force from January 2015, requires banks to hold a certain amount of highly liquid assets, increasing V and V^*.

Second, some regulatory reforms may increase the marginal cost of raising USD for non-U.S. banks, increasing the parameter η^* of the cost function $c_f(D_{US})$. Money market reforms require institutional prime money market funds (MMF), which principally invest in CDs and CP, to shift from constant net asset value to floating/variable net asset value, while institutional government MMFs are exempt from this rule. The rule is to be implemented by October 2016, and institutional investors have been switching from prime MMFs to government MMFs, as shown in Figure 7. Reduced investment by prime MMFs in CDs and CP issued by non-U.S. banks lowers the availability of their wholesale USD funding. This implies that it costs more for non-U.S. banks to raise USD in the U.S. market than in the past. They have to invest in advertising and promotions, and the more they increase their dollar assets, the greater the marginal costs of dollar funding.

Third, stricter financial regulations increase the marginal cost for arbitrageurs of expanding their balance sheets, increasing the parameters θ and θ^* of the cost functions $\kappa_f(D_{US}^*)$ and $\kappa_h(D_{JP}^*)$. The new leverage ratio framework, along with the public disclosure requirements introduced in January 2015, has increased the cost of arbitrage activities, as intended. In addition, due to liquidity regulations applied to individual currencies, arbitrageurs have less scope to take advantage of the differences in funding costs. 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. This has induced U.S. banks to be cautious and avoid arbitrage through FX swap transactions.

With our theoretical model, we then assess how regulatory reforms affect CIP deviation through an increase in the marginal cost of dollar funding and liquidity needs. Note that, for simplification, we continue to assume that for both non-U.S. financial institutions and U.S. arbitrageurs, 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 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 much more easily from the U.S. money market.[27] Indeed, CIP deviations in the 2000s remained almost zero until the global financial crisis occurred and financial regulation was tightened (Figure 2). This is probably because unusually easy financial conditions in this period made the value of these parameters negligible.[28]

CIP deviations take a positive value when 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.

$$\frac{\partial\left(\frac{\partial\Delta}{\partial(IMD)}\right)}{\partial\theta} = \frac{(\eta^2\gamma\theta+\tau\gamma\eta^2)(\tau+\gamma)}{\left((\tau+\eta)\gamma\theta+\tau(\gamma+\theta)\eta\right)^2} > 0, \quad \frac{\partial\left(\frac{\partial\Delta}{\partial(IMD)}\right)}{\partial\eta} = \frac{(\eta^2\gamma\theta+\tau\gamma\eta^2)\tau\gamma}{\left((\tau+\eta)\gamma\theta+\tau(\gamma+\theta)\eta\right)^2} > 0. \tag{20}$$

In other words, a rise in the value of 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, 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 Figure 3 & 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 Figure 3 & 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).

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27 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.

28 See Akram et al. (2008) for developments in CIP deviations during the pre-crisis period.

We can also derive the relationship regarding how coefficients of liquidity needs (V, V^*) vary with the two parameters. Denoting these coefficients by $\partial\Delta/\partial V$ and $\partial\Delta/\partial V^*$ respectively, we can show that the following qualitative relationships hold.

$$\frac{\partial\left(\frac{\partial\Delta}{\partial V}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial\Delta}{\partial V}\right)}{\partial\eta}, \frac{\partial\left(\frac{\partial\Delta}{\partial V^*}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial\Delta}{\partial V^*}\right)}{\partial\eta} > 0. \tag{21}$$

Again, this equation shows 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.

$$\frac{\partial\left(\frac{\partial\Delta}{\partial\alpha}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial\Delta}{\partial\alpha^*}\right)}{\partial\theta} > 0, \text{ and } \frac{\partial\left(\frac{\partial\Delta}{\partial\alpha}\right)}{\partial\eta}, \frac{\partial\left(\frac{\partial\Delta}{\partial\alpha^*}\right)}{\partial\eta} < 0. \tag{22}$$

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 is suppressed, resulting in a modest rise in CIP deviation.

Empirical evidence for the impact on CIP deviation

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 (12), 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 staring period of the sample period to January 2007 and allow the ending point to differ across examples. Note that the effect of new regulations is expected to appear in the later stages of the sample period. As explained above, against the backdrop of MMF reforms, institutional investors have been switching from prime MMFs to government MMFs since fall 2015. As for the new leverage ratio framework, the public disclosure requirements were introduced in January 2015, and the Volcker rule also took effect in July 2015.

The upper panels in Figure 8 show the results. The x-axis represents the end of the sample period. The y-axis represents the estimated coefficients of each explanatory variable. We can see that the coefficient of interest margin differentials increases gradually as the ending point of the sample period is extended forward. This observation is consistent with the model's prediction in equation (20). 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 (22).[29]

In order to examine whether the change in the coefficients of an 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 U.K.

$$\Delta_{it} = (\delta_T + \delta_T^D \times DUM_t^T)[(q_t^* - r_t^*) - (q_{it} - r_{it})] + \beta_T \alpha_{it} + \beta_T^* \alpha_t^* + \lambda_T VIX_t + c_{Ti} + \varepsilon_{Tit} \ , \tag{23}$$

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

The lower panel of Figure 8 shows the estimation results. 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 results suggest that the sensitivity of a CIP deviation to interest margin differentials becomes higher from around 2014, which corresponds to the period when financial

[29] The estimated coefficients of VIX are also stable, although equation (21) suggests that the sensitivity of a CIP deviation to liquidity needs (V, V^*) rises with higher θ and η. This may be related to the fact that VIX is an imperfect measure of liquidity needs, as we have discussed.

regulations related to the parameters θ and η become stricter. The sensitivity of a CIP deviation in 2015 is about two times higher than before.

Impact on the liquidity of FX swap markets

Market contacts suggest that regulatory reforms affect not only arbitrage trading but also market-making by banks in the FX swap market.[30] Specifically, some of the current regulatory reforms have made it difficult for banks to change the size of their balance sheets flexibly, which has reduced their capacity for market making services, thereby reducing market liquidity. While our model does not incorporate market-maker's activities, we can examine indirectly how the liquidity in the FX swap market changes.

The importance of market liquidity in CIP deviations is highlighted in several existing studies, such as Coffey et al. (2009) and Pinnington and Shamloo (2016). Market liquidity and CIP deviation are considered to interact closely. For example, a decline in market liquidity may discourage arbitrage trading and market-making activity by banks, amplifying the widening of CIP deviations.

The upper panel of Figure 9 shows the bid-ask spread for USD/JPY in the Tokyo FX swap market. The bid-ask spread is a commonly used indicator of market liquidity. It increased sharply during the middle of the Lehman crisis, then evolved at a low level for about seven years until it started to rise again in the latter half of 2015, suggesting that the market has recently become less liquid than before.

As a market-maker in FX swaps, banks borrow USD from other market participants with a short tenor, typically less than a month, and lend USD with a longer tenor to borrowers of USD. When the bid-ask spread is high, banks may perceive that losses are incurred in continuing market making activities, because it is more difficult to match the needs of market participants. Consequently, banks limit their market-making activities and reduce the supply of USD in the FX swap market, resulting in a higher CIP deviation. According to existing studies such as Elliot (2015) and Pinnington and

[30] We thank Teppei Nagano (Bank of Japan) for his valuable information on liquidity of the FX swap markets. See also Arai et al. (2016).

Shamloo (2016), the bid-ask spreads reflect perceived uncertainty from the market makers' perspective in the FX swap market, as well as the cost of executing transactions. When market makers expect the demand or supply of USD tomorrow will be very different from that of today, they then raise the bid-ask spread so as to prepare for the uncertainty, which in turn reduces liquidity in the market.

In order to quantitatively assess the effect of these channels, we run the following equation for USD/JPY using the EGARCH-in-Mean model.

$$\Delta_t = \delta[(q_t^* - r_t^*) - (q_t - r_t)] + \beta\alpha_t + \beta^*\alpha_t^* + \lambda VIX_t + \pi\sigma_t + c + \epsilon_t \tag{24}$$

$$ln\sigma_t^2 = c_o + c_1\left|\frac{\epsilon_{t-1}}{\sigma_{t-1}}\right| + c_2\left(\frac{\epsilon_{t-1}}{\sigma_{t-1}}\right) + c_3 ln\sigma_{t-1}^2 + c_4\xi_t.$$

Here, σ_t^2 is the conditional variance which captures the effect of liquidity of the FX swap market on CIP deviation. In the conditional variance equation, the variable ξ_t is the liquidity stress of the U.S. money market, which may interact with the liquidity of the FX swap market.[31]

Table 6 shows the estimation results. All the estimated coefficients have the correct sign, and not only the coefficients of interest margin and banks' default probability, but the coefficient of conditional standard deviation (σ_t) is also statistically significant. Note also that the liquidity shock of the U.S. money market has a statistically significant impact on the conditional variance (σ_t^2). The upper panel of Figure 9 shows the estimated conditional standard deviation (σ_t) together with the bid-ask spread. The estimated standard deviation (σ_t) closely tracks the movement of the bid-ask spread, indicating that the recent decline in market liquidity has contributed to a rise in CIP deviation.

In order to examine if there is a change in the way that market liquidity affects CIP deviations, we also estimate the above EGARCH-in-Mean model using different sample periods. If regulatory reforms influence not only arbitrage trading but also banks' market-making, there should be a rise in the sensitivity of CIP deviation to both interest

[31] The LIBOR-OIS spread can be considered a good indicator of credit risk and liquidity premium. In order to extract liquidity premium from the LIBOR-OIS spread and use it as a proxy of the variable ξ_t, we regress the USD Libor-OIS spread on the EDF of large U.S. banks (i.e., a proxy of their credit risk). The residual series of the regression is used as the variable ξ_t.

margin differentials and market liquidity (proxied by conditional variance). Similar to the exercise conducted above, we estimate the model, setting the starting point of the sample to January 2007 and gradually extending the ending point forward. As shown in Figure 9, both coefficients of interest margin differential and conditional standard deviation (σ_t) increase as the ending point is extended, particularly in 2015 and beyond, implying that regulatory reform plays a definite role.

4.3. Real money investors as alternative arbitrageurs

While arbitrage trading activities by banks have declined partly due to regulatory reforms, real money investors, such as asset management companies, sovereign wealth funds (SWFs) and foreign official reserve managers, have increased their supply of USD in the FX swap market. For example, market contacts suggest that against the backdrop of widening CIP deviations, foreign real money investors supply USD through the FX swap market to invest in JPY-denominated assets. Indeed, foreign investors have continued to increase their holdings of Japanese Government Bonds in spite of low or negative yields. 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.

Methodology

Based on equations (10) and (11), we first estimate the following equations for USD/JPY.[32]

$$\Delta_t = \delta_1^*(q_t^* - r_t^*) + \delta_1(q_t - r_t) + \beta_1\alpha_t + \beta_1^*\alpha_t^* + \lambda_1 VIX_t + c_1 + v_{1t} \tag{25}$$

$$S_t = \delta_2^*(q_t^* - r_t^*) + \delta_2(q_t - r_t) + \beta_2\alpha_t + \beta_2^*\alpha_t^* + \lambda_2 VIX_t + c_2 + v_{2t} \tag{26}$$

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^*). Note that, as shown in equation (5), an increase in non-U.S. banks' liquidity needs (V) means a rightward shift in the demand curve for USD through the FX swap market, which leads to an increase in both

[32] 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.

CIP deviation (Δ) and the transaction volume of FX swap (S). In contrast, as shown in equation (9), an increase in arbitrageurs' liquidity needs (V^*) or a decrease in their wealth endowment (W^*) means a leftward shift in the supply curve for USD through 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 next decompose the error terms into two components: (i) *demand shock* related to non-U.S. banks' liquidity needs, and (ii) *supply shock* related to arbitrageurs' liquidity needs and wealth endowment.[33] 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 shock and supply shock by making use of sign restrictions.

Estimation results

The upper panel in Figure 10 shows the time paths of two estimated structural shocks for USD/JPY. The middle panels show the decomposition of a CIP deviation and swap transaction volume into interest margin differential, banks' EDFs, VIX, and two structural shocks based on the model.[34] Both demand and supply shocks have been an important source of variations in CIP deviation Δ and transaction volume *S*. Demand shock affected CIP deviation Δ and the transaction volume *S* positively in the latter half of 2015 and beyond. While supply shock lowered CIP deviation Δ and boosted the transaction volume *S* in 2012 and 2013, the sign of the shock's effects was flipped in the middle of 2014, increasing CIP deviation Δ and lowering the transaction volume *S*.

As regards supply shock, we are unable to disentangle the contributions of V^* and

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[33] In order to estimate demand and supply shocks from residual series v_{1t} and v_{2t}, we first formulate the vector autoregression (VAR) that consists of these two residual series, and then extract 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}. See Uhlig (2005) for details of VAR identification with sign restrictions.

[34] 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.

W^*, and only able to discuss the combined role played by liquidity needs of arbitrageurs and their wealth endowment. However, what we observe from the lower panel of Figure 10 is the presence of the sovereign wealth funds (SWFs) of oil-producing countries in the FX swap market. This panel shows that the correlation with oil price is negative for the impact of supply shock on CIP deviation, and positive for that on FX swap transaction volume. In addition, for both CIP deviation and FX swap transaction volume, the absolute values of the correlation coefficients are recently larger than before, indicating that the relationship between supply shock and oil price has become strong. Market contacts indicate that SWFs in oil-producing countries have supplied USD in the FX swap market. 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 leftward shift of the supply curve of USD through the FX swap market. Indeed, in this period, supply shocks tend to be negative (Figure 10 (1)), and they contribute to a decline in CIP deviation and an increase in FX swap transaction volume (Figure 10 (2)).

However, market contacts say that since oil prices plummeted in 2015, 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 through the FX swap market. Indeed, from mid-2014, supply shocks tend to be positive (Figure 10 (1)), and they contribute to an increase in CIP deviation and a decline in FX swap transaction volume (Figure 10 (2)). 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 market currency depreciation in mid-2015, official reserve managers shifted their USD-denominated assets from less liquid cross-currency funding markets to US Treasury bills, driven by their increased need to intervene in the FX markets to support their home-currency.[35] Again, such a change in

[35] According to US Treasury (2016), 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

real money investors' portfolios is reflected in supply shock, i.e. a decline in arbitrageurs' wealth endowment (W^*) in our model.

It should be also noted that stricter financial regulations (i.e., higher θ and η in our model) increases the sensitivity of CIP deviations to wealth endowment shocks. That is, from equation (10), the following qualitative relationships hold.

$$\frac{\partial\left(\frac{\partial \Delta}{\partial W^*}\right)}{\partial \theta}, \frac{\partial\left(\frac{\partial \Delta}{\partial W^*}\right)}{\partial \eta} < 0. \tag{27}$$

When 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 of 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 in the asset management sector, such as a fall in the AUM of real money investors, is amplified by stricter financial regulations.

4.4. Implications for financial stability

Historically, non-U.S. bank's creditworthiness has largely affected their overseas dollar lending and financial stability through variations in CIP deviation. During both Japan's banking crisis in the late 1990s and the eurozone sovereign debt crisis in 2011, an increase in CIP deviation brought about by a worsening of banks' creditworthiness was followed by a cut in overseas lending extended by non-U.S. banks. In the former crisis, as Peek and Rosengren (2001, 2002) document, because of the deterioration in their balance sheet conditions and an increase in the dollar funding premium (the

intervention caused central banks to dip into their stocks of foreign exchange reserves.

so-called “Japan premium”), Japanese banks cut lending, in particular wholesale lending to the U.S. As for the latter crisis, Ivashina et al. (2015) document that eurozone banks cut their dollar lending more than their euro lending. The impact of non-U.S. banks' creditworthiness on the dollar funding premium and their dollar lending in cases such as these is well described in our model. Differentiating equations (6) and (10) with respect to non-U.S. banks' default probability (α) yields the following relationships:

$$\frac{\partial \Delta}{\partial \alpha} > 0, \text{ and } \frac{\partial L_{US}}{\partial \alpha} < 0. \tag{28}$$

In recent years, however, the linkage between banks' creditworthiness and CIP deviation has been weakened. One possible reason behind the diminishing impact of banks' creditworthiness is advances in regulatory reforms, such as revised capital requirements based on the Basel Accords. Instead of banks' creditworthiness, interest margin differentials due to diverging monetary stances have a larger impact on the dollar funding premium, as explained in Section 4.1. This then begs the question, how does monetary policy divergence, especially resulting from changes in the Fed's policy stance, affect non-U.S. financial institutions' lending and investing behavior? Although a rise in the U.S. interest margin ($q^* - r^*$) encourages non-U.S. financial institutions to “search for yield” on USD-denominated assets (i.e., $\frac{\partial L_{US}}{\partial (q^*-r^*)} > 0$), our model suggests that regulatory reforms limit the impact of U.S. monetary policy on their activities. That is, the following qualitative relationships hold.[36]

$$\frac{\partial\left(\frac{\partial L_{US}}{\partial (q^*-r^*)}\right)}{\partial \theta}, \frac{\partial\left(\frac{\partial L_{US}}{\partial (q^*-r^*)}\right)}{\partial \eta} < 0\ . \tag{29}$$

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 (20)), such reforms dampen the impact of a rise in the U.S. interest margin ($q^* - r^*$) on non-U.S. financial institutions' lending and investments (L_{US}) and prevent them from engaging in excessive “search for yield” activities. This

[36] 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.

then helps the U.S. monetary authorities avoid financial imbalances like Alan Greenspan's "bond conundrum," and contributes to global financial stability.[37]

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 wealth shocks facing arbitrageurs. Namely, we can derive the following qualitative relationships from equations (6) and (10).

$$\frac{\partial\left(\frac{\partial L_{US}}{\partial V}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial L_{US}}{\partial V}\right)}{\partial\eta}, \frac{\partial\left(\frac{\partial L_{US}}{\partial V^*}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial L_{US}}{\partial V^*}\right)}{\partial\eta} < 0, \text{ and } \frac{\partial\left(\frac{\partial L_{US}}{\partial W^*}\right)}{\partial\theta}, \frac{\partial\left(\frac{\partial L_{US}}{\partial W^*}\right)}{\partial\eta} > 0. \tag{30}$$

An increase in banks' liquidity needs and a decline in the total AUM of real money investors leads to a tightening of demand-supply balance in the FX swap market and a higher dollar funding premium. This effect is amplified by stricter regulations which increase the marginal costs of dollar funding for banks. As a result, given interest margin differentials, non-U.S. financial institutions further reduce their USD-denominated investments. If their investments are cut rapidly and on a large scale, this may destabilize the global financial system.

Although financial regulations, such as LCR and NSFR, contribute to reducing the risk of liquidity shortage for global banks, there remains the risk of adverse shocks in the asset management sector, whose presence in the FX swap market has increased recently. Our model suggests that the impact of severely adverse shocks in the asset management sector, such as a sharp fall in the AUM of real money investors, are amplified by stricter financial regulations (i.e., higher θ and η) and transmitted to the FX swap market and beyond, inducing non-U.S. banks to further cut back on their USD-denominated lending. This then feeds back into the asset management sector by driving down asset prices and thereby having a further negative impact on the real money investors' AUM.

[37] See, for instance, King (2006) for a discussion of the conundrum.

5. Conclusion

In this paper, we study the determinants of CIP deviations and outline the implications for monetary policy divergence and financial stability. First, we theoretically show that CIP deviation is driven by several factors: interest margin differentials, banks' default probabilities, banks' liquidity needs, and the wealth endowment of arbitrageurs. We then empirically show that our model's predictions are consistent with the data. In addition, we find that in recent years the key driver of CIP deviation has changed from banks' default probabilities to interest margin differentials. Given that interest margin is largely affected by the monetary policy stance, this result suggests the growing importance of monetary policy divergence in the FX swap market.

We also discuss the impact of regulatory reforms on the FX swap market and non-U.S. banks' lending and investing behavior. While stricter regulations limit non-U.S. banks' excessive "search for yield" activities resulting from monetary policy divergence, they amplify the impact of adverse shocks in the asset management sector on the dollar funding market and hence non-U.S. banks' dollar lending. Both these positive and negative effects of regulatory reforms are attributable to an increase in the marginal cost of banks' dollar funding. We have pointed out that the latter negative (and unintended) effect of regulations has become potentially larger due to changes in the cross-currency market structure, particularly in the type of arbitragers as USD liquidity providers. 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, as well as U.S. banks, may sell off their USD-denominated assets and/or 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. It is therefore important to seek measures that minimize the unintended negative effects of financial regulations without compromising their positive effect.[38]

[38] Financial Stability Board (2016) proposes policy recommendations to address structural vulnerabilities from asset management activities. These policies are expected to help reduce the risk of adverse shocks in the asset management sector.

Appendix. Model with a third-country effect

In this appendix, we describe a model in which there is one other jurisdiction in addition to Japan, say the euro area. We denote any variable or parameter Z that is related to the euro area by $\tilde{Z}$. Under settings similar to a Japanese bank, a eurozone bank's demand for USD through the EUR/USD FX swap is given as

$$\tilde{S} = \frac{1}{2\tilde{\tau}}\left\{[(q^* - r^*) - (\tilde{q} - \tilde{r})] - \frac{\tilde{\tau}+\tilde{\eta}}{\tilde{\eta}}\tilde{\Delta} + \frac{\tilde{\tau}\tilde{p}}{\tilde{\eta}}\tilde{\alpha} + \tilde{\tau}\tilde{V}\right\}, \tag{A1}$$

where $\tilde{\tau}, \tilde{\eta},$ and $\tilde{p}$ are technology parameters that take positive values. A CIP deviation for EUR/USD, $\tilde{\Delta}$, is defined as

$$(1 + r^*) + \tilde{\Delta} = \tilde{X}_1 \times \tilde{X}_0^{-1}(1 + \tilde{r}).$$

Since there are now two types of non-U.S. banks, the profit maximization problem of an arbitrageur in the U.S. is now formulated as follows.

$$\max_{\substack{L^*_{US}, L^*_{JP}, L^*_{EU} \\ D^*_{US}, D^*_{JP}, D^*_{EU}, \\ M^*, S, and\ \tilde{S}}} \left\{\begin{array}{c} h_f(L^*_{US}) + h_h\left(L^*_{JP}\right) + h_{\tilde{h}}(L^*_{EU}) - \kappa_f(D^*_{US}) - \kappa_h\left(D^*_{JP}\right) - \kappa_{\tilde{h}}(D^*_{EU}) \\ +(X_1 \times X_0^{-1} - 1)S + \left(\tilde{X}_1 \times \tilde{X}_0^{-1} - 1\right)\tilde{S} \end{array}\right\} \tag{A2}$$

subject to

$$\begin{gathered} M^* \geq V^* \\ L^*_{US} + M^* = W^* + D^*_{US} - S - \tilde{S} \\ L^*_{JP} = D^*_{JP} + S \\ L^*_{EU} = D^*_{EU} + \tilde{S}, \end{gathered} \tag{A3}$$

where

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

Here, L^*_{EU} is the amount of euro lending, and D^*_{EU} is that of euro funding. Taking the first order condition of an arbitrageur's profit maximization problem above, we can derive the supply function for USD through the FX swap transactions for the currency pair EUR/USD as well as for USD/JPY. Note that in this setting the supply of USD through the EUR/USD FX swap and that through the USD/JPY FX swap are interrelated. Namely, the supply for USD through the USD/JPY FX swap, denoted as S, is expressed as follows:

$$S = \psi_{q^*-r^*}(q^* - r^*) + \psi_{q-r}(q - r) + \psi_{\tilde{q}-\tilde{r}}(\tilde{q} - \tilde{r}) + \psi_{\alpha^*}\alpha^* + \psi_{\Delta}\Delta + \psi_{\tilde{\Delta}}\tilde{\Delta} + \psi_{V^*-W^*}(V^* - W^*), \tag{A4}$$

where coefficient ψ_Z that is attached to a variable Z is given as the combination of parameters $\theta, \theta^*, \tilde{\theta}, \gamma, \gamma^*, \tilde{\gamma}, p^*$. Assuming that $\gamma = \gamma^* = \tilde{\gamma}$ and $\theta = \theta^* = \tilde{\theta}$, the signs of these coefficients can be determined such that $\psi_{q^*-r^*}$, $\psi_{\tilde{q}-\tilde{r}}$, $\psi_{V^*-W^*}$, $\psi_{\tilde{\Delta}} < 0$ and $\psi_{q-r}, \psi_{\alpha^*}, \psi_{\Delta} > 0$. The symmetric equation holds for USD supply of an arbitrageur to Eurozone banks, which is

$$\tilde{S} = \phi_{q^*-r^*}(q^* - r^*) + \phi_{q-r}(q - r) + \phi_{\tilde{q}-\tilde{r}}(\tilde{q} - \tilde{r}) + \phi_{\alpha^*}\alpha^* + \phi_{\Delta}\Delta + \phi_{\tilde{\Delta}}\tilde{\Delta} + \phi_{V^*-W^*}(V^* - W^*), \tag{A5}$$

where coefficient ϕ_Z that is attached to a variable Z is given as the combination of parameters $\theta, \theta^*, \tilde{\theta}, \gamma, \gamma^*, \tilde{\gamma}, p^*$. Assuming the same conditions for the parameters, the signs of these coefficients can be determined again, such that $\phi_{q^*-r^*}, \phi_{q-r}, \phi_{V^*-W^*}, \phi_{\Delta} < 0$ and that $\phi_{\tilde{q}-\tilde{r}}, \phi_{\alpha^*}, \phi_{\tilde{\Delta}} > 0$.

Using equations (5), (A1), (A4), and (A5), the CIP deviation for USD/JPY at the equilibrium is expressed as follows.

$$\Delta = \rho_{q^*-r^*}(q^* - r^*) + \rho_{q-r}(q - r) + \rho_{\tilde{q}-\tilde{r}}(\tilde{q} - \tilde{r}) + \rho_{\alpha^*}\alpha^* + \rho_{\alpha}\alpha + \rho_{\tilde{\alpha}}\tilde{\alpha} + \rho_{V^*}V^* + \rho_V V + \rho_{\tilde{V}}\tilde{V} + \rho_{W^*}W^* \tag{A6}$$

Coefficient ρ_Z that is attached to a variable Z is given as the combination of technology parameters. It can be shown that under the symmetric assumption about the parameter values, their signs are pinned down such that ρ_{q-r}, $\rho_{\tilde{q}-\tilde{r}}$, ρ_{α^*}, $\rho_{W^*} < 0$ and $\rho_{q^*-r^*}$, ρ_{α}, $\rho_{\tilde{\alpha}}$, ρ_V, ρ_{V^*}, $\rho_{\tilde{V}} > 0$. [39]

It is seen from equation (A6) that CIP deviation Δ of USD/JPY is now influenced not only by the interest rate margin in Japan, together with the Japanese bank's default probability and its liquidity needs but also by those associated with the euro area. For instance, other things being equal, a widening interest margin in the euro area reduces the demand for USD by Eurozone banks, which then increases USD available for

[39] We assume, similar to discussion in Section 2, that inequality $\eta\gamma > \theta\tau$ holds here.

Japanese banks in the FX swap market. Consequently, CIP deviation falls.

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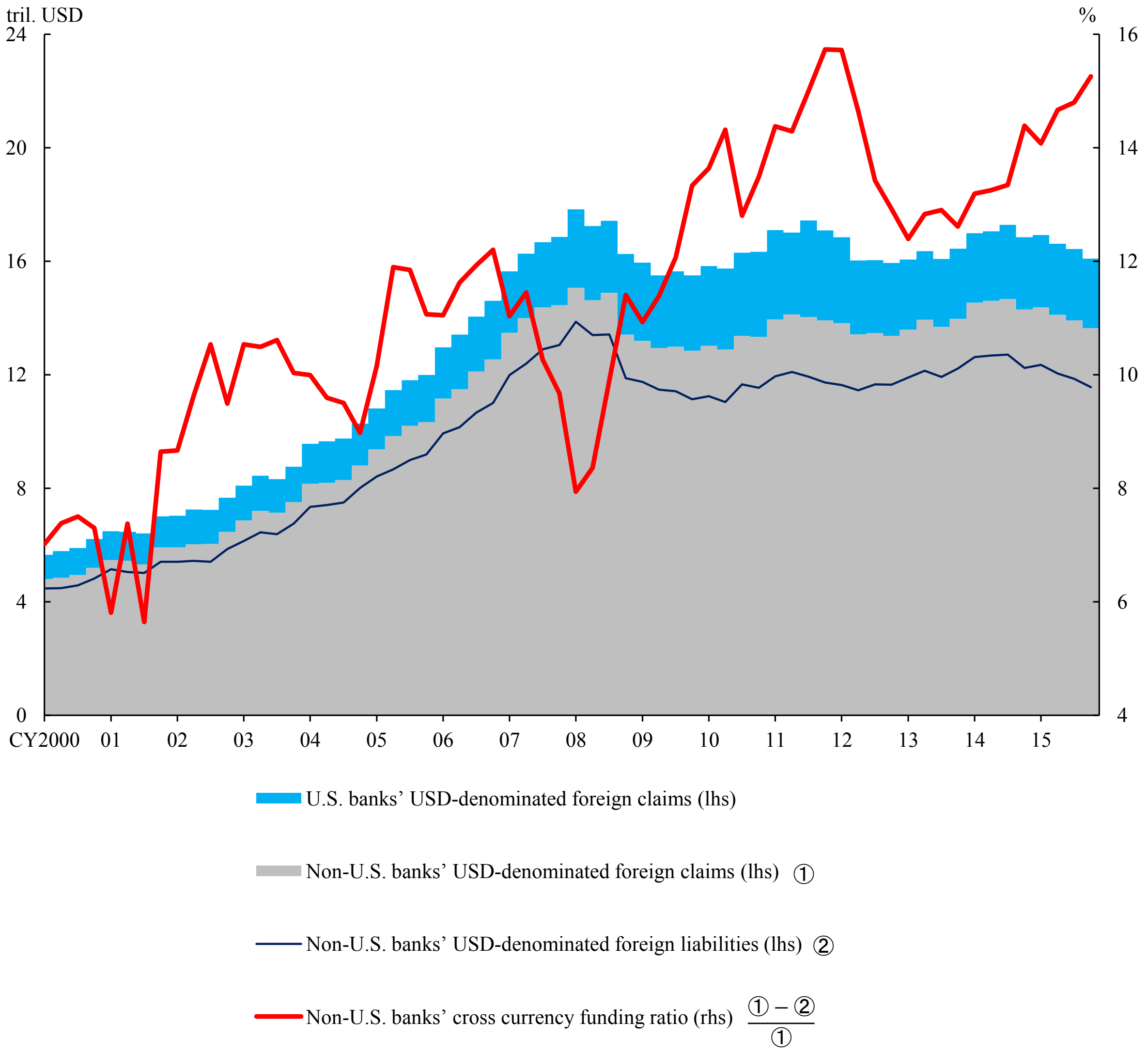
Figure 1: USD-denominated foreign position of banks

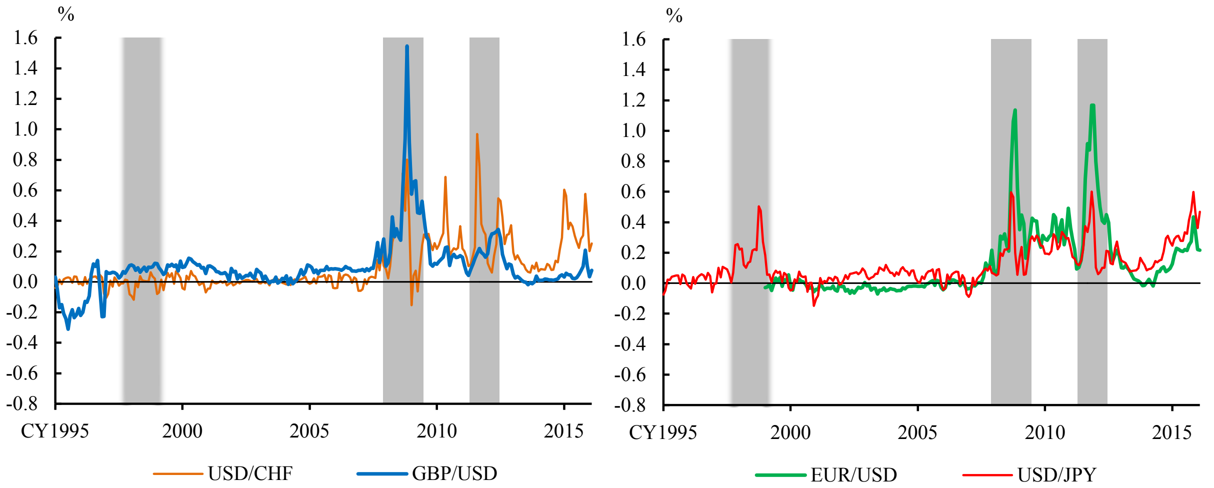


Note: "Non-U.S. banks' USD-denominated foreign claims" and "Non-U.S. banks' USD-denominated foreign liabilities" are calculated as USD-denominated foreign claims and liabilities of all countries minus those of U.S. banks, respectively. "Non-U.S. banks' cross currency funding (i.e., FX swap)" is defined 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.

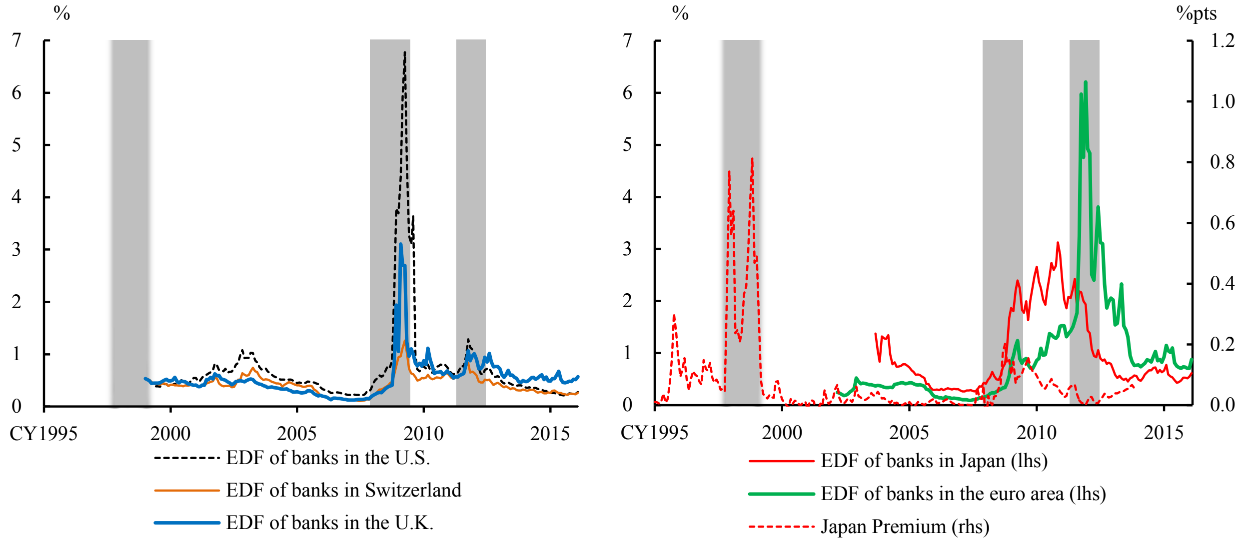
Source: BIS consolidated banking statistics (immediate borrower basis); BIS locational banking statistics by nationality.

Figure 2: CIP deviation and banks' default probability

(1) CIP deviation (3M)



(2) Banks' default probability



Notes: 1. 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 eurozone sovereign debt crisis (May 2011 through June 2012).

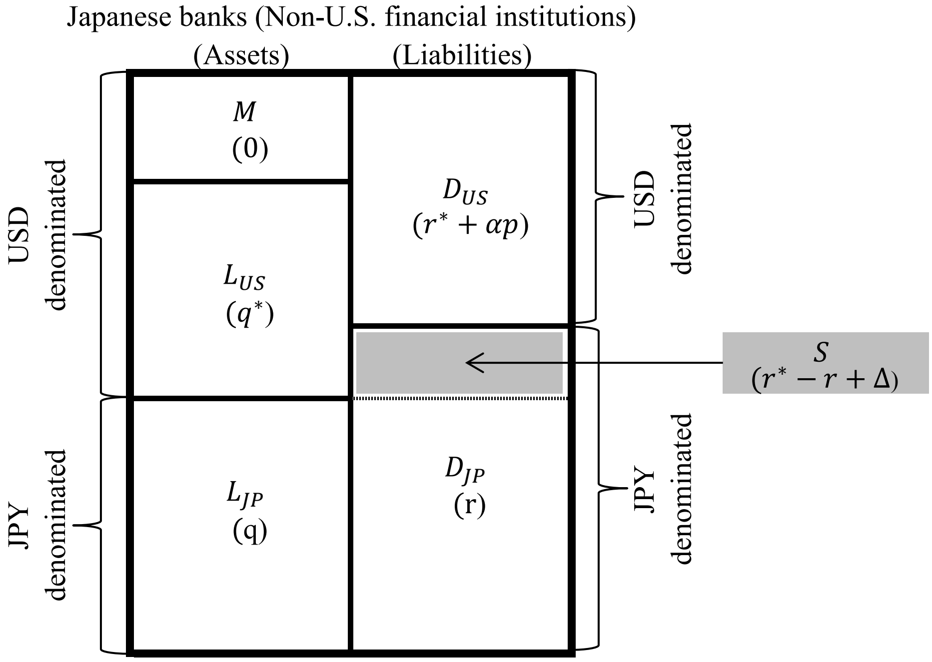
2. CIP deviation is calculated as FX swap-implied dollar rates minus USD Libor.

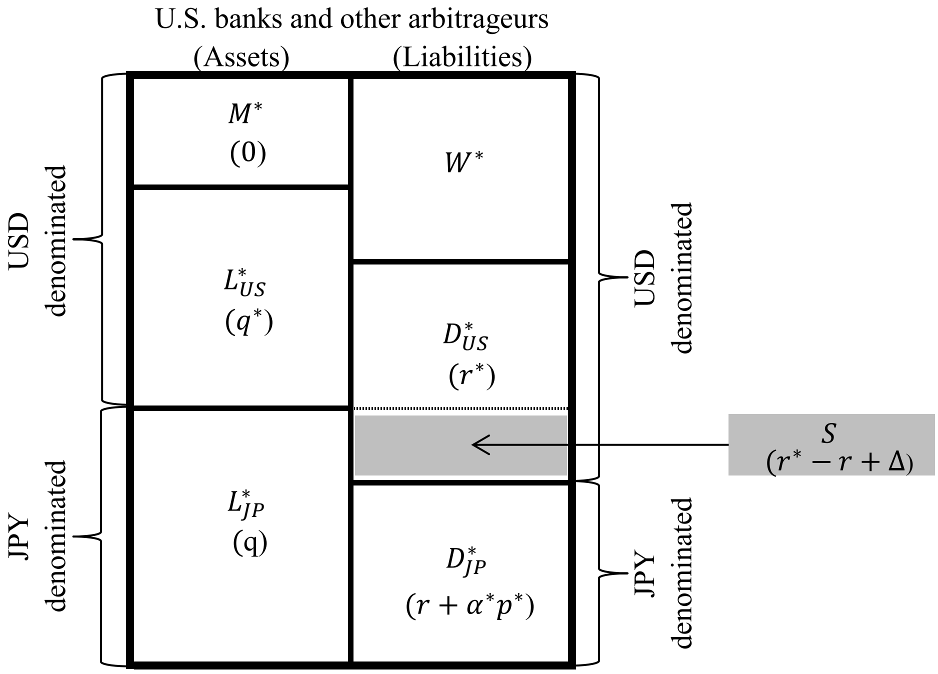
3. The average of the Expected Default Frequency (EDF) of the GSIBs, which are headquartered in each country, is used as the measure of banks' default probability. For the euro area, the average of the EDF of the GSIBs in France, Germany, and Italy is used.

4. "Japan Premium" is calculated as 3-month USD TIBOR minus 3-month USD LIBOR.

Source: Bloomberg; Moody's; BOJ.

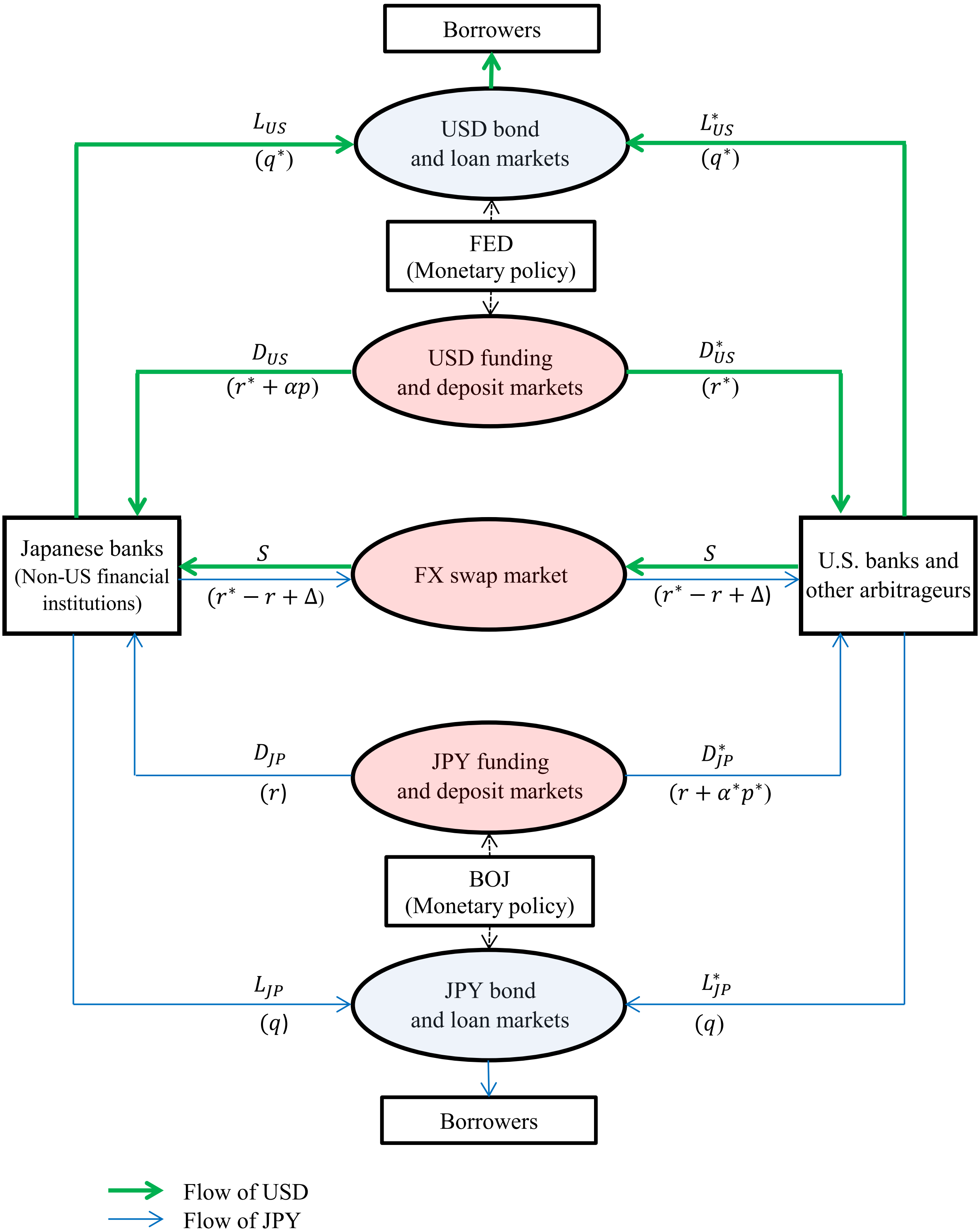
Figure 3: Balance sheets of global banks in the model economy





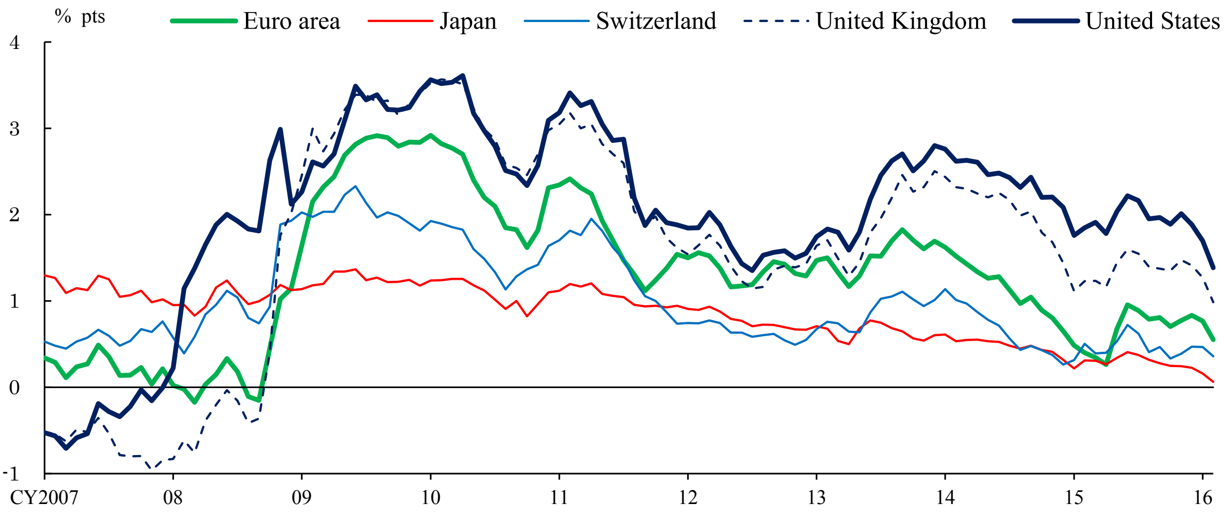
Note: The figures in parentheses are the interest rates applied to each asset or liability.

Figure 4: Flow of funds in the model economy



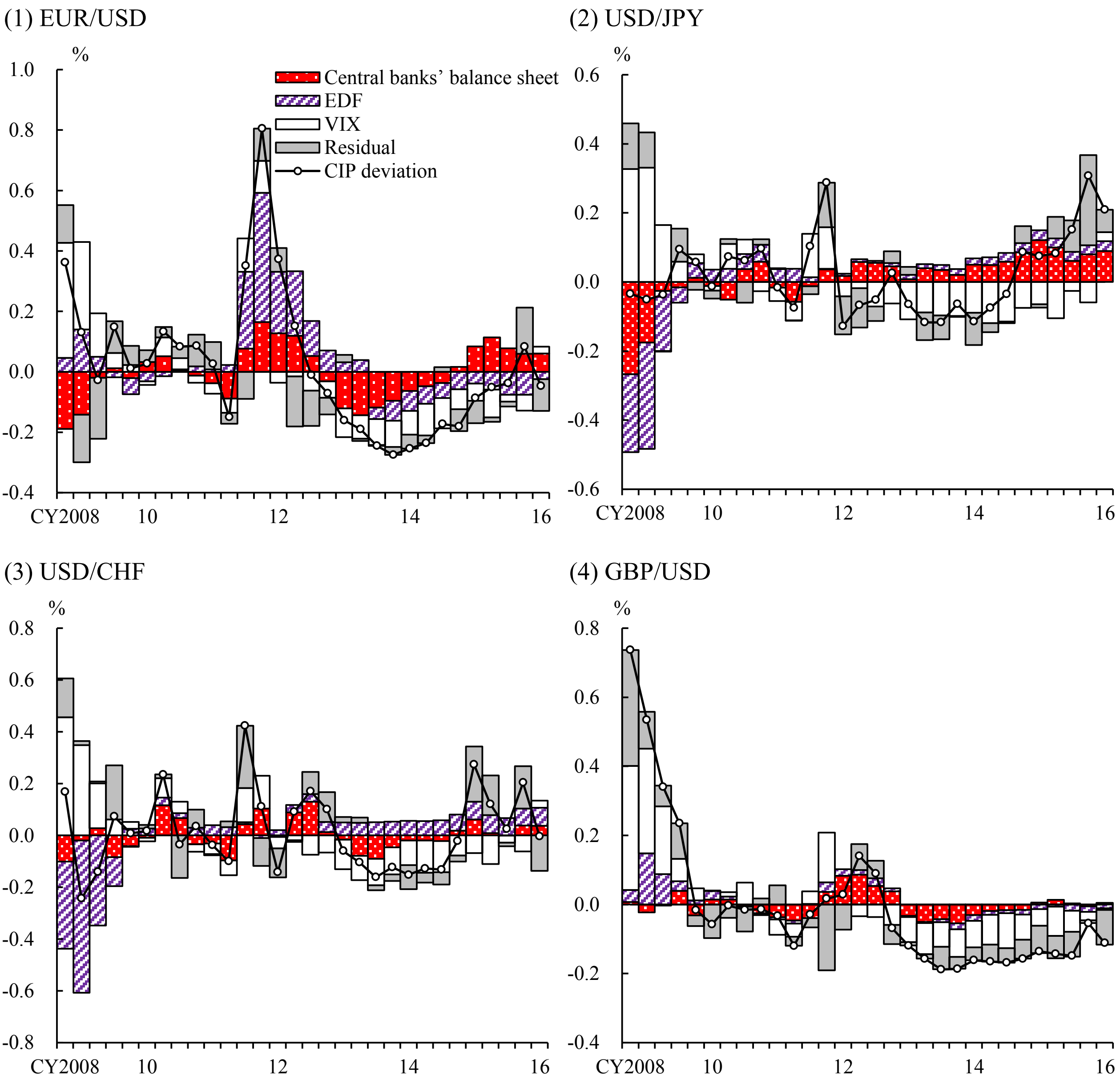
Note: The figures in parentheses are the interest rates applied to each asset or liability.

Figure 5: Interest margin



Note: Interest margin is calculated as 10-year government bond rate minus 3-month OIS rate.
Source: Bloomberg; Authors' calculations.

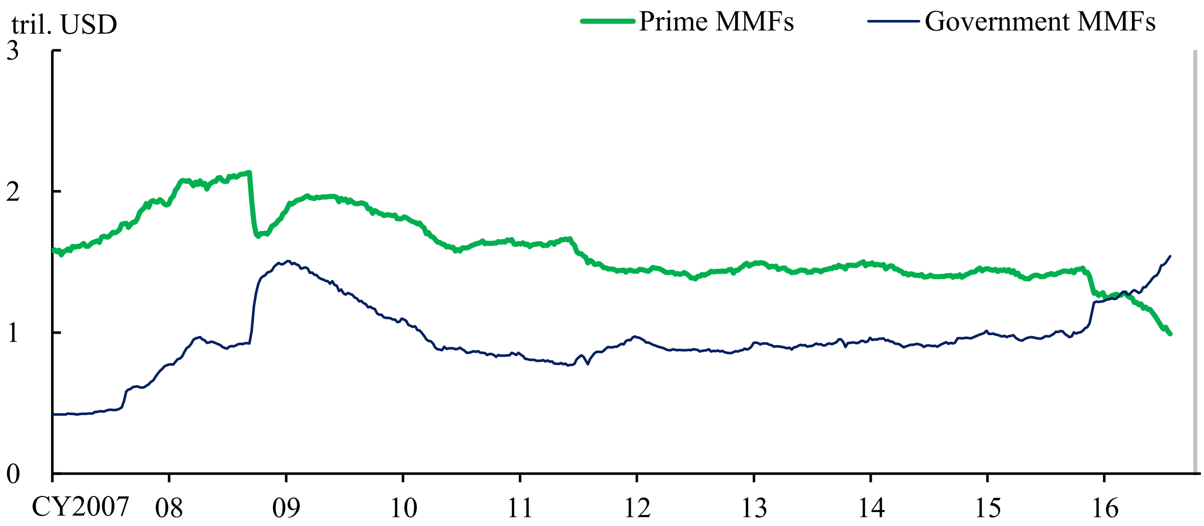
Figure 6: Decomposition of CIP deviation



Notes: 1. Each panel shows the quarterly average of the decomposition of a CIP deviation based on the regression results of Model 3 shown in table 5. Contributions of constant terms are not depicted.

2. "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 U.S., indicating the net effect of banks' default probabilities. Residuals in each panel include the contribution of control variables.

<u>Figure 7: MMF total assets</u>



Notes: 1. Government MMFs are defined as MMFs that invest 99.5% 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.

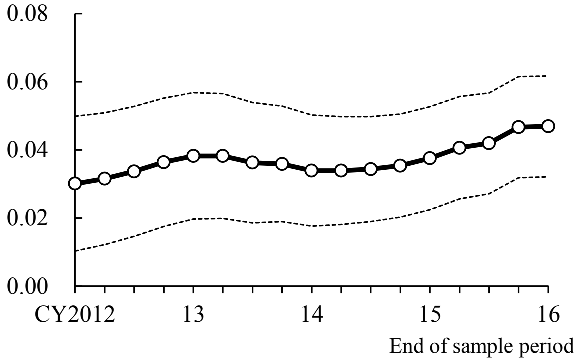
2. The vertical line corresponds to the compliance date for amendments related to MMF reforms released by the Securities and Exchange Commission (October 2016).

Source: Investment Company Institute.

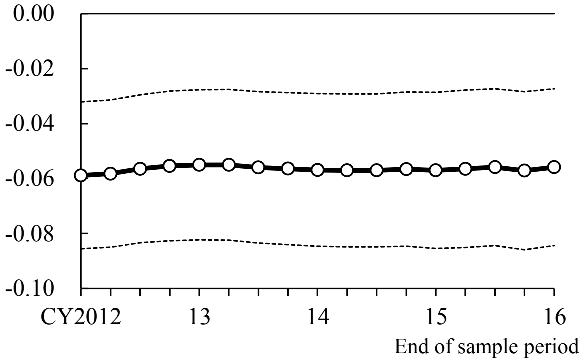
Figure 8: Estimated effects of regulatory reforms

(1) Coefficients estimated based on different sample periods

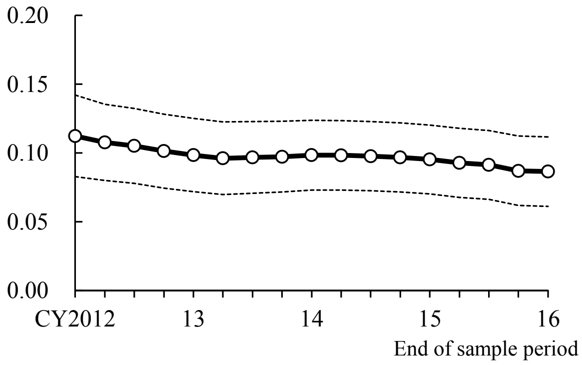
(a) Interest margin differential



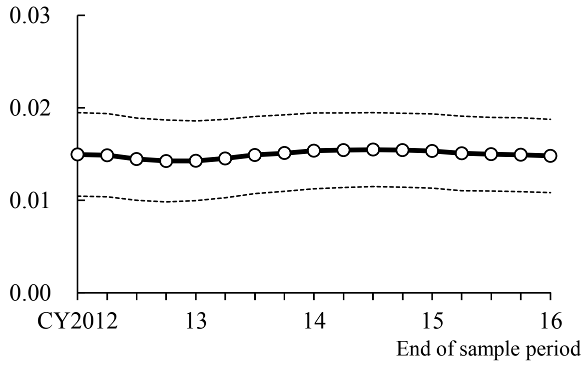
(b) US banks' EDF



(c) Non-US banks' EDF

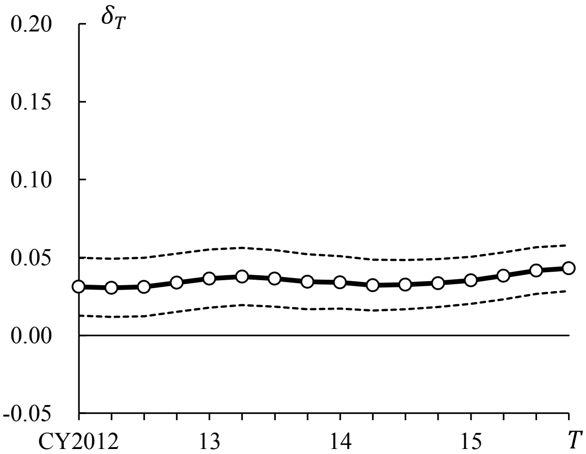


(d) VIX

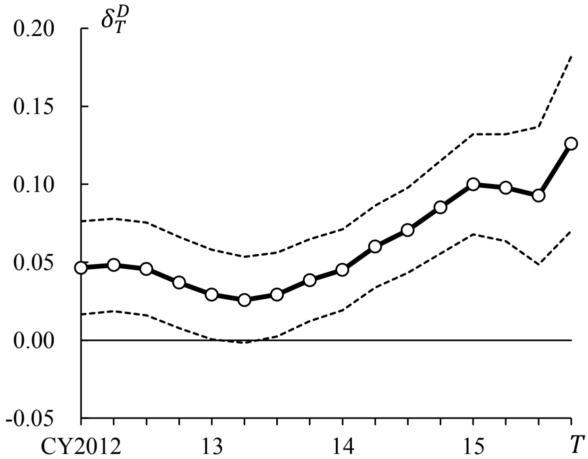


(2) Coefficients of interest margin differential based on the dummy-variable approach

(a) Interest margin differential



(b) DUM × Interest margin differential

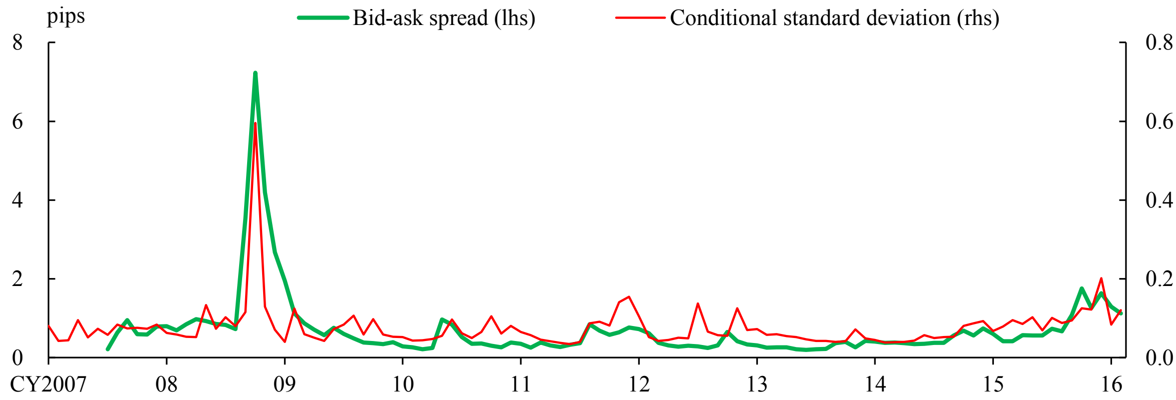


Notes: 1. For panels (1), the x-axis denotes the end of the sample period used to estimate the coefficient of the variable, which is depicted in the y-axis. Dotted lines indicate 95 percent confidence intervals.

2. For panels (2), the x-axis denotes the starting period from which the dummy variable takes unity. Dotted lines indicate 95 percent confidence intervals.

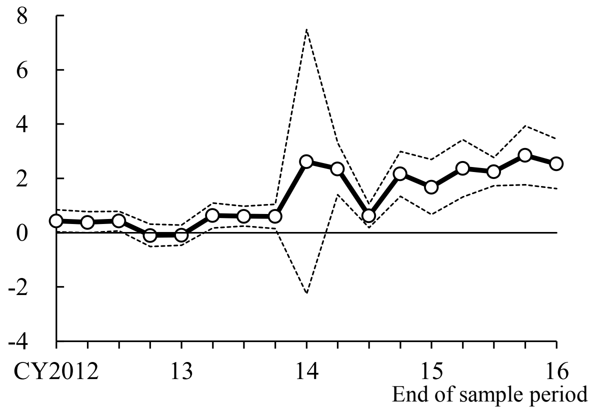
Figure 9: Effects of market liquidity on CIP deviation

(1) Bid-ask spread of FX forwards (3M) and conditional standard deviation estimated by EGARCH model

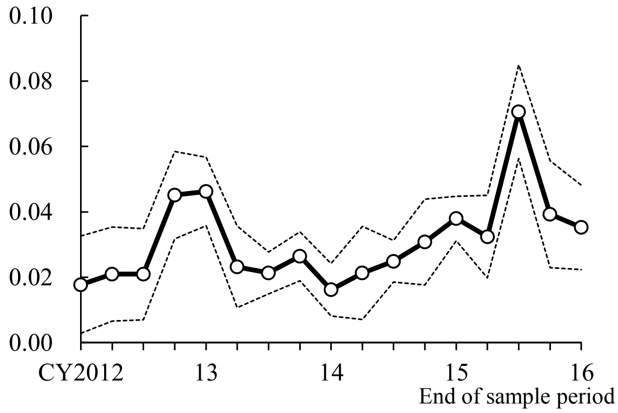


(2) Coefficients of explanatory variables in EGARCH model

(a) Conditional standard deviation $[\sigma_t]$



(b) Interest margin differential $[(q_t^* - r_t^*) - (q_t - r_t)]$

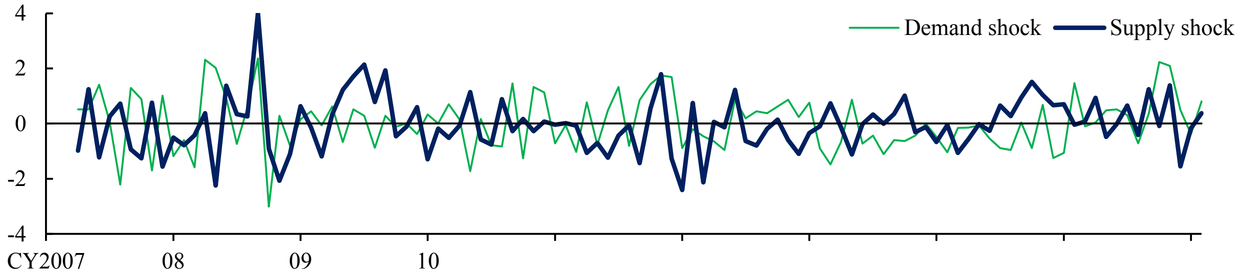


Note: For panels (2), the x-axis denotes the end of the sample period used to estimate the coefficient of the variable, which is depicted in the y-axis. Dotted lines indicate 95 percent confidence intervals.

Source: Bloomberg; BOJ; Authors' calculations.

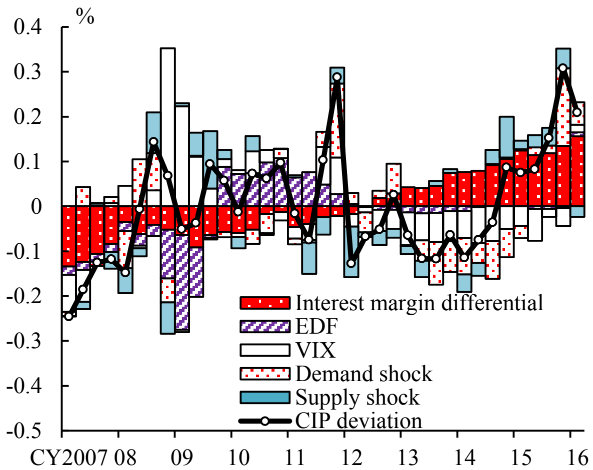
<u>Figure 10: Decomposition of CIP deviation and FX swap transaction volume (USD/JPY)</u>

(1) Demand and supply shocks

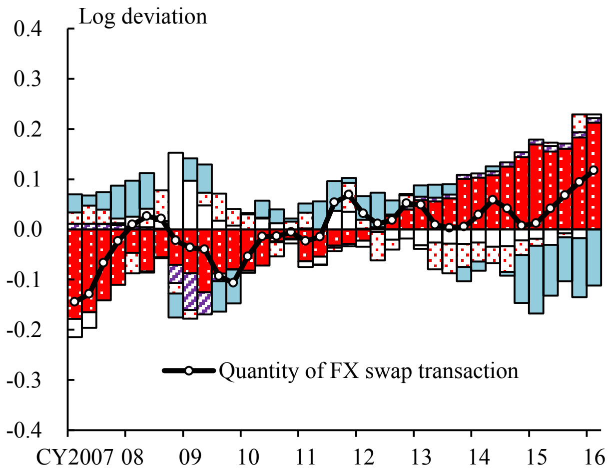


(2) Decomposition of CIP deviation and FX swap transaction volume

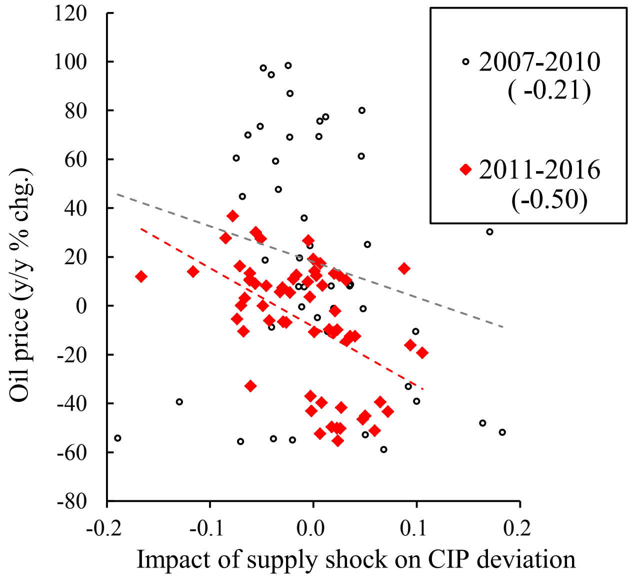
(a) CIP deviation

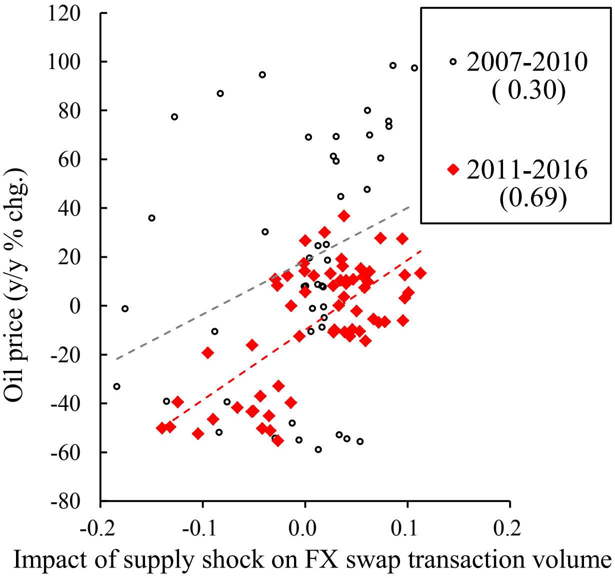


(b) FX swap transaction volume



(3) Relationship between oil price and the impact of supply shocks





Notes: 1. The size of demand and supply shocks is normalized so that its variance is unity.

2. The middle panel 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 U.S., and the sum of the contribution of EDF in Japan and the U.S., respectively. "FX swap transaction volume" is the log deviation of the volume from its average in 2006.

3. For panel (3), figures in parenthesis are correlation coefficients. We use WTI (West Texas Intermediate) as the measure of oil price.

Source: Bloomberg; Authors'calculations.

Table 1: Panel regressions of CIP deviations (3M)

	Model 1	Model 2	Model 3			
			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}		0.0436 ***				
		(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:
1. Sample period: 2007M1-2016M2.
2. Figures in parentheses are t-statistics. Standard errors are calculated based on period weights (PCSE) method.
3. ***, **, and * respectively indicate significance at the 1%, 5%, and 10% level.

Table 2: Panel regressions of CIP deviations of different terms

	Dependent variable: CIP deviation (3M)	CIP deviation (6M)	CIP deviation (1Y)
Interest margin^{US}	0.0469 ***	0.0510 ***	0.0736 ***
－Interest margin$^{non\text{-}US}$	(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:
1. Sample period: 2007M1-2016M2.
2. Figures in parentheses are t-statistics. Standard errors are calculated based on period weights (PCSE) method.
3. ***, **, and * respectively indicate significance at the 1%, 5%, and 10% level.

Table 3: Panel regressions of CIP deviations computed using OIS

	$\alpha, \alpha^{*}: EDF$	$\alpha, \alpha^{*}: CDS$
Interest margin^{US}	0.0729 ***	0.0819 ***
−Interest margin$^{non\text{-}US}$	(5.71)	(5.33)
Default probability of US banks (α^{*})	-0.0897 ***	-0.0009 ***
	(-4.65)	(-3.62)
Default probability of non-US 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:

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

Table 4: Panel regressions of CIP deviation (3M) with the third-country effect

Interest margin^{US}	0.0597 ***
	(6.13)
Interest margin$^{non\text{-}US}$	-0.0572 ***
	(-5.23)
Interest margin$^{3rd\ country}$	-0.0475 ***
	(-2.74)
EDF^{US}	-0.0431 ***
	(-2.84)
EDF$^{non\text{-}US}$	0.0926 ***
	(6.65)
EDF$^{3rd\ country}$	0.0307
	(1.63)
VIX	0.0135 ***
	(6.51)
Constant	-0.1359 ***
	(-4.00)
Fixed effects	Yes
R-squared	0.50
RMSE	0.15
No. of observations	440

Notes:

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

Table 5: Panel regressions of the impact of monetary policy divergence on CIP deviation (3M)

	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:

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

Table 6: CIP deviation and market liquidity

Dependent variable: CIP deviation	
Mean equation	
Interest margin^{US} $-$ Interest margin^{JP}	0.0437 ***
	(5.61)
EDF^{US}	-0.0338 ***
	(-3.68)
EDF^{JP}	0.0313 ***
	(2.70)
VIX	0.0028
	(1.64)
Constant	-0.1044 ***
	(-3.34)
Conditional standard deviation (σ_t)	2.5463 ***
	(7.74)
Variance equation $\ln(\sigma_t^2) = c_0 + c_1\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert + c_2(\varepsilon_{t-1}/\sigma_{t-1}) + c_3 ln(\sigma_{t-1}^2) + c_4(Liquidity\ shock)$	
C_0	-3.6760 ***
	(-12.31)
C_1	0.2443 **
	(2.13)
C_2	0.6720 ***
	(8.75)
C_3	0.3509 ***
	(5.29)
Liquidity shock	0.7787 **
	(2.43)
Log likelihood	141.49
No. of observations	110

Notes:
1. Sample period: 2007M1-2016M2
2. Figures in parentheses are z-statistics. Standard errors are calculated based on Bollerslev-Wooldridge method.
3. ***, **, and * respectively indicate significance at the 1%, 5%, and 10% level.
4. Liquidity shock is calculated as the residual of the regression of USD LIBOR-OIS spread on US banks' EDF.