Unconventional Monetary Policy and Covered Interest Rate Parity Deviations: is there a Link?

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Abstract

A fundamental puzzle in international finance is the persistence of covered interest rate parity (CIP) deviations. Since 2008, these deviations have implied a persistent dollar financing premium for banks in the Euro area, Japan and Switzerland. Using a model of the foreign exchange (FX) swap market, I explore two channels through which the unconventional monetary policies of the European Central Bank, Bank of Japan and Swiss National Bank can create an excess demand for dollar funding. In the first, quantitative easing leads to a relative decline in domestic funding costs, making it cheaper for international banks to source dollars via FX swaps, relative to direct dollar borrowing. In the second, negative interest rates cause a decline in domestic interest rate margins, as loan rates fall and deposit rates are bound at zero. This induces banks to rebalance their portfolio toward dollar assets, again creating a demand for dollars via FX swaps. To absorb the excess demand, financially constrained arbitrageurs increase the premium that banks must pay to swap domestic currency into dollars. I show empirically that CIP deviations have tended to widen around negative rate and QE announcements. I also document a rising share of dollar funding via the FX swap market for U.S. subsidiaries of Eurozone, Japanese and Swiss banks in response to a decline in domestic credit spreads.

Keywords: exchange rates, foreign exchange swaps, dollar funding, quantitative easing, negative interest rates

JEL Classifications: E43, F31, G15

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1 Introduction

Covered interest rate parity (CIP) is one of the most fundamental tenets of international finance. An arbitrage relationship, it states that the rate of return on equivalent domestic and foreign assets should be equal upon covering exchange rate risk with a forward contract. But deviations in excess of transaction costs have been a regularity for advanced economies since 2008 (Figure 1). CIP deviations are typically widest for the euro/$, chf/$ and yen/$ pairs.[1] These deviations suggest Euro Area, Swiss and Japanese banks are paying a premium to swap euros, swiss francs and yen into dollars in the foreign exchange (FX) swap market. The initial deviation from CIP in 2008 was plausibly attributable to the financial crisis, during which increases in default risk for non U.S. banks in interbank markets translated into a significant premium for borrowing dollars. But the persistence of CIP deviations since then, and especially since 2014 is more difficult to explain, since measures of default risk in interbank markets have returned to pre-crisis levels.[2] One suspects that an explanation resting entirely on arbitrage frictions will be incomplete, given that the FX swap market is one of the deepest and most liquid financial markets, with an estimated 3.2 Trillion USD daily turnover (BIS, 2019). That markets in the specific currency pairs on which this paper focuses – the euro/$, chf/$ and yen/$ -- are especially liquid reinforces the point.

[INSERT FIGURE 1 ABOUT HERE]

In this paper I propose an explanation that focuses on unconventional monetary policies, specifically the quantitative easing (QE) and negative interest rates of the European Central Bank (ECB), Bank of Japan (BOJ) and Swiss National Bank (SNB). Since 2014, these central banks have adopted negative interest rates. They have undertaken asset purchases that increased the size of their balance sheets absolutely and relative to the Federal Reserve System (Figure 2). To illustrate how these channels work, consider a Euro Area, Swiss or Japan bank desiring long-term USD funding. They can borrow those dollars directly at the USD funding cost, or alternatively can obtain them synthetically, by borrowing euros, swiss francs or yen and swapping them into dollars. The difference between the direct and synthetic dollar cost is equal to the CIP deviation. QE programs by the ECB, such as the Corporate Bond Purchase Program of 2016, entail purchases of privately-issued debt, with a consequent decline in domestic funding costs. All else equal, a European bank will borrow euros at a lower funding

[1] The euro/$, chf/$ and yen/$ will be the three bilateral pairs that I focus on this paper. All pairs are measured with respect to the US dollar. This is the most relevant bilateral pair given the predominance of the US dollar as one of the two legs in a FX swap, and the euro/$ and yen/$ accounting for over 50% of all FX swap transactions.

[2] The typical way to measure default risk in interbank markets is the LIBOR-OIS spread, which is the difference between the London interbank offer rate (LIBOR) and the overnight index swap rate (ois).

cost, and then swap into dollars in the FX swap market. This leads to a reallocation of dollar funding toward FX swaps, which have become cheaper relative to direct dollar borrowing.

Negative interest rates, for their part, squeeze domestic interest margins because they reduce the returns on loans more than the cost of deposits, which cannot fall below zero. Lower domestic interest margins induce further portfolio rebalancing toward dollar assets, since relative returns on dollar assets are now higher. Assuming that banks seek to maintain a currency neutral balance sheet, a rising dollar asset position therefore leads to increased demand for dollar funding. Banks can satisfy this demand using FX swaps. Euro Area, Swiss and Japanese banks therefore swap euros, Swiss francs and yen for dollars, matching the currency composition of their assets and liabilities. Like QE, negative interest rates consequently result in an increase in bank demands for dollars via FX swaps.

Arbitrageurs are at the other end of these bank FX swap transactions. They provide the dollars that Euro Area, Swiss and Japanese banks seek in order to match their assets and liabilities. To satisfy a growing demand for dollar funding from banks, financially constrained arbitrageurs therefore raise the premium at which euros, yen and Swiss francs are swapped into dollars, causing a widening of CIP deviations.

[INSERT FIGURE 2 ABOUT HERE]

To rationalize these two channels, I introduce a model with two agent types. The first agent is a non U.S bank that has a portfolio of domestic and dollar assets. They are funded by domestic deposits, dollar bonds and dollar funding obtained via FX swaps. The bank maximizes returns in a standard portfolio choice problem, yielding a demand for dollars in the FX swap market. The second agent is an arbitrageur, that takes the other end of the FX swap transaction. By borrowing in dollars at a risk-free rate, and lending them in the FX swap market, they make an arbitrage profit equal to the CIP deviation. Arbitrageurs are risk averse, and incur exchange rate risk that rises proportionally with the size of the swap position in the event that the counterparty defaults. An equilibrium in the FX swap market is defined by a market clearing condition; bank demands for dollar funding in the FX swap market are met by a supply of dollars by arbitrageurs.

I model QE as central bank purchases of privately-issued debt, in contrast to conventional QE that focuses on sovereign bond purchases. This allows central bank purchases to directly raise the price of privately issued debt and lower its yield.[3] In turn this compresses domestic credit spreads, defined as domestic bond yields in excess of the risk-free rate. All else equal,

[3] Implicitly, I am assuming private and public sector debt are imperfect substitutes. It is possible, however, for sovereign debt purchases to have a similar effect in causing a decline in bank funding costs. This would be the case if banks are actively issuing sovereign bonds in the secondary market as a source of funding. However, as a notational convenience in the model, I only consider private sector purchases as being able to directly affect the domestic credit spread.

this lowers the synthetic dollar cost of funding, leading the bank to reallocate dollar funding toward FX swaps. Arbitrageurs scale their balance sheet to supply dollars in the FX swap market. To absorb the increased demands, they demand a higher forward premium and profit from the arbitrage trade. Therefore, CIP deviations widen in equilibrium.

To analyze the effects of negative rates, I assume an asymmetric pass-through of the central bank rate to loan and deposit rates. As the central bank rates become negative, loan rates fall, but that deposits rates fall by less because they are bounded below by zero. This squeezes domestic interest rate margins, and the risk-adjusted return on dollar assets therefore increases relative to the risk-adjusted return on domestic assets. Banks consequently shift the composition of their portfolios toward additional dollar assets. For banks constrained in direct dollar funding, this results in an increased demand for dollars obtained via FX swaps. Arbitrageurs absorb the increased demands for dollar funding by increasing the forward premium of the arbitrage trade, causing CIP deviations to widen. The effects on prices are thus directionally the same as in the case of QE.

I proceed to empirical evidence to support model predictions. To construct a surprise measure of monetary policy, I compute interest rate futures around scheduled monetary announcements of the ECB, BOJ and SNB. The identifying assumption is that changes in interest rate futures on announcement days respond only to monetary news. I estimate a panel regression framework in which I test the aggregate effect of monetary surprises across the term structure of CIP deviations for the euro/$, chf/$ and yen/$ pairs. In particular, I test for a regression discontinuity in the sensitivity of CIP deviations to monetary surprises, with the model predicting a higher sensitivity during the period of unconventional monetary policy. Consistent with the model prediction, I find a 1 basis point expansionary monetary surprise by the ECB, SNB and BOJ leads to a widening of CIP deviations by approximately 0.3 to 0.8 basis points for all 3 pairs during the period of unconventional monetary policy. This result is robust to using alternative benchmarks, with similar results for a CIP deviation based on LIBOR or Treasury rates. Second, I test the model prediction that QE led to a decline in euro/$, chf/$ and yen/$ credit spreads induced by asset purchase programs, and led to a widening of CIP deviations. Using scheduled monetary announcements as an instrument for credit spreads, I find that a 1 basis point decline in credit spreads leads to estimates ranging between a 0.5 to 1.4 basis point widening of CIP deviations.

My evidence has focused on significant price effects through adjustment of CIP deviations. In addition, the model predicts that both QE and negative interest rates lead banks in the Eurozone, Japan and Switzerland to reallocate dollar funding toward FX swaps. To test this, I construct a novel measure of FX swaps held by banks using balance sheet data from the Chicago Federal Reserve Call Reports. This dataset contains information on U.S. subsidiaries of Eurozone, Japanese and Swiss banks. The specific balance sheet item I use is interoffice flows, which are defined as net borrowings of the U.S. subsidiary from the parent. For the purposes of my analysis, I assume interoffice flows represent borrowings in euros, swiss francs and yen that are swapped into dollars. This is plausible given U.S. based subsidiaries are likely operating a dollar balance sheet, and the parent operates a balance sheet primarily in domestic currency. Based on this data, I find that a decline in domestic credit spreads causes a rise in the share of total assets funded by interoffice flows. Statistically, a 1 per cent (100 basis point) decline in credit spreads leads to a 20 per cent increase in the ratio of dollar funding sourced via FX swaps during the period of unconventional policy. This is consistent with the model, which predicts a reallocation of dollar funding toward FX swaps in response to QE. I validate the result with further robustness checks, by finding the effects hold when instrumenting for credit spreads using a measure of QE, and checking that there are no effects of credit spreads for a set of countries that did not undergo unconventional monetary policy.

Related Literature. Since 2008, there have been a number of proposed factors to explain CIP deviations. They can be divided broadly into two strands, factors that stress CIP deviations are predominantly driven by constraints on the supply of dollars available for FX swaps, and factors that stress the demand for dollar funding by cross-border banks. On the supply front, explanations range from rising counterparty risk during the financial crisis Baba and Packer (2009), rising balance sheet costs and regulatory requirements limiting arbitrage capital (Du et al., 2018a; Liao, 2020; Bräuning and Puria, 2017; Cenedese et al., 2019; Anderson et al., 2019; Correa et al., 2020), the strengthening of the dollar in limiting risk bearing capacity (Avdjiev et al., 2016), and rising bid-ask spreads (Pinnington and Shamloo, 2016). Within the literature on supply factors, the most compelling evidence is significant rises in short-term (<3 month) CIP deviations at quarter-ends as banks off-load their holdings of short-term swap contracts (Du et al., 2018a). Similarly, Cenedese et al. (2019) use micro-level evidence and show that dealers that are more leveraged are more sensitive to structural imbalances in the FX swap market, and price significantly higher forward premia, and CIP deviations.

A second strand deals with demand side factors for dollar funding in the FX swap market. This includes the impact of monetary policies, (Bahaj and Reis, 2018; Iida et al., 2016; Borio et al., 2016; Dedola et al., 2017; Du et al., 2018a; Bräuning and Ivashina, 2017; Andersen et al., 2019), shocks to dollar funding for European banks during the sovereign debt crisis (Ivashina et al., 2015), and differences in funding costs across currencies (Syrstad, 2018; Rime et al., 2017; Liao, 2020; Kohler and Müller, 2018). I make two empirical contributions to this literature. First, I use market-based measures of underlying interest rate futures around monetary announcements and document a systematic effect of monetary surprises on CIP deviations. Second, I provide evidence on quantities, using data on interoffice flows of U.S. subsidiaries of banks in the Euro area, Japan and Switzerland. Taking these as a proxy for holdings of FX swaps, I find an increase in the share of dollar funding sourced via FX swaps in response to a decline in domestic funding costs.

I also contribute to a recent literature on modeling CIP deviations. These models focus on factors increasing limits to arbitrage, either by imposing an outside cost of capital (Ivashina et al., 2015), or by tightening balance sheet constraints of arbitrageurs supplying dollars in the FX swap market (Liao, 2020; Liao and Zhang, 2020; Gabaix and Maggiori, 2015; Avdjiev et al., 2016; Sushko et al., 2017; Malamud and Schrimpf, 2018; Fang and Liu, 2019), segmented markets (Vayanos and Vila, 2009; Greenwood et al., 2019; Gourinchas et al., 2019) or through an affine general equilibrium asset pricing model (Du et al., 2019; Augustin et al., 2020; Hebert et al., 2018). I contribute to this literature by formalizing the channels through which monetary policy can cause a rise in bank demands for dollar funding in the FX swap market. In particular, I examine the role of both negative interest rates and QE and show how these policies affect the trade-off between direct and synthetic dollar funding via FX swaps. In the optimal allocation, direct and synthetic dollar funding costs are equated. This gives rise to a condition in which the CIP deviation reflects differences in dollar and domestic credit spreads.

My paper also draws on an empirical literature on the effects of unconventional monetary policy on both funding costs and bank profitability. Studies have shown that both corporate and sovereign bond purchase programs have an effect in reducing domestic bond yields (Abidi et al., 2017; Koijen et al., 2017), and the impact of negative interest rates on bank profitability (Ampudia and Van den Heuvel, 2018; Altavilla et al., 2018; Borio and Gambacorta, 2017; Lopez et al., 2018; Claessens et al., 2018; Ulate, 2018; Brunnermeier and Koby, 2016). For example, Abidi et al. (2017) find that the corporate asset purchase program (CSPP) implemented by the ECB in 2016 led to a decline in yields of approximately 15 basis points for bonds that satisfied the conditions for purchase.[4] This evidence motivates my assumption that the effects of QE are via reducing domestic credit spreads, which in turn causes the bank to substitute toward dollar funding sourced via FX swaps. The literature on negative rates find evidence on a decline in net interest income. This supports the channel of negative interest rates in my paper, as my theory is that a decline in a bank's domestic net interest income then causes a rebalancing of the portfolio to hold more dollar assets. To hedge the balance sheet, this in turn causes a rise in dollar funding via FX swaps.

Finally, my paper speaks to the rising role of the dollar in cross-border banking and mutual fund holdings (Bergant et al., 2018; Maggiori et al., 2020; Goldstein et al., 2018). In Bergant et al. (2018),they find asset purchase programs by the ECB in 2016 led banks in the Eurozone to significantly increase their exposure to US dollar denominated assets. Similarly, Maggiori et al.

[4]They use a regression discontinuity design, in which they compare bonds that are accepted by CSPP to bonds that are similarly rated but just below the threshold to be eligible for CSPP. The identifying assumption is that the classification of bonds by credit standards are exogenous to macroeconomic conditions and other shocks that affect yields.

(2020) document a secular trend since 2008 of rising dollar and falling euro share based on data on mutual fund portfolios. The findings of these papers support a general trend of portfolio rebalancing toward dollar assets in both the corporate and financial sector. This supports the portfolio rebalancing channel, in which negative rates causes a rebalancing toward dollar assets, which then creates a hedging demand for dollars in the FX swap market.

Roadmap. The rest of the paper is structured as follows. In section 2, I present some stylized facts on the FX swap market. In section 3, I introduce the model, with a setup of the agents, solution for optimal demand and supply of FX swaps, and an analysis of the effects of QE and negative rates on the CIP deviation. In section 4, I provide empirical evidence on the effect of monetary policy announcements on credit spreads and the CIP deviation, as well as cross-sectional evidence on bank holdings of FX swaps. Section 5 concludes.

2 Motivating Facts

The following facts provide empirical evidence that I explore through the lens of the model. The first fact states that there is an observed positive correlation between the level of the interest rate differential and the CIP deviation. Second, I show that once you construct a measure of CIP deviations that takes into account differences in funding costs across currencies, this measure is much closer to parity for the euro/$ and yen/$ pairs. Before I outline the facts, I will briefly cover two important definitions, how CIP deviations are measured, and FX swaps.

Covered interest rate parity

Covered interest rate parity (CIP) states that two assets with identical characteristics in terms of credit risk and maturity, but denominated in different currencies, have the same rate of return after accounting for exchange rate risk using a forward contract. To illustrate, let us consider an investor that can borrow at the risk-free rate in dollars or euros. The total cost of borrowing 1 dollar directly is $1 + r^f_\$$. Alternatively, the investor can borrow dollars via the FX swap market. To do so, they borrow $\frac{1}{S}$ euros, where S is the quotation in dollars per euro. The total cost in euros is then $\frac{1+r^f_d}{S}$. They then hedge exchange rate risk with a forward contract, which gives a synthetic dollar cost of $\frac{F}{S}(1 + r^f_d)$. The CIP deviation is defined as the difference between the direct and synthetic dollar borrowing cost, whichI formally state in equation 1.

$$\Delta = \underbrace{1 + r^f_\$}_{\text{direct}} - \underbrace{\frac{F}{S}(1 + r^f_d)}_{\text{synthetic}} \tag{1}$$

Since 2008, European, Swiss and Japanese Banks have been paying a a higher synthetic dollar cost to borrow dollars in the FX swap market, and the CIP deviation can therefore be interpreted as a synthetic dollar borrowing premium.

Foreign exchange swaps

Foreign exchange swaps, also known as spot-forward contracts, are used by banks and corporates to hedge balance sheet risk. To give perspective on how widespread it is used in financial markets, foreign exchange swaps are the most traded foreign exchange instrument worldwide, with a turnover of approximately 3.2 Trillion USD. This accounts for nearly half of global turnover of 6.6 Trillion USD based on the BIS triennial survey, with spot foreign exchange accounting for only 2.0 Trilion USD.

A bank may hedge the FX exposure due to a mismatch of their currency assets or liabilities, with evidence in Borio et al. (2016) that Japanese banks have significantly higher dollar assets than liabilities, causing them to turn to the FX swap market for dollar funding. [5] I illustrate the legs of the FX swap in Figure 3, using the Euro and USD as the currencies of exchange. In the first leg of the contract, the customer exchanges a principal of X Euros at the current spot rate S dollars per Euro. The customer receives SX Dollars. Both parties then agree to re-exchange the principals at maturity at a specified forward rate, this is known as the forward leg of the contract. The customer receives their X Euros, and the dealer then receives FX Dollars, where F is the forward rate of the contract.

[INSERT FIGURE 3 ABOUT HERE]

At maturities of greater than 3 months, the predominant risk hedging instrument is a cross-currency swap. A cross-currency swap begins with an exchange of principals at a spot rate, whichI illustrate in Figure 4. For illustration, let us suppose the customer engages in a 10 year swap, with the customer receiving SX Dollars and the dealer receiving X Euros as before. For every 3 months until maturity, the customer pays 3 month USD LIBOR interest payments, and the dealer in return pays 3 month Euro LIBOR plus the addition of the cross-currency basis. At maturity of the contract, the principals are then re-exchanged at the initial spot rate. The dealer of a cross-currency swap sets the cross-currency basis Δ.

[INSERT FIGURE 4 ABOUT HERE]

In this paper , I deal primarily with cross-currency swaps. This is the primary use of hedging for banks with long-term funding, and is more applicable in our setting, which considers a U.S. subsidiary of a Euro area, Japan or Swiss Bank considering long term funding. In particular, QE programs, through the lens of the model, impacts long term funding costs. Therefore

[5] Similarly, a corporate may hedge the currency mismatch of their cash flows, for example if a European corporate has profits in dollars from their offshore activities, they will hedge the Foreign exchange risk by swapping their dollar receivables with euros.

the impact of monetary policies are more pronounced on CIP deviations at longer maturities, whereas other factors, such as regulatory constraints, may play a role for short-term FX swaps.[6]

Fact #1 *In the cross-section, high interest rate currencies have a more positive CIP deviation.*

Examining a set of advanced economies, countries with a higher interest rate typically have a more positive CIP deviation (Figure 5). This result can be explained through the hedging demands of banks pursing a carry trade strategy; by borrowing in low interest rate currencies and going long in high interest rate currencies. For example, consider a bank borrowing in yen, and taking a long position in USD. If the bank hedges the FX risk of the carry trade, they need to swap their yen liabilities into USD. An arbitrageur can provide dollars in the FX swap market by borrowing in dollars at a risk-free interbank rate, swap dollars into yen and invest in the equivalent yen denominated asset. This will earn a premium equal to the absolute value of the yen/$ CIP deviation. If there are limits to arbitrage, the hedging demands by banks for dollars in the FX swap market cannot be fully absorbed by arbitrageurs, resulting in an increase in the premium at which yen is swapped into dollars. The role of hedging demand in explaining the cross-section of CIP deviations is also discussed in Borio et al. (2016).

The relationship in Figure 5 supports the theory of negative interest rates in the model. A higher interest rate differential, all else equal, increases the relative return on dollar assets, which are funded by dollars sourced via FX swaps. The theory is also consistent with high interest rate currencies (typically the AUD and NZD) as having a positive cross-currency basis, because the carry trades are more profitable, leading to a greater hedging demand. The non-zero slope in Figure 5 is also an indication that limits to arbitrage matter. Therefore, forces inhibiting the supply of dollars in the FX swap market can account for the non-zero slope. [7]

[INSERT FIGURE 5 ABOUT HERE]

Fact #2 *CIP deviations are much smaller when accounting for differences in funding costs across currencies*

The channel of QE works through easing domestic funding costs. In other words, following a QE asset purchase program, a domestic bank can now obtain liquidity in euros, Swiss francs and yen with relative ease compared to direct dollar funding. Therefore, CIP deviations based on an interbank rate like LIBOR and the overnight index swap (OIS) rate do not take into account the true funding costs in the respective currencies of the swap. To illustrate, suppose the synthetic

[6]See Du et al. (2018a) for effects of quarter-end reporting regulations on CIP deviations of short-term maturities.

[7]The relationship in Figure 5 is based on taking an average of the CIP deviation and interest-rate differential over the period 2014-2018. I can obtain a similar but weakly positive relationship for the period since 2008, however the slope is close to zero for the pre-2008 period.

cost of issuing a domestic currency bond is equal to the domestic credit spread ℓ_d, defined as the excess of the bond yield above a risk-free rate, plus the CIP deviation Δ (expressed as an absolute value as it is the premium paid to swap domestic currency into dollars). The cost of issuing a dollar bond is governed by the dollar credit spread, ℓ_d. In equation 2 , I equate the synthetic and direct dollar funding costs. This gives us an expression for the CIP deviation as reflecting differences in funding costs across currencies.[8]

$$\ell_d + |\Delta| = \ell_\$ \implies |\Delta| = \ell_\$ - \ell_d \tag{2}$$

To substantiate this relationship, in Figure 6, I compare a measure of the 5 year CIP deviation for the euro/$ and yen/$ pairs, against a measure that includes the differences in funding costs (by plotting $\ell_\$ - \ell_d - |\Delta|$). To account for funding costs, I use data on bank credit spreads obtained from Norges Bank for a set of A1 rated French and Japanese banks. Once the CIP deviation is adjusted for differences in funding costs, these deviations are smaller in magnitude and closer to parity. This finding is consistent with other papers that document CIP deviations in risk-free rates are much smaller when taking into account the funding liquidity premium of the USD (Syrstad, 2018; Rime et al., 2017; Liao, 2020; Kohler and Müller, 2018).

[INSERT FIGURE 6 ABOUT HERE]

3 Model

I introduce a model with two agents, a domestic (non U.S.) bank and arbitrageurs. To simplify the setting, I consider a bank with a parent-subsidiary structure. The parent invests in domestic assets at home, or in dollar assets through the U.S. subsidiary. To fund the dollar asset position, the subsidiary can borrow dollars directly or synthetically, by borrowing domestic currency from the parent, and then swapping the proceeds into dollars in the FX swap market. In the equilibrium allocation, the bank is indifferent between direct and synthetic dollar borrowing.

Arbitrageurs are the intermediaries through which banks settle transactions in the FX swap market. As they take the other end of the swap, they supply dollars in exchange for the domestic currency. Arbitrageurs are risk averse, and in the event of default, incur exchange rate risk that rises with the size of the swap position. This imposes a limit to arbitrage, and means they satisfy a growing demand for dollar funding from banks by resetting the forward

[8] An alternative way of expressing equation 2 is as follows. The dollar bond cost is $r^f_\$ + \ell_\$$. The synthetic dollar bond cost is the domestic bond yield plus the forward premium, $r^f_d + \ell_d + f - s$. Equating the direct and synthetic dollar cost, $r^f_d + \ell_d + f - s = r^f_\$ + \ell_\$$, and using the fact that the CIP deviation $|\Delta| = f - s + r^f_d - r^f_\$$, gives us equation 2.

rate, and therefore increase the premium banks pay to swap domestic currency into dollars. In equilibrium, market clearing requires a forward rate such that arbitrageurs fully absorb the demands for dollar funding by banks.

Arbitrageur

Following Sushko et al. (2017), I model a arbitrageur that has expected exponential utility over next period wealth W_{t+1}. Formally, I define $U_t = E_t\left[-e^{-\rho W_{t+1}}\right]$, where ρ is a measure of risk aversion. The arbitrageur lends his dollar wealth in the FX swap market. The evolution of next period wealth W_{t+1} is provided in equation 3. When wealth is supplied in a FX swap, where principals are exchanged at a specified spot exchange rate s_t dollars per unit of domestic currency, with an agreement to re-exchange principals at maturity at forward rate f_t. The arbitrageur then earns the profit of the forward premium plus the return on the domestic currency during the period of the forward contract, this is the second term in equation 3. In addition, the arbitrageur bears exchange rate risk. In the event of a default with a given probability θ, the arbitrageur does not earn the forward premium $f_t - s_t$ on the trade, but instead earns a stochastic return based on the realized spot rate exchange rate s_{t+1}. This gives rise to the third term, which is the payoff to the arbitrageur in the default state.

$$W_{t+1} = W_t(1 + r^f_\$) + (1-\theta)x_{\$,t}\underbrace{(f_t - s_t + r^f_d - r^f_\$)}_{\text{payoff if no default}} + \theta x_{\$,t}\underbrace{(s_{t+1} - s_t + r^f_d - r^f_\$)}_{\text{payoff if default}} \tag{3}$$

The CIP deviation, Δ_t, is defined as the excess of the forward premium over the interest rate differential, $\Delta_t = f_t - s_t - (r^f_\$ - r^f_d)$. Using this, I can re-express the evolution of wealth in equation 4 as the sum of returns on initial wealth, CIP arbitrage profits and the difference between the actual spot rate at t+1 and the forward rate.

$$W_{t+1} = \underbrace{W_t(1 + r^f_\$)}_{\text{return on wealth}} + \underbrace{x_{\$,t}\Delta_t}_{\text{cip arbitrage}} + \underbrace{\theta x_{\$,t}(s_{t+1} - f_t)}_{\text{counterparty risk}} \tag{4}$$

I assume $s_{t+1} \sim N(f_t, \sigma^2_s)$. Drawing on the properties of the exponential distribution, maximizing the log of expected utility is equivalent to mean-variance preferences over wealth[9].

$$\max_{x_{\$,t}} \rho\left(W_t(1 + r^f_\$) + x_{\$,t}\Delta_t - \frac{1}{2}\rho\theta^2 x^2_{\$,t}\sigma^2\right) \tag{5}$$

[9] To derive this formula, note that $U_t = -e^{-\rho\left(W_t(1+r^f_\$)+x_{\$,t}\Delta_t-\theta x_{\$,t}f_t\right)}E_t e^{-\rho\theta x_{\$,t}s_{t+1}}$. Using the properties of the exponential distribution, $E_t e^{-\rho\theta x_{\$,t}s_{t+1}} = e^{-\rho\theta x_{\$,t}f_t - \frac{1}{2}\rho\theta^2 x^2_{\$,t}\sigma^2}$. Taking logs and simplifying yields the expression in equation 5.

The optimal supply of dollars by a arbitrageur is given by $x^*_{\$t}$.

$$x^*_{\$t} = \frac{\Delta_t}{\rho\theta^2\sigma^2} \tag{6}$$

Taking the CIP deviation as given, a rise in counterparty risk, exchange rate risk and risk aversion lead to a lower supply of dollars.[10]

Bank

I consider an International bank with a parent-subsidiary structure. The parent operates the domestic currency side of the balance sheet, and invests in domestic assets, A_d, and holds domestic deposits D. Meanwhile, the bank's U.S. subsidiary is in charge of the dollar currency side of the balance sheet. The subsidiary has access to direct dollar funding $B_\$$, and invests in dollar assets $A_\$$. The parent can provide domestic currency funding to its U.S. subsidiary, which are then swapped into dollars to fund the subsidiary's dollar balance sheet. I denote this as the level of synthetic dollar funding $x^D_\$$. A stylized representation of the consolidated balance sheet is illustrated in Figure 7. Critically, the parent-subsidiary structure maintains a currency neutral balance sheet with zero exchange rate risk.

[INSERT FIGURE 7 ABOUT HERE]

The asset returns are stochastic with distributions $\tilde{y}_d \sim N(y_d, \sigma^2_d)$ and $\tilde{y}_\$ \sim N(y_\$, \sigma^2_\$)$, and with covariance $\sigma_{d,s}$. The borrowing cost on domestic deposits c_d is assumed fixed. The cost of direct dollar borrowing is the sum of the dollar credit spread $l_\$$ and the risk-free rate in dollar borrowing, $r^f_\$$. To obtain dollars synthetically, the bank first issues a domestic currency bond with a yield equal to the addition of the credit spread l_d and a risk-free rate r^f_d. It then engages in a FX swap, paying the forward premium $f - s$ to swap domestic currency into dollars. In addition to these costs, I also impose an imperfect substitutability between direct and synthetic dollar funding, by imposing a convex hedging cost in swapping domestic currency into dollars via FX swaps.

Definition [Convex Hedging Cost]: *Hedging cost in FX swap $F(x^D_\$)$ is convex, with $F'(.) > 0$ and $F''(.) > 0$.*

To motivate the addition of convex hedging costs, I find empirical evidence in Abbassi and Bräuning (2018), that find banks pay a dollar borrowing premium increasing in the size of their dollar funding gap, which is the amount of dollars obtained via FX swaps to hedge

[10] As the subject of this paper is to focus on demand side factors, the parameters governing supply are assumed constant. However, in times of severe stress in interbank markets, rises in counterparty risk and risk aversion are critical to understand the widening of the euro/\$, yen/\$ and chf/\$ CIP deviation during the financial crisis of 2008, and subsequently in the euro crisis.

currency exposure. [11] Other reasons for a convex hedging cost include the cost of providing dollar collateral that increases with the size of the position, and regulations on the funding of subsidiaries of non U.S. banks, such as the BEAT tax on interoffice funding. [12] The convex hedging cost creates an imperfect substitution between the direct and synthetic sources of dollar funding, allowing for an interior allocation. This is consistent with banks in practice, as U.S. subsidiaries typically have a mix of direct and synthetic dollar funding.[13]

Portfolio Problem

The bank maximizes the value of the portfolio after the realization of asset returns, subject to equations 8,9,10 and 11.

$$\max_{A_{d,t},A_{\$,t},x^D_{\$,t},B_{\$,t},D_{d,t}} V_{t+1} = \tilde{y}_d A_{d,t} + \tilde{y}_\$ A_{\$,t} - (\ell_\$ + r^f_\$)B_{\$,t} - (\ell_{d,t} + r^f_d + f_t - s_t)x^D_{\$,t,} - c_d D_{d,t} - F(x^D_{\$,t}) \tag{7}$$

Subject to

$$a^T \Sigma a \leq \left(\frac{K}{\alpha}\right)^2, a = \begin{bmatrix} A_{d,t} & A_{\$,t} \end{bmatrix}^T \Sigma = \begin{bmatrix} \sigma^2_d & \sigma_{d,\$} \\ \sigma_{d,\$} & \sigma^2_\$ \end{bmatrix} \leq \left(\frac{K}{\alpha}\right)^2 \tag{8}$$

$$K = A_{d,t} + A_{\$,t} - D_{d,t} - B_{\$,t} - x^D_{\$,t} \tag{9}$$

$$A_{\$,t} = x^D_{\$,t} + B_{\$,t} \tag{10}$$

$$B_{\$,t} \leq \gamma K \tag{11}$$

Equation 8 is a value at risk constraint which determines the optimal risk-adjusted weights of domestic and dollar assets. [14] Equation 9 states that bank equity K is the difference between total assets and total liabilities. Equation 10 states that the balance sheet of the bank is currency neutral, consistent with banking regulations that are designed to impose capital charges on banks that have unhedged currency exposure (Abbassi and Bräuning, 2018). Equation 11 is a constraint on dollar denominated debt to be within a fraction γ of bank capital. To justify this

[11] They interpret this result as reflecting a higher shadow cost of capital for a bank with a larger funding gap. This is because regulators impose capital charges on bank balance sheets that have unhedged currency exposure.

[12] For more details on the BEAT tax implemented in 2018, please refer to https://ftalphaville.ft.com/2018/03/23/1521832181000/Cross-currency-basis-feels-the-BEAT/. U.S. subsidiaries have to pay a tax on interoffice funding they obtain from the parent.

[13] In section 4, I find that U.S. subsidiaries of Euro Area, Japan and Swiss banks share of synthetic dollar funding typically have a mix of synthetic and direct dollar funding. See Table 6 for more details.

[14] The use of the value at risk constraint is also found in Avdjiev et al. (2016). The authors consider a setup of a bank that is engaged in supplying dollars in the FX swap market, and has a portfolio of dollar and foreign (euro) assets. My paper takes a different approach, as I am separating the bank and arbitrageur arms. In my model, the bank is demanding dollars via FX swaps, and the arbitrageur is supplying dollars.

constraint, in practice, non U.S. banks direct dollar borrowing is relatively uninsured compared to domestic currency liabilities for a non U.S. bank.[15]

The first order conditions with respect to $A_{d,t}$, $A_{\$,t}$, $x^D_{\$,t}$, $D_{d,t}$ and $B_{\$,t}$ are shown in equations 12 to 15, where the Lagrangian for constraints 8,9,10 and 11 are given by ϕ_t, μ_t λ_t and ξ_t.

$$\begin{array}{l} A_{d,t}: \\ A_{\$,t}: \end{array} \begin{bmatrix} y_d \\ y_\$ \end{bmatrix} - 2\phi_t \Sigma \begin{bmatrix} A_{d,t} \\ A_{\$,t} \end{bmatrix} - \begin{bmatrix} \mu_t \\ \mu_t + \lambda_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{12}$$

$$x^D_{\$,t}: \quad -(\ell_{d,t} + r^f_d + f_t - s_t) - F'(x^D_{\$,t}) + \lambda_t + \mu_t = 0 \tag{13}$$

$$D_{d,t}: \quad -c_d + \mu_t = 0 \tag{14}$$

$$B_{\$,t}: \quad -\ell_\$ - r^f_\$ + \mu_t + \lambda_t - \xi_t = 0 \tag{15}$$

Using equations 13 and 15, I can express the relation between direct and synthetic dollar borrowing costs in equation 16.

$$\underbrace{\ell_{d,t} + r^f_d + f_t - s_t + F'(x^D_{\$,t})}_{\text{synthetic dollar cost}} = \underbrace{\ell_{\$,t} + r^f_\$ + \xi_t}_{\text{direct dollar cost}} \tag{16}$$

This condition can be interpreted as a law of one price in bond issuance, after covering exchange rate risk with a forward contract. Using the definition of the CIP deviation as the excess of the forward premium over the interest rate differential, $\Delta_t = f_t - s_t + r^f_d - r^f_\$$, I can express the CIP deviation as the difference between dollar and domestic credit spreads, stated in equation 17. CIP deviations (measured in a risk-free rate) reflect differences in funding costs across currencies, consistent with evidence in the following papers (Rime et al., 2017; Liao, 2020; Kohler and Müller, 2018).

$$\Delta_t = \ell_{\$,t} - \ell_{d,t} + \xi_t - F'(x^D_{\$,t}) \tag{17}$$

I define $R = \begin{bmatrix} y_d - c_d & y_\$ - (\ell_{d,t} + \Delta_t + F'(x^D_{\$,t})) \end{bmatrix}^T$. The bank holds an optimal level of dollar and domestic assets that is proportional to the Sharpe ratio of the asset (equation 18). The solution for the optimal allocation of direct and synthetic dollar funding is provided in equation 19, and dollar borrowing is similarly defined in equation 20. Critically, the allocation is dependent on whether the bank is in the constrained or unconstrained regions of dollar borrowing. In the constrained region, the bank borrows dollars directly up to a fraction of equity, with the residual dollar funding coming from FX swaps. Alternatively, in the unconstrained region, the bank optimises its level of swap funding, and direct dollar funding is the difference

[15] For example, non U.S. banks typically have lower credit ratings and do not have the equivalent level of deposit insurance as a U.S. domiciled bank.

between total dollar assets and synthetic funding.

$$\begin{bmatrix} A_{d,t} \\ A_{\$,t} \end{bmatrix} = \frac{K}{\alpha\sqrt{R^T\Sigma^{-1}R}}\Sigma^{-1}R \tag{18}$$

$$x^D_{\$,t} = \begin{cases} F'^{-1}\left(\ell_\$ - (\ell_d + \Delta)\right) & \xi_t = 0 \text{ [unconstrained]} \\ A_{\$,t} - \gamma K & \xi_t \neq 0 \text{ [constrained]} \end{cases} \tag{19}$$

$$B^D_{\$,t} = \begin{cases} A_{\$,t} - \frac{\ell_\$ - (\ell + \Delta)}{\ell'_d(x^D_{\$,t})} & \xi_t = 0 \text{ [unconstrained]} \\ \gamma K & \xi_t \neq 0 \text{ [constrained]} \end{cases} \tag{20}$$

Equilibrium

The equilibrium is defined by a simple market clearing condition. On the demand side, the bank optimises its demands for dollar funding through maximising the value of its portfolio. On the supply side, there are N symmetric arbitrageurs with the same risk aversion, that each supply $x^D_{j,\$}$ determined in equation 6. The equilibrium forward price of the swap is such that bank demands for dollar funding are equated to arbitrageur supply. I define the equilibrium formally below.

Definition [Equilibrium]: *An equilibrium in the FX swap market in period t is characterized by the following:*

1. *Arbitrageurs supply $x^*_{\$,t}$ dollars, optimizing mean-variance preferences over wealth (equation 6).*
2. *A representative bank demands $x^D_{\$,t}$ dollars, optimizing the value of their portfolio (equation 19).*
3. *The arbitrageur sets Δ_t such that bank demands for dollar funding are directly met by arbitrageur supply. $x^D_{\$,t}(\Delta_t) = Nx^*_{\$,t}(\Delta_t)$*

I provide a graphical illustration of the equilibrium in Figure 8. The supply of arbitrage capital is positively related to the CIP deviation Δ, indicating limits to arbitrage. The focus of this paper is to examine demand side factors. QE affects the demand for dollar funding through affecting credit spreads, which in turn determine the cost of synthetic dollar funding. Negative rates, in contrast, affect the relative return on domestic assets, and cause a portfolio rebalancing to hold dollar assets. Both factors lead to an excess demand for synthetic dollar funding, and a widening of CIP deviations. I capture this in Figure 8 through a shift of demand, from the initial equilibrium $[x_{\$,0}, \Delta_0]$ to the final equilibrium of $[x_{\$,1}, \Delta_1]$. I formalise each of these channels subsequently in propositions 1 and 2.

[INSERT FIGURE 8 ABOUT HERE]

Quantitative Easing

To outline the effect of QE, I introduce a parameter M_t which measures an increase in central bank asset purchases.

Definition [Domestic credit spread]: *The domestic credit spread ℓ_d is a function of central bank asset purchases M_t, $\ell_{d,t} = G(M_t)\bar{\ell}_{d,t}$, where $G'(.) < 0$.*

The relationship between central bank asset purchases and the domestic credit spread is consistent with models of preferred habitat imperfect arbitrage in segmented markets, in which the relative decline in the supply of private bonds raises prices and lowers yields (Vayanos and Vila, 2009; Williamson et al., 2017; Gourinchas et al., 2019). Through the lens of preferred habitat theory, central bank purchases of private sector debt reduce the effective market supply of private debt. A decline in market supply requires a fall in bond yields to induce banks to increase supply to the market. The corresponding decline in bond yields compresses domestic credit spread ℓ_d, defined as the difference between the bond yield and a risk-free rate.

A formal statement of the effects of QE is provided in proposition 1. The decline in domestic credit spreads causes a decline in synthetic dollar borrowing costs, all else equal, and causes the bank to reallocate dollar funding toward FX swaps. To absorb excess demands, arbitrageurs increase the premium to swap domestic currency into dollars.

Proposition 1 [Quantitative Easing]: *Assume the domestic credit spread is $\ell_d = G(M_t)\bar{\ell}_{d,t}$, where $G'(.) < 0$. Define $R = \begin{bmatrix} R_d & R_\$ \end{bmatrix}^T$, where $R_d = y_d - c_d$, $R_\$ = y_\$ - (\ell_{d,t} + r^f_\$ + \Delta_t + F'(x^D_\$))$ are the excess returns on domestic and dollar assets. An unanticipated increase in central bank asset purchases M_t in period 1 leads to:*

1. *A decline in domestic credit spreads ℓ_d, and an increase in $x^D_\$$ to equate synthetic and direct costs of funding.*

2. *In equilibrium, arbitrageurs increase the premium at which domestic currency is swapped into dollars. The CIP deviation widens for banks in both the unconstrained and constrained regions of direct dollar borrowing,*

$$\frac{\partial \Delta}{\partial M} = \begin{cases} -\dfrac{\bar{\ell}_d G'(M)}{1+\frac{NF''(x^D_\$)}{\theta\rho\sigma^2_s}} > 0 & ,\xi_t = 0 \text{ [unconstrained]} \\ -\dfrac{\bar{\ell}_d G'(M)}{1+\frac{NF''(x^D_\$)}{\theta\rho\sigma^2_s}+\frac{N}{\theta\rho\sigma^2_s A_\$}\left(\frac{1}{\frac{1}{R_\$}+\frac{R_\$}{R^T R}}\right)} > 0 & ,\xi_t \neq 0 \text{ [constrained]} \end{cases}$$

Proof: See Appendix A

To further illustrate the effects of QE on bank demands for direct and synthetic dollar funding, Figure 9 characterizes the bank's new equilibrium allocation of dollar funding for varying levels of γ . The threshold γ^* in equation 21 is the boundary at which a bank transitions from the unconstrained to constrained regions of direct dollar borrowing.

$$\gamma^* = \frac{A_\$ - F'^{-1}(\ell_\$ - (\ell_d + \Delta))}{K} \tag{21}$$

In Figure 9, the total increase in bank demands for dollar funding after QE is denoted by the area $x^D_{\$,1} - x^D_{\$,0}$. The increase in bank demands for banks in the unconstrained region of dollar borrowing ($\gamma \geq \gamma^*$) is denoted by area $b + c$. For these banks, the new level of synthetic swap funding is such that the costs of synthetic and direct dollar funding are equalized. A decline in domestic credit spreads is offset by a rise in Δ and a rise in the convex hedging cost. The intuition is provided in equation 22.

$$\Delta_t \uparrow + \ell_{d,t} \downarrow + F'(x^D_{\$,t} \uparrow) \uparrow = \ell_{\$,t} \tag{22}$$

For constrained banks, with $\gamma < \gamma^*$, the increase in synthetic dollar funding is given by area a in Figure 9. Given direct dollar funding is fixed, QE still affects the bank by causing an increase in the excess return on dollar assets, $R_{\$,t} = y_\$ - (\ell_{d,t} + r^f_\$ + \Delta_t + F'(x^D_\$))$. A decline in domestic credit spreads, all else equal, causes a rise in the dollar excess return. The increase in dollar assets is hedged by dollar funding via FX swaps.

[INSERT FIGURE 9 ABOUT HERE]

Negative interest rates

Negative interest rates work through imposing an asymmetric pass-through to loan and deposit rates. I assume simple functional forms for domestic loan and deposit rates. $y_d = r_m + \mu_A$, and $c_d = min\{0, r_m\}$. This assumes a simple pass-through of the central bank rate to loan rates y_d, which are given at a constant mark-up to the central bank rate equal to μ_A. In contrast, deposit rates are equal to the central bank rate when $r_m > 0$, and is bounded below by zero. I motivate this assumption as a zero lower bound on retail deposit rates, given the incentive for households to prefer holding cash in the event retail deposits go below zero.[16]

I formally state the effects of negative interest rates in proposition 2. A decline in r_m in the region $-\mu_A < r_m < 0$ reduces the excess return on domestic assets. The relative decline in

[16]This assumption is validated through a series of empirical papers that document the decline in net interest income in periods of negative interest rates (Altavilla et al., 2018; Borio and Gambacorta, 2017; Lopez et al., 2018; Claessens et al., 2018) theoretical banking models that impose the assumption of differential pass-through to loan and deposit rates (Ulate, 2018; Brunnermeier and Koby, 2016).

domestic asset returns tilts the bank's portfolio toward dollar assets. Increased bank demands for dollar funding are met via FX swaps for sufficiently dollar constrained banks ($\gamma < \gamma^*$ based on equation 21). Arbitrageurs absorb excess demands by increasing the premium banks pay to swap domestic currency into dollars.

Proposition 2 [Negative Rates]: *Assume the bank is in the constrained dollar borrowing region, and domestic loan and deposit rates are given by the functions* $y_d = r_m + \mu_A$, $c_d = min\{0, r_m\}$. *Define* $R = \begin{bmatrix} R_d & R_\$ \end{bmatrix}^T$, *where* $R_d = y_d - c_d$, $R_\$ = y_\$ - (\ell_{d,t} + r^f_\$ + \Delta_t + F'(x^D_\$))$ *are the excess returns on domestic and dollar assets. An unanticipated decline in the policy rate* r_m *in the region* $-\mu_A < r_m < 0$ *by the central bank leads to:*

1. *A decline in domestic excess return* R_d*, and a portfolio rebalancing to hold more dollar assets,* $\frac{\partial A_\$}{\partial r_m} = -\frac{R_d A_\$}{R^T R} < 0$. *Consequently, banks increase their hedging demand for dollar funding via FX swaps.*

2. *In equilibrium, arbitrageurs increase the premium at which domestic currency is swapped into dollars. The CIP deviation widens for banks in the constrained region of dollar borrowing,*

$$\frac{\partial \Delta}{\partial r_m} = \begin{cases} 0 & , \xi_t = 0 \text{ [unconstrained]} \\ -\dfrac{R_d}{\frac{NR^T R}{\rho\theta\sigma^2 A_\$} + \left(1 + \frac{NF''(x^D_\$)}{\theta\rho\sigma^2_s}\right)\left(\frac{R^T R}{R_\$} + R_\$\right)} < 0 & , \xi_t \neq 0 \text{ [constrained]} \end{cases}$$

Proof: See Appendix A

To further illustrate the effects of negative interest rates on bank demands for direct and synthetic dollar funding, Figure 10 characterizes the bank's new equilibrium allocation of dollar funding for varying levels of γ . In Figure 10, the total increase in bank demands for dollar funding after QE is denoted by the area $x^D_{\$,1} - x^D_{\$,0}$. This increase is denoted by area a, and occurs only for constrained banks that hedge the additional demand for dollar assets by borrowing dollars synthetically.

Banks in the unconstrained region ($\gamma > \gamma^*$) can fund additional dollar assets by borrowing dollars directly, this is denoted by area $b + c$ in the diagram. The intuition is simple, for an unconstrained bank, direct and synthetic dollar funding are equal. $\ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_{\$,t}$. Convex hedging costs imply an unconstrained bank will choose to hedge the additional dollar assets via direct dollar funding at the margin.

[INSERT FIGURE 10 ABOUT HERE]

Model extensions

U.S. Monetary Policy

The focus of propositions 1 and 2 were on QE and negative rates implemented by the domestic central bank, that is, the central banks of the Euro Area, Japan and Switzerland. However, through the lens of the model, one can analyse policies by the U.S. Federal Reserve. In particular, the model implies symmetric effects for the effect of QE by the Federal Reserve. U.S. QE lowers dollar funding costs and makes it cheaper to source direct dollar funding, all else equal. This causes a reallocation toward direct dollar funding, reducing demands for FX swap funding. Similarly, while the U.S. did not pursue negative rates, the policy of offering a rate on excess reserves increases incentives for non U.S. banks to borrow at risk-free rates and earn the excess reserve rate with the Federal Reserve, which was significantly used during the 2008-2012 period (Bräuning and Ivashina, 2017). Our focus on negative rates and QE are that they are contemporary to the time period of discussion in this paper, which is to explain the persistence of CIP deviations since 2014.

A final point is to distinguish between conventional and unconventional policies. Conventional policies have been studied in a CIP context, for example see Iida et al. (2016). Through the lens of the model, conventional policy can affect demands for synthetic funding, and in turn CIP deviations, if there is an asymmetric pass-through to loan and deposit rates, which is motivated in discussing negative rates in proposition 2. In principle, any shock to the relative dollar asset return can induce a portfolio rebalancing toward dollar assets, and increase hedging demand for dollars in the FX swap market.

Central bank swap Lines

I outline a further proposition in Appendix B, in which I discuss central bank swap lines. I model a swap line as an additional source of dollar funding, but at a penalty to the risk-free rate. In the optimal allocation, for a sufficiently constrained bank, the cost of synthetic dollar funding is equal to the cost of obtaining funds via the swap line. A decline in the penalty rate increases the incentive for a bank to draw funds from the swap line, reducing demands for dollar funding in the FX swap market, with a consequent decline in CIP deviations. Empirical support for the effects of a decline in the penalty rate is found in Bahaj and Reis (2018).[17] They present quantitative evidence of a decline in CIP deviations when the Federal Reserve reduced the penalty rate on swap line borrowings by 50 basis points on November 30, 2011.

[17]For further empirical evidence on the effects of CIP deviations, see the following papers (Fleming and Klagge, 2010; Goldberg et al., 2011), and for a general equilibrium model of CIP deviations and swap lines, (Eguren Martin, 2020).

Quantitative Exercise

I conduct a simple numerical exercise to test the validity of the model in Appendix C. I estimate the parameters based on setting a pre-crisis CIP deviation of approximately 5 basis points. I calibrate the sensitivity of credit spreads to asset purchases based on estimates of the corporate asset purchase program of the ECB by Abidi et al. (2017). Normalizing the money supply in the pre-crisis to one, I find a widening of CIP deviations by 10 basis points for a doubling of the money base. For perspective, the increase in money base of the ECB during this period from 2007 to 2018 is from 1.5 Trillion USD to 4 Trillion USD over this period. Based on the model calibration, approximately 20-30 basis point widening of CIP deviations can be attributed to QE. In contrast, the effects of negative interest rates are less pronounced, a negative interest rate of 1% generates a very marginal widening of CIP deviations from 5 to 7.5 basis points. The mute effect of negative rates can be attributed to the given calibration; total dollar assets are relatively insensitive to changes in domestic and dollar returns.

To conclude, the model has provided a rationale for the effects of QE and negative interest rates on the FX swap market. These policies can be viewed as factors affecting bank demands for dollar funding. QE lowers the relative cost of synthetic dollar funding, causing the bank to reallocate dollar funding toward FX swaps. Negative interest rates increase the relative return on dollar assets, causing the bank to increase dollar funding via FX swaps to hedge exchange rate risk.

4 Empirical Evidence

In response to unconventional monetary policies of the Euro area, Japan and Switzerland, the model makes two key predictions. First, as bank demands for dollar funding in the FX swap market increase, arbitrageurs absorb this excess demand by raising the premium at which euros, Swiss francs and yen are swapped into dollars, causing a widening of the CIP deviation. To identify the effects of monetary policy on the CIP deviation, I examine the change in interest rate futures in a high-frequency window around scheduled monetary announcements of the ECB, BOJ and SNB, and document a widening of CIP deviations around unconventiional monetary announcements.

Second, the model predicts that in response to a decline in domestic credit spreads induced by QE, banks in the Eurozone, Japan and Switzerland substitute toward dollar funding in the FX swap market. To test this, I construct a novel measure of FX swaps held by subsidiaries of banks in the Euro area, Japan and Switzerland, and document an increased share of dollar funding via FX swaps In response to a decline in domestic credit spreads.

Data

Monetary surprises

I use shocks to interest rate futures around scheduled monetary announcements to measure an unanticipated surprise in monetary policy. The identifying assumption is that changes in interest rate futures around announcements is a response to news about monetary policy, and not to other news related to the economy during that period. While the vast majority of the literature deals with computing changes in the Fed funds rate (Kuttner, 2001; Gurkaynak et al., 2004), I construct an equivalent monetary surprise for the policy rates of the ECB, BOJ and SNB, and use interest rate futures for the 90 day rate. I use 90 day contracts as the equivalent to 1 month contracts of the Federal Reserve policy rate are not available, and have been used as an alternative in the following papers (Ranaldo and Rossi, 2010; Brusa et al., 2020).

Intraday changes Δf_t are calculated as the difference between futures f_t δ^- minutes prior to the meeting and δ^+ minutes after the meeting. I use a wide window 15 minutes prior to the announcement and 45 minutes after the announcement, and extend the wide window 105 minutes after the announcement for the ECB. For the U.S., I scale the change in the interest rate futures based on the specific day of the announcement during the month.[18]A summary of interest rate futures for the central bank policy rate is provided in Table 1. Descriptive statistics for the foreign monetary shocks, including contract length, are provided in Table 2.

$$\Delta f_t = f_{t+\delta^+} - f_{t-\delta^-}$$

[INSERT TABLE 1 ABOUT HERE]

[INSERT TABLE 2 ABOUT HERE]

CIP Deviation

To calculate CIP deviations based on a LIBOR benchmark, I use the cross-currency basis, which is quoted for cross-currency swaps, obtained from Bloomberg. The cross-currency basis is available for maturities ranging from 3 months to 30 years. The cross-currency swap is used by the bank as a tool to hedge interest rate risk in foreign currency. [19] The cross-currency basis Δ measures the net cost of engaging in the cross-currency swap. It is expressed in equation

[18] The change in implied 30-day futures of the Federal Funds rate $\triangle f1_t$ must be scaled up by a factor related to the number of days in the month affected by the change, equal to $D_0 - d_0$ days, where d_0 is the announcement day of the month, and D_0 is the number of days in that month.

$$MP_t = \frac{D_0}{D_0 - d_0} \Delta f_t$$

[19] See section 2 for more details on the cross-currency swap

23, where $IRS_{\$,t}$ and $IRS_{d,t}$ are the fixed-floating interest rate swaps in USD and domestic currency respectively, and $f - s$ measures the forward premium. A negative Δ indicates that synthetic dollar borrowing costs exceed local borrowing costs.

$$\Delta_t = \underbrace{IRS_{\$,t}}_{\text{direct}} - \underbrace{(IRS_{d,t} + f_t - s_t)}_{\text{synthetic}} \tag{23}$$

The cross-currency basis measures CIP deviations using a LIBOR benchmark. To construct alternative benchmark using Treasury rates, I use a dataset which computes the CIP deviation for Treasuries provided in Du et al. (2018b). The CIP deviation now reflects differences in the Treasury yields of dollar and domestic currency, $y_{\$,t}$ and $y_{d,t}$, expressed in equation 24.

$$CIP_t^T = \underbrace{y_{\$,t}^T}_{\text{direct}} - \underbrace{\left(y_{d,t}^T + f_t - s_t\right)}_{\text{synthetic}} \tag{24}$$

Substituting the formula for the forward premium in equation 23, I obtain a formula for the CIP deviation in Treasuries that is a function of Treasury yields, interest rate swap yields, and the cross-currency basis in equation 25. Treasury yields, interest rate swap rates and the cross-currency basis are obtained from Bloomberg.

$$CIP_t^T = y_{\$,t}^T - y_{d,t}^T - (IRS_{\$,t} - \Delta_t - IRS_{d,t}) \tag{25}$$

Credit spreads

Law of one price in bond issuance implies a condition in which the CIP deviation reflects differences in credit spreads across currencies. I define credit spreads as the excess of a corporate bond index over a risk-free rate. In the absence of detailed bank bond issuance, I construct a proxy by taking the difference between a corporate bond index and a risk-free rate at the corresponding maturity. I use corporate bond indices available at Bloomberg, which provide a weighted average over tenors ranging from 1Y to 10Y and credit rating. For a measure of the risk-free rate, I use the interest rate swap at a 5 year maturity. [20]

Monetary Surprises and CIP Deviations

High frequency response to negative interest rate announcements

First, I examine the high frequency response of the 1 year cross-currency basis around negative interest rate announcements. The relevant interest rates are the deposit facility rate of the ECB, interest rate on current account balances of the BOJ, and the interest rate on

[20] An interest rate swap swaps a fixed for floating interbank rate. Given there is no collateral risk, it is considered a proxy for the risk-free rate in lending currency in the interbank market

sight deposits of the SNB. In each case, the central bank charges a negative rate of interest on reserves financial institutions hold with the central bank.

The ECB made gradual changes to its deposit facility rate. The first announcement was on 5th of June, 2014, in which the deposit facility rate was introduced at -10 basis points. This was further reduced to -20 basis points on September 4th, 2014. This was unanticipated by financial markets, and led to a 5 basis point decline in 90 day interest rate futures. [21] The SNB implemented a negative rate on sight balances of 25 basis points on 18th December, 2014.[22] The surprise component of the expansionary announcement led to a 10 basis point decline in interest rate futures. BOJ's interest rate announcement on January 29th, 2016 led to a -10 basis point rate on current accounts with the central bank.[23] This move surprised the market for interest rate projections, leading to a decline of 6 basis points in interest rate futures. In Figure 11, there is compelling evidence of a widening of the CIP deviation for the euro/$, chf/$ and yen/$ in response to the negative rate announcements of the ECB, SNB and BOJ, with full adjustment taking place approximately 2 hours after the policy event window.

[INSERT FIGURE 11 ABOUT HERE]

High frequency response to QE announcements

Identifying the high frequency impact of QE announcements is difficult, as QE announcements are typically on the details of a program to be implemented at a later date. QE announcements that led to an immediate expansion of the central bank balance sheet are expansions conducted by the SNB in August and September of 2011. The SNB believed the Swiss Franc to be overvalued, and engaged in a large scale purchase of short-term government securities and an accumulation of foreign reserves. This led to a consequent increase in reserves, also known as sight deposits, held at the central bank.

The announcements of August 3rd, 10th and 17th increased the level of sight deposits from 30 to 200 Billion Swiss Francs. The SNB then decided to set of a floor of 1.20 Swiss Francs per Euro on September 6th, and proposed to intervene in FX markets an indefinite amount to maintain the floor. In a detailed account of these policies (Christensen et al., 2014), the authors find a cumulative 28 basis point decline in long-term Swiss Confederate bond yields. I find evidence of a significant widening of deviations shortly after each announcement, ranging from 10 to 30 basis points in Figure 12.

[21] Press release for ECB announcement: https://www.ecb.europa.eu/press/pr/date/2014/html/pr140904.en.html

[22] Press release for SNB announcement: https://www.snb.ch/en/mmr/reference/pre_20141218/source/pre_20141218.en.pdf. In addition to setting the target for sight balances, the SNB maintains a target for 3 month LIBOR to be between -0.75% and 0.25%.

[23] Press release for BOJ announcement: https://www.boj.or.jp/en/announcements/release_2016/k160129a.pdf

[INSERT FIGURE 12 ABOUT HERE]

Monetary surprises: domestic announcements

I test the effects of monetary announcements using an event study approach, by regressing daily changes of the CIP deviation on monetary shocks of the policy rate. The model prediction is that unconventional monetary policy announcements that are based on QE or negative rates should widen the CIP deviation. I use a panel regression discontinuity framework in equation 26. The dependent variable is the daily change in the CIP deviation, $CIP_{i,t} - CIP_{i,t-1}$ for a currency pair (euro/$, chf/$ or yen/$) of a given maturity i.[24]

$$CIP_{i,t} - CIP_{i,t-1} = \alpha_i + \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t \tag{26}$$

Explanatory variables include the monetary surprise MP_t calculated as the change in interest rate futures around ECB, SNB and BOJ announcements. The fixed effect α_i controls for idiosyncratic variation in CIP deviations across the term structure. I use an indicator $\mathbb{1}[U_{MPt}]$ for the period of unconventional monetary policy, and interact it with the monetary surprise. The regression discontinuity framework allows for a different sensitivity of CIP deviations to monetary surprises in the periods of normal and unconventional monetary policy. The coefficient β measures the sensitivity during conventional periods, and $\beta+\gamma$ measures the sensitivity during unconventional periods.

To select the starting dates of the unconventional period, I set August 2010 for Japan, which coincides with the period when the BOJ introduces its asset purchase program. For the SNB, the relevant starting date is the introduction of a ceiling on the Swiss Franc in August of 2011. In order to prevent an overvalued currency, the SNB intervened in foreign exchange markets by selling Swiss Francs and accumulating foreign reserves. For the ECB, the starting date is June of 2014, when the deposit facility rate first entered negative rates.

The results for the CIP deviation based on the LIBOR benchmark for the euro/$, chf/$ and yen/$ are presented in columns (1), (2) and (3) of Table 3. LIBOR is the most appropriate benchmark rate to use, given the dollar borrowing premium in the model is reflecting differences between direct and synthetic dollar funding costs in the interbank market. The coefficient δ measures the net effect of monetary surprises during the period of unconventional monetary policy ($\delta = \beta + \gamma$ based on the specification in equation 26). Based on the regression estimates, a 1 basis point monetary surprise in the domestic central bank policy rate leads to a 0.5 to 0.8 basis point widening of CIP deviations.

In addition, I also test for the effects of monetary surprises on the CIP deviation measured using treasury rates for the euro/$, chf/$ and yen/$ in columns (4) (5) and (6) of Table 3.

[24]Maturities selected in the panel are $3m, 1Y, 2Y, 5Y$, and $10Y$, typically the most liquid for cross-currency swaps.

Consistent with the model prediction , I find quantitatively similar effects on the Treasury CIP deviation, with 1 basis point monetary surprise leading to a 0.3 to 0.8 basis point widening of CIP deviations based on a Treasury benchmark. This provides support that the forward premium is adjusting in response to excess demands for dollar funding in the FX swap market. This also rules out alternative hypotheses that center on incorrect measurement of benchmark rates to explain the observed response of CIP deviations around monetary announcements.

[INSERT TABLE 3 ABOUT HERE]

Monetary surprises: Federal Reserve announcements

In addition to domestic monetary announcements, I measure the effect of U.S. monetary policy surprises, measured as the change in Fed Fund Futures on scheduled monetary announcements, on CIP deviations. The period of unconventional monetary policy is characterized by 3 QE programs, which involve purchases of mortgage-backed securities as well as long-term maturities. The dates of QE1, QE2, and QE3, were implemented from December 2008 to March 2010, November 2010 to June 2011, and September 2012 to October 2014 respectively. The model predicts that QE programs implemented by the Federal Reserve in the period 2008-2012 should have an equal and opposite effect.

Regression results are reported in Table 4. For the LIBOR based CIP deviations for euro/$, chf/$ and yen/$ in columns (1), (2) and (3), there is a statistically weak effect of Federal Reserve monetary surprises, with elasticities ranging from -0.1 to -0.2 for the euro/$ and yen/$ pairs. In contrast , I find stronger effects for the euro/$, chf/$ and yen/$ CIP deviations based on the Treasury benchmark in columns (4), (5) and (6) in Table 4. The coefficient estimates for the marginal impact of a 1 basis point monetary surprise the period of unconventional monetary policy ($\delta = \beta + \gamma$) range from 0.5 to 1.4 basis points. Following an expansionary QE announcement by the Federal Reserve, there is a narrowing of the Treasury CIP deviation.

In discussing the findings in Table 4, I note that Federal Reserve QE programs of 2008-2012 are public asset purchases, and are less likely to impact corporate credit spreads, compared to private sector programs like the ECB Corporate Securities Purchase Program (CSPP) in 2016. The effects of U.S. QE in narrowing the Treasury CIP deviation are consistent with the following papers (Du et al., 2018b; Jiang et al., 2018a; Greenwood et al., 2019). Theories of the Treasury premium suggest that QE by the Federal Reserve changes the relative supply of safe assets, and in turn compresses the Treasury premium. This is different to the credit channel of private sector QE which is the focus of this paper.

[INSERT TABLE 4 ABOUT HERE]

Domestic credit spreads and CIP deviations

Proposition 1 of the model states that QE causes a decline in domestic credit spreads and a widening of CIP deviations. To construct the corporate credit spread, I use Bloomberg corporate bond indices for the euro, Swiss franc and yen as a measure of corporate yields, and the interest rate swap at an equivalent maturity as a measure of the risk-free rate. The credit spread is then computed as the difference between the corporate bond yield and the risk-free rate. Similar to the prior specification, I use a panel regression discontinuity framework in equation 27. The dependent variable is the daily change in the CIP deviation, $CIP_{i,t} - CIP_{i,t-1}$ for a currency pair (euro/\$, chf/\$ or yen/\$) of a given maturity i.[25]

$$CIP_{i,t} - CIP_{i,t-1} = \alpha_i + \mathbb{1}[U_{MPt}] + \beta \Delta cs_t + \gamma \mathbb{1}[U_{MPt}] \times \Delta cs_t + u_t \tag{27}$$

The explanatory variable is now the daily change in credit spreads as $\Delta cs_t = cs_t - cs_{t-1}$. Similar to the previous specification, I interact the change in credit spreads with an indicator $\mathbb{1}[U_{MPt}]$ for the period of unconventional monetary policy. The regression discontinuity framework allows for a different sensitivity of CIP deviations to monetary surprises in the periods of normal and unconventional monetary policy. The coefficient β measures the sensitivity during conventional periods, and $\beta + \gamma$ measures the sensitivity during unconventional periods.

The regression results for the LIBOR based CIP deviations for euro/\$, chf/\$ and yen/\$ are reported in columns (1), (2) and (3) of Table 5.The coefficient δ measures the net effect of monetary surprises during the period of unconventional monetary policy ($\delta = \beta + \gamma$ based on the specification in equation 26). Based on the regression estimates, a 1 basis point decline in domestic credit spreads leads to a 0.05 to 0.2 basis point widening of CIP deviations.

The significant relationship between credit spreads and CIP deviations can be potentially driven by non-monetary factors. For example, consider a bank subject to a domestic funding shock, in which funding in domestic interbank markets becomes scarce. This shock can simultaneously cause a rise in credit spreads, and a widening of CIP deviations as FX swap markets price default risk. To address endogeneity concerns and identify the change in credit spreads due to monetary factors, I use the constructed measure of monetary surprises as an instrument for credit spreads. The identifying assumption is that monetary surprises in the period of unconventional monetary policy affect CIP deviations through the channel of a decline in domestic credit spreads. The results for the euro/\$, chf/\$ and yen/\$ CIP deviations are presented in columns (4) to (6) in Table 5. The coefficient measuring the net impact of credit spreads increases. A 1 basis point decline in credit spreads leads to a widening of CIP deviations of 0.5 for the euro/\$ pair, 1.4 for the chf/\$ pair and 0.9 for the yen/\$.

[25] Maturities selected in the panel are $3m, 1Y, 2Y, 5Y$, and $10Y$, typically the most liquid for cross-currency swaps.

[INSERT TABLE 5 ABOUT HERE]

Quantity Effects: Evidence on Bank FX Swap Positions

I now turn to evidence based on FX swaps held by Euro Area, Japanese and Swiss banks. Both propositions 1 and 2 of the model predict that QE and negative increase bank excess demands for dollar funding in the FX swap market. To obtain a proxy for FX swap holdings, I use call report data from the Chicago Federal Reserve, which report a large set of balance sheet items of U.S. subsidiaries of foreign (non U.S.) branches.[26] The key variables I use from the call reports are total dollar assets and net flows due to the head office. The variable names in call report data are RCFD2944, *Net due to head office and other related institutions in the U.S. and in foreign countries*, and RCFD2170: *Total assets*, respectively.

Interoffice flows measure funding U.S. subsidiaries of foreign (non U.S) banks receive from head quarters. This corresponds to the parent-subsidiary structure used in the model framework. Interoffice flows is a valid approximation to FX swaps under two assumptions. First, the parent only operates a domestic currency balance sheet. Second, the U.S. subsidiary's balance sheet only consists of dollar assets. When these conditions are met, all interoffice flows are domestic funding received from the parent that is swapped into dollars. Limitations of this approximation include instances where the parent is managing the dollar asset position directly, or if the U.S. subsidiary issues domestic bonds and swaps into dollars without requiring borrowings from the parent. In both cases, interoffice flows are an *understatement* of the true level of dollar funding via FX swaps.

Table 6 documents the share of interoffice funding to total dollar assets for all banks with head quarters in the Euro area, Switzerland, Japan, as well as a set of control countries Australia, Canada and the United Kingdom. The banks are ranked by their average dollar asset position in the period 2014-2017. To examine if there are structural breaks in the share of interoffice flows, I stratify the sample into two periods, 2007-2013, and 2014-2017, and compute the average share of interoffice funding for banks in each period (Table 6). Indeed, interoffice flows as a proportion of total dollar assets is quite high for a set of major non U.S. banks. For example, Deutsche Bank finances up to 60% of its balance sheet of approximately 150 Billion USD through interoffice flows in the period 2014-2017. In contrast, Deutsche only funded 15% of its balance sheet in the former period. Other banks, like Commerzbank and Landesbank, experience a similar trend of relying on interoffice flows to fund its balance sheet in the period 2014-2017.

[INSERT TABLE 6 ABOUT HERE]

[26] The relevant form for non-U.S. bank balance sheet items is the FFIEEC 002. In related work (Correa et al., 2020), the authors infer FX swaps from balance sheet data, however their dataset only covers major U.S. lenders, and not U.S. subsidiaries of Euro area, Japan and Swiss banks which is the focus of this paper.

I test the regression specification in equation 28. The outcome variable is the share of interoffice flows as a proportion of total dollar assets, which I denote S_{ijt}. The U.S. subsidiary j has headquarters in country i, and period t is quarterly.[27]

$$S_{ijt} = \alpha_j + \gamma_t + \beta X_{it} + \gamma X_{it} \times \mathbb{1}[U_{MPt}] + \epsilon_t \tag{28}$$

Explanatory variables X_{it} include the difference between the domestic and US dollar OIS rates, and the domestic corporate credit spread. [28] To test for a difference across periods of conventional and unconventional monetary policy, I interact the explanatory variable with an indicator $\mathbb{1}[U_{MPt}]$ for the period of unconventional monetary policy.[29] In addition, I incorporate time and bank fixed effects. Time fixed effects control for global or US specific factors, as well as changes in US regulations that may impact the relative trade-off between synthetic and dollar funding. For example, policies such as the U.S. excess rate on reserves will be absorbed by time fixed effects.[30] Bank fixed effects absorb idiosyncratic factors such as differences in corporate structure, and bank-specific funding shocks. For example, banks have varying capital requirements and credit ratings. Banks that have varying access to commercial paper markets will cause differences in the fraction of synthetic funding. I choose 2007 as the starting period for the analysis because it coincides with the beginning of CIP deviations in which systematic differences in direct and synthetic dollar funding costs occur. Prior to 2007, it is likely that the share of dollar assets funded by interoffice flows are largely based on other factors, such as corporate structure and regulation.

The model prediction is that a decline in domestic credit spreads, other things equal, causes a reallocation toward synthetic dollar funding. Likewise, lower domestic interest rates should lead to a portfolio rebalancing to hold more dollar assets, which in turn require more synthetic funding. Results for U.S. subsidiaries with head quarters in the Euro area, Japan and Switzerland support these predictions (Table 7). In column (1), a 100 basis point decline in the domestic OIS rate, all else equal, increases the share of synthetic dollar funding by 10 percentage points. In column (2), a decline in credit spreads has a similar quantitative effect. However, the net effect of credit spreads in the period of unconventional monetary policy is much higher. A 100 basis point decline in domestic credit spreads increases the share of synthetic funding

[27] I aggregate all U.S. branches of bank j, by using the dataset variable RSSD9035, which is the parent ID. In most cases, a bank has most of its dollar assets at the New York branch.

[28] OIS rates are obtained from Bloomberg. These rates are a fixed-floating interest rate swap, and are a measure of a risk-free interbank rate.

[29] Refer to the empirical evidence on monetary announcements for more details on the indicator for unconventional periods

[30] The Federal Reserve policy of having an excess rate on reserves is the focus of Bräuning and Ivashina (2017). The authors find that increasing the excess rate on Reserves encouraged non U.S. banks to park reserves at the Federal Reserve. In particular, some banks may have resorted to interoffice funding to accumulate dollar reserves.

by approximately 20 basis points during this period. The higher sensitivity of synthetic dollar funding to credit spreads during the period of QE policies is consistent with the model. This is precisely the time during which domestic credit spreads were compressed. This in turn leads to a decline in the relative cost of synthetic dollar funding and a substitution toward dollar funding via FX swaps.

[INSERT TABLE 7 ABOUT HERE]

A relevant concern with the specification is the endogeneity of domestic credit spreads. Consider a bank subject to a domestic funding shock, in which funding in domestic interbank markets becomes scarce. This shock can cause both a rise in domestic credit spreads, and a decline in the share of synthetic dollar funding as headquarters is less able to provide funding. To address endogeneity, I use the lagged relative growth of the domestic central bank balance sheet as an instrument for domestic credit spreads. The identifying assumption is that QE affects the share of synthetic dollar funding solely through causing domestic credit spreads to decline, and second, I use lagged central bank balance sheet as it is plausibly exogenous to domestic funding shocks in the current period. Column (3) uses the instrument for credit spreads, and find an increase in the effect of credit spreads on the synthetic funding share over the entire period.

A final placebo check is to conduct regressions for a set of banks with headquarters in countries of Australia, Canada and the UK. These countries did not practice unconventional monetary policy, and so the model predicts that it is a relevant benchmark with which to compare the effects. In columns (4) and (5), I find there is no significant effect of interest rates and credit spreads on the share of synthetic dollar funding for these banks.

5 Conclusion

One of the central tenets of international finance is covered interest rate parity, an arbitrage condition that has been consistently violated since the financial crisis of 2008. Initial deviations were due to rises in default risk in interbank markets. But since 2014, rationalizing the consistent violation of an arbitrage condition is difficult, given that default risk in interbank markets has returned to pre-crisis levels, and that the pairs for which deviations are widest, the euro/$, yen/$ and chf/$, are traded in especially deep and liquid markets.

I propose a theory in which the unconventional monetary policies of the ECB, BOJ and SNB explain the persistence of CIP deviations. I model QE as central bank purchases of privately-issued debt. In reducing the market supply of privately-issued debt, QE compresses domestic credit spreads. This reduces the cost of swapping euros, Swiss francs and yen into dollars. Banks therefore reallocate dollar funding toward FX swaps. Negative interest rates for their part cause a relative decline in domestic asset returns. This induces banks to rebalance their portfolios toward dollar assets, which in turn are funded by obtaining dollars via FX swaps. Both policies therefore increase bank demands for swapping euros, Swiss francs and yen into dollars. Risk averse arbitrageurs supply dollars in the FX swap market and absorb the excess demands for dollar funding. Because they face balance sheet risk that rises with the size of the swap position, they raise the premium at which banks swap domestic currency into dollars, widening the CIP deviation.

I then provide empirical evidence to support the predictions of the model. Using an event study approach, I find CIP deviations tend to widen around QE and negative interest rate announcements. Using interoffice flows from call reports, I document a rise in the share of FX swap funding for U.S. subsidiaries of Euro area, Japan and Swiss banks in response to a decline in domestic credit spreads.

This paper has implications for policy and suggestions for future work. First, the daily turnover in FX swap markets amounts to 3.2 Trillion USD, and pairs of the euro/$ and yen/$ account for almost half of the turnover in all FX swaps. With a post 2014 CIP deviation of approximately 50 basis points, this suggests a sizable hedging cost to bank balance sheets that may cause inefficiencies in the bank's portfolio and erode bank profits. Second, the paper points to unconventional monetary policy as a key factor in leading to a structural imbalance for dollar funding in the FX swap market. This implies a tapering of the balance sheet by the ECB, BOJ and SNB, combined with a return to positive interest rates, is necessary for CIP to hold.

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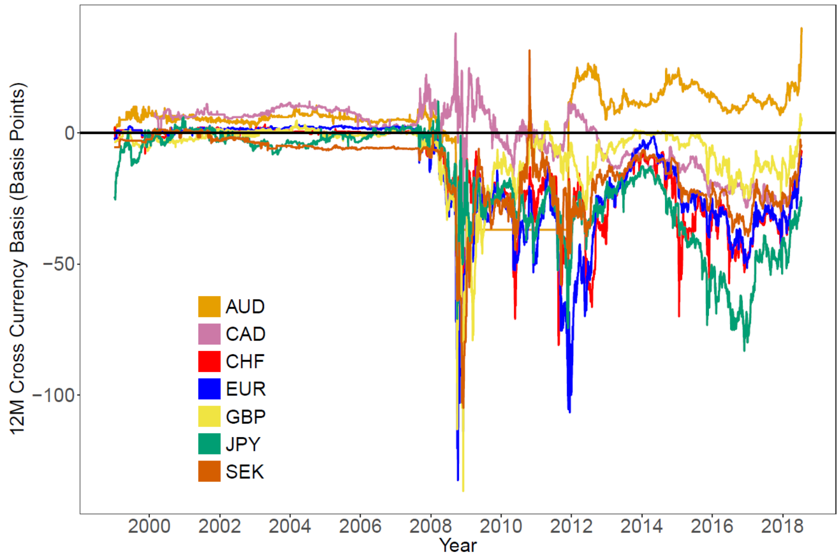
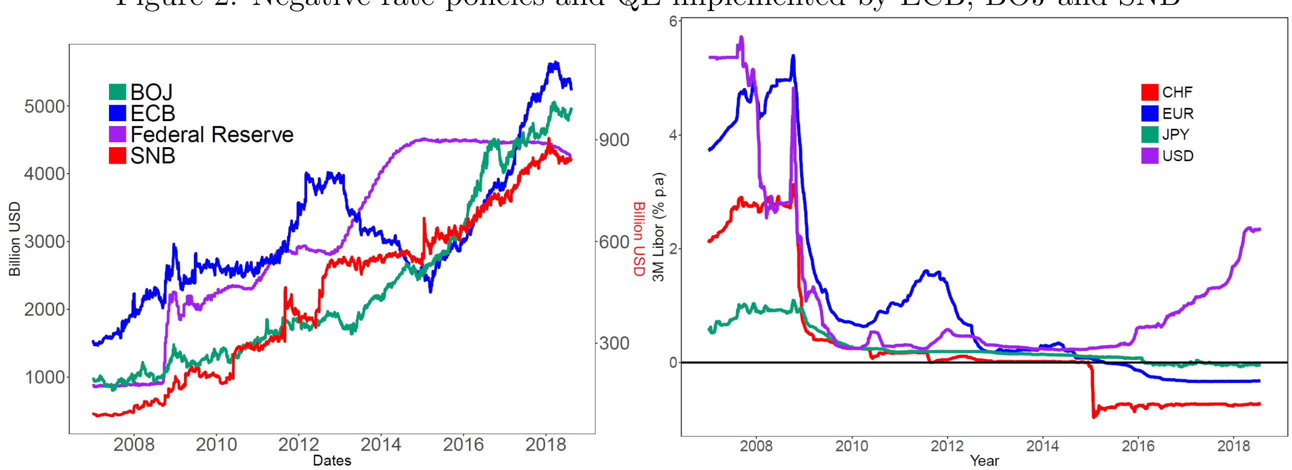
Figures

Figure 1: The puzzle of persistent CIP deviations



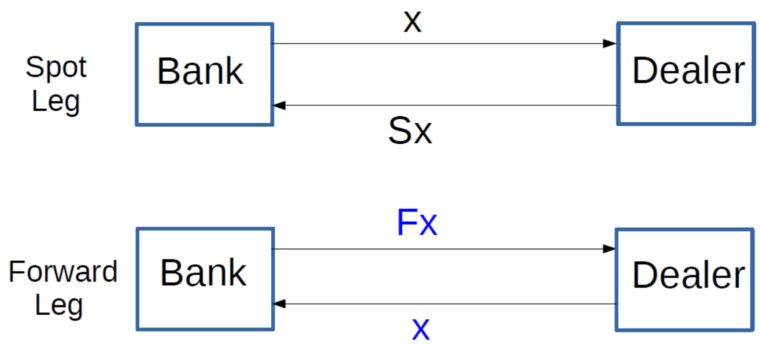
Note: This figure plots the 12M CIP deviation measured in basis points, obtained from Bloomberg, for the sample period 01/2000 to 04/2018. This provides a measure of CIP deviations based on a LIBOR benchmark rate. Deviations are defined as the difference between the direct dollar borrowing rate and the synthetic dollar borrowing rate, which is the cost of borrowing in the domestic currency, and then swapping into dollars through the FX swap market. Negative deviations indicate a dollar borrowing premium for the euro/\$, chf/\$ and yen/\$ pairs.

Figure 2: Negative rate policies and QE implemented by ECB, BOJ and SNB



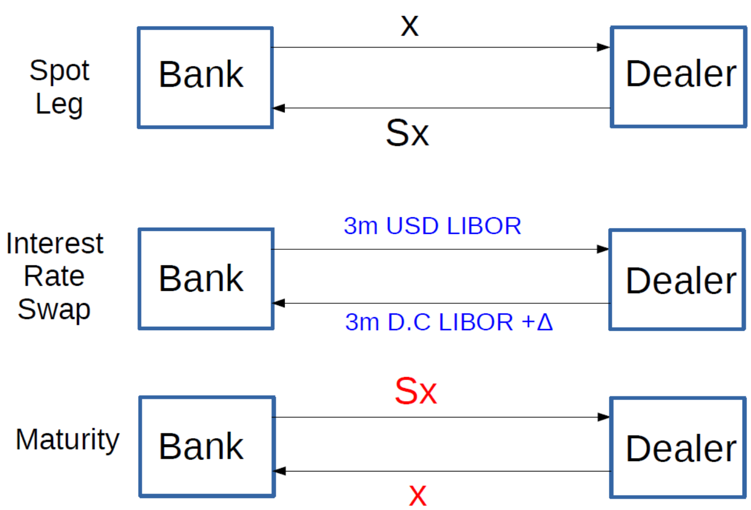
Note: This figure plots, on the left, total assets (in Billion USD) of ECB, Federal Reserve, BOJ and SNB. SNB scale is on right-axis. On the right, 3 month LIBOR rates. Data obtained from Bloomberg. Sample period is from 01/2007 to 04/2018

Figure 3: Foreign exchange swap



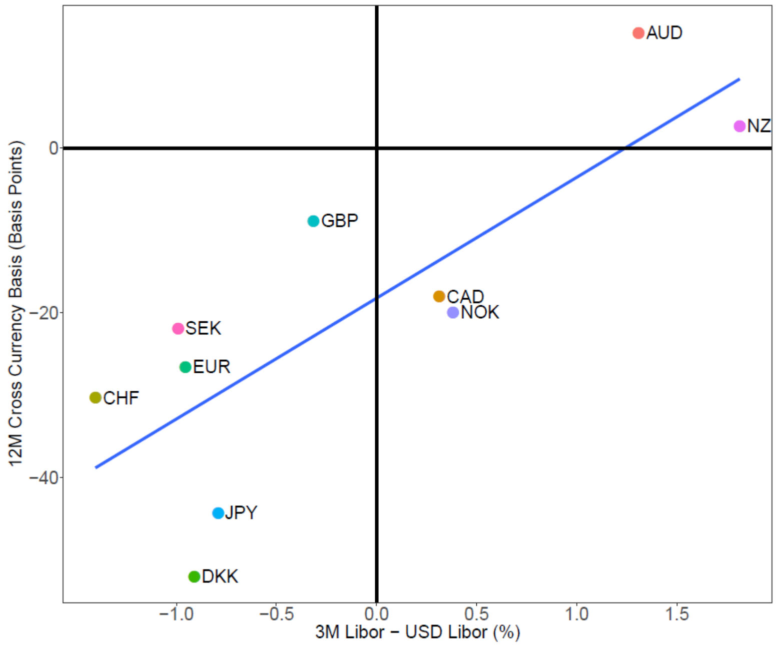
Note: This figure plots the legs of a FX swap, which is typically for maturities at less than 3 months. At the spot leg, domestic currency and dollars are swapped at the prevailing spot rate. At maturity, the principals are then re-exchanged at the forward rate.

Figure 4: Cross-currency swap



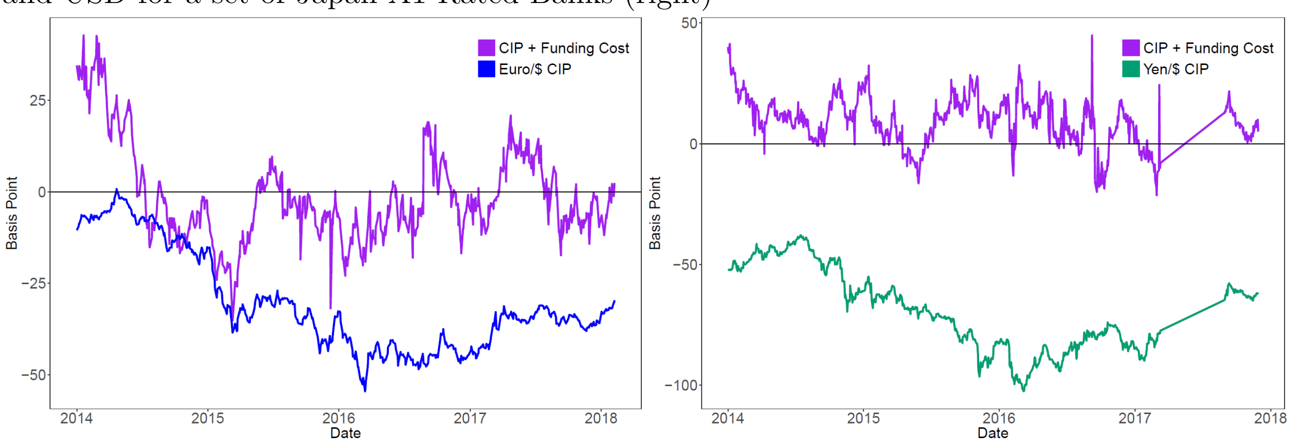
Note: This figure plots the legs of a Cross-Currency Swap. This is typically for maturities >3m. In the spot leg, dollars are exchanged at spot. The bank and dealer then engages in an interest rate swap, in which the bank pays 3m USD LIBOR, and the dealer pays 3m LIBOR in domestic currency with the addition of the cross-currency basis Δ. At maturity the principals are re-exchanged at the initial spot rate.

Figure 5: CIP Deviations and LIBOR interest rate differential, advanced economies, 2014-present



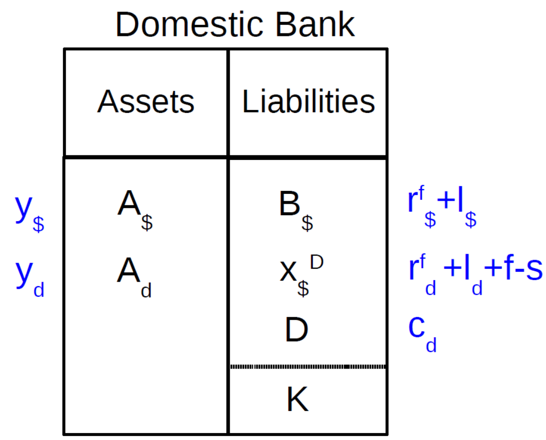
Note: This figure takes the average of the 12 month CIP deviation, and LIBOR interest rate differential between the domestic and U.S. rate, in the period from 01/2014-04/2018. 12M CIP deviations are defined as the difference between the direct dollar borrowing rate and the synthetic dollar borrowing rate. Data is obtained from Bloomberg.

Figure 6: Credit Spreads in Euros and USD for a set of French A1 Rated Banks(left) and Yen and USD for a set of Japan A1 Rated Banks (right)



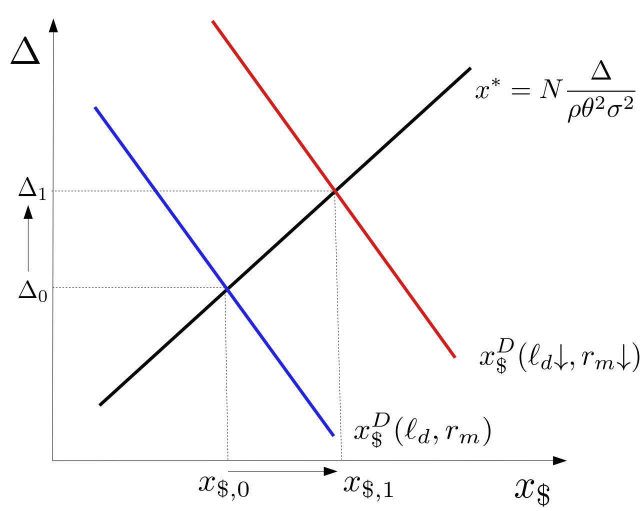
Note: This figure plots CIP deviations for the euro/\$ (left) and yen/\$ (right), as well as a measure that takes into account funding costs across currencies. The CIP deviation is the 5 Year cross-currency basis based on LIBOR rates. The measure of CIP+funding costs takes into account funding cost differences between the dollar and domestic currencies. For example, the 5Y cross-currency basis is added to the difference between dollar and domestic credit spreads (by plotting $\ell_\$ - \ell_d - |\Delta|$). To account for funding costs, I use data on bank credit spreads obtained from Norges Bank for a set of A1 rated French and Japanese banks. Sample period is from 01/2014 to 04/2018.

Figure 7: Bank Balance Sheet



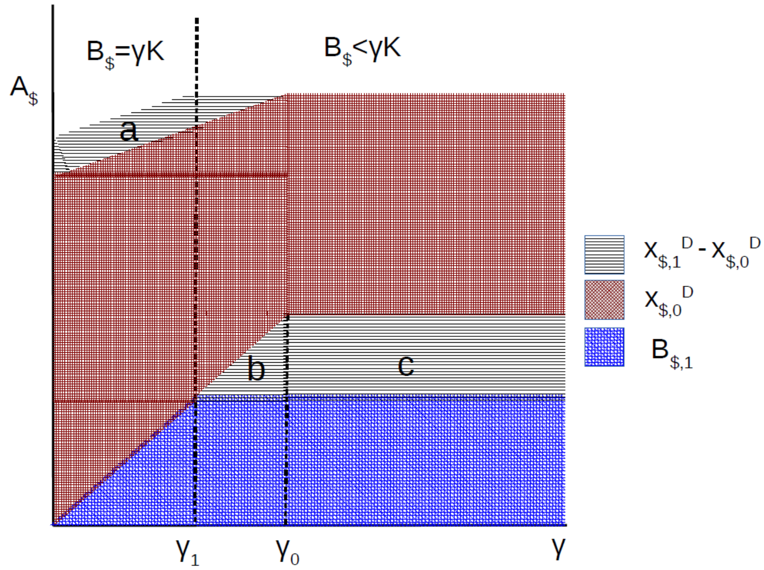
Note: This figure illustrates a stylized balance sheet of a domestic bank with equity K. On the asset side, the bank invests in domestic and dollar assets A_d and $A_\$$, with returns y_d and $y_\$$ respectively. They fund their balance sheet with domestic deposits D with cost c_d. They have two sources of dollar funding. Direct dollar borrowing $B_\$$ with cost $r^f_\$ + l_\$$, which is the cost of issuing a dollar bond, decomposed into the risk-free rate and the dollar credit spread. Synthetic dollar borrowings via FX swaps $x^D_\$$, with cost $r^f_d + l_d + f - s$. This is the cost of issuing a domestic bond, which is then swapped into dollars based on the forward premium $f - s$.

Figure 8: Graphical representation of equilibrium in FX swap market



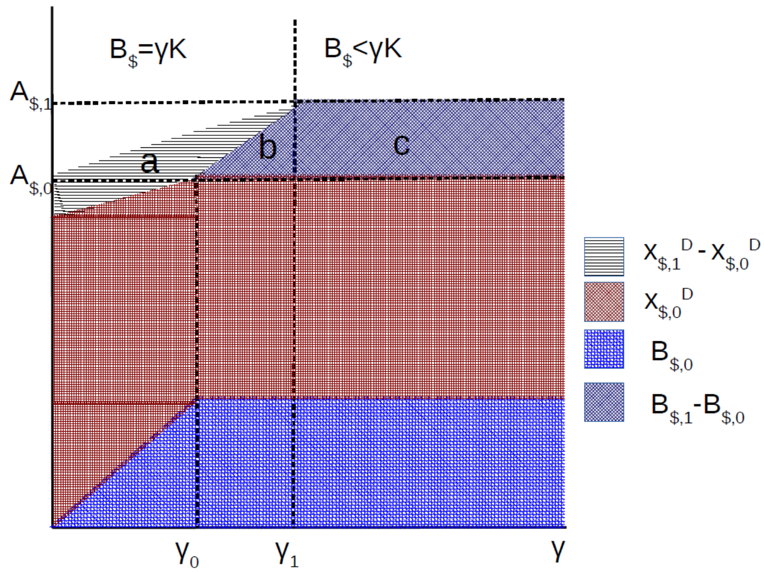
Note: This figure illustrates equilibrium in the FX swap market. Equilibrium Δ equates the supply of dollars by arbitrageurs to the demand for synthetic funding by the representative bank. Initial equilibrium is denoted by $[x_{\$,0}, \Delta_0]$. Monetary policies shift the demand for synthetic funding. Two key factors are domestic credit spreads ℓ_d and the central bank rate r_m, which are policy tools for QE and negative rates respectively.

Figure 9: Allocation of direct and synthetic dollar funding sources for banks with varying γ. Both initial and final equilibrium after QE is shown.



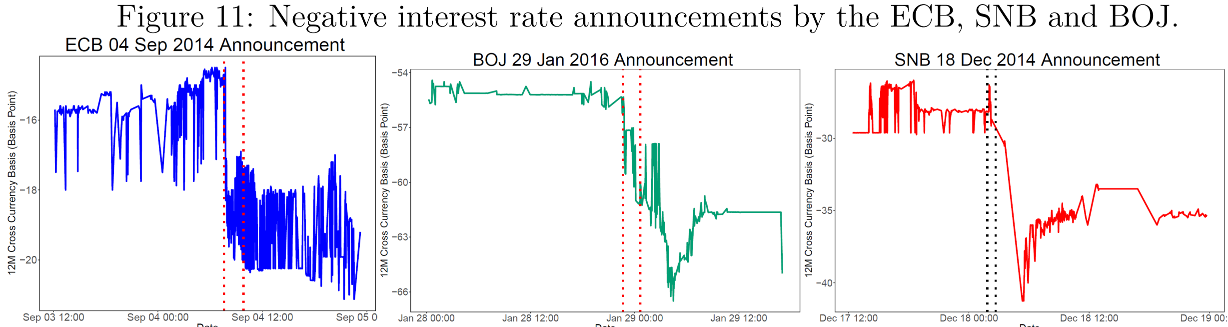
Note: This figure illustrates the effects of QE on the allocation of direct and synthetic dollar funding. For a bank that is not dollar constrained, with $\gamma > \gamma_1$, they increase their demands for synthetic dollar funding. This is denoted by areas b and c. For banks that are constrained in dollar borrowing, with $\gamma < \gamma_1$, there is a substitution toward synthetic funding as well, given by area a.

Figure 10: Allocation of direct and synthetic dollar funding sources for banks with varying γ. Both initial and final equilibrium after negative rates is shown.



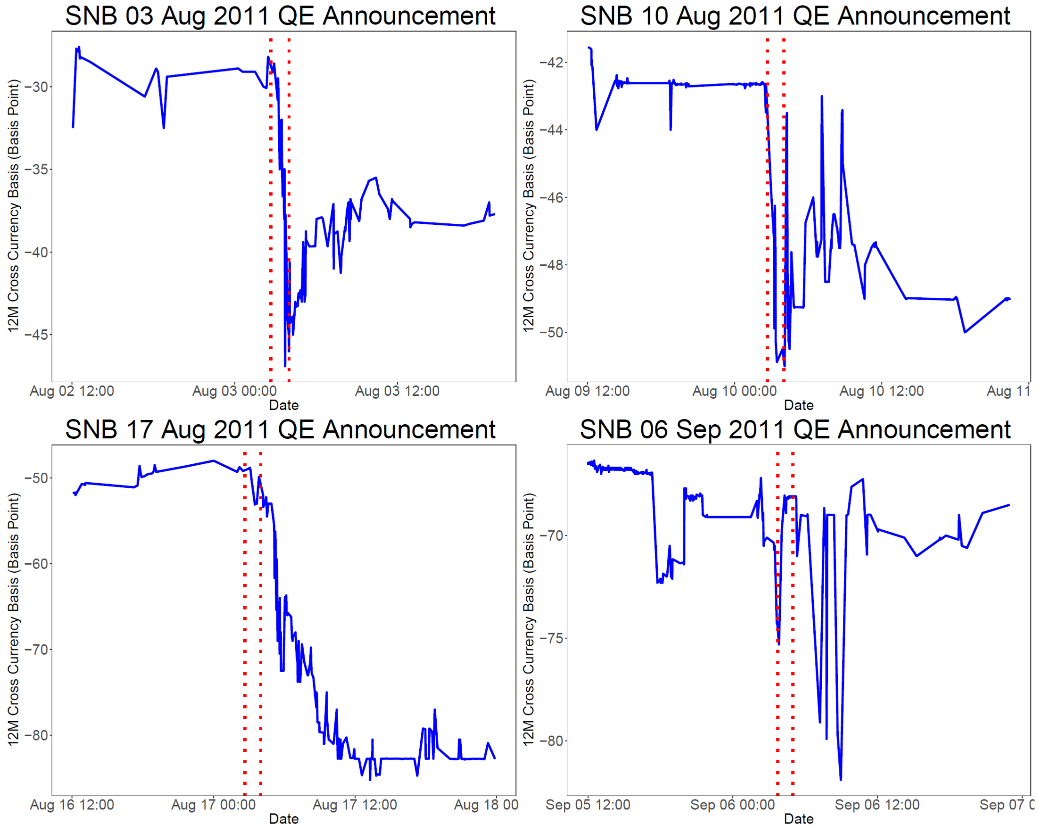
Note: This figure illustrates the effects of negative interest rates on the allocation of direct and synthetic dollar funding. For a bank that is not dollar constrained, with $\gamma > \gamma_1$, the increase in dollar assets is funded entirely by an increase in direct dollar borrowing. This is denoted by area c. For banks that are constrained in direct dollar borrowing, with $\gamma < \gamma_0$, the increase in dollar assets is met by an increase in synthetic dollar funding, denoted by area a. For banks that are partially constrained, with $\gamma_0 < \gamma < \gamma_1$, the increase in dollar assets is funded by both direct and synthetic sources.

Figure 11: Negative interest rate announcements by the ECB, SNB and BOJ.



Note: This figure plots the high frequency response of the 12M CIP deviation of the euro/\$, chf/\$ and yen/\$ around select negative interest rate announcements. For the ECB, the announcement on 4th September, 2014 resulted in a decline in the deposit facility rate by 10 basis points. Japan's negative rate announcement on January 16th, 2016 led to a 10 basis point decline in the current account rate, and Switzerland's negative rate announcement on 18th December, 2014 led to a 25 basis point change in the sight deposit rate. Source: Thomson Reuters Tick History

Figure 12: QE announcements by the SNB in August and September of 2011



Note: This figure plots the high frequency response of the 12M CIP deviation of the chf/$ around key announcements of the SNB in August and September of 2011. On 3rd August, 2011 sight deposits increased from 30B to 80B Chf. On 10th August, 2011, sight deposits increased from 80B to 120B Chf. On 17th August, 2011, sight deposits increased from 120B to 200B Chf. On 6th September, 2011, the SNB introduced a floor of 1.20 Chf/Euro. Source: Thomson Reuters Tick History

Tables

Table 1: Underlying interest rate futures to measure monetary shocks

Central Bank	Underlying policy rate	Monetary shock
ECB	EUREX 3-Month Euribor	$MP_{EU,t} = \Delta f1^{surprise}_{EU,t}$
BOJ	TFX (TIFFE) 3-Month Euroyen Tibor	$MP_{JPY,t} = \Delta f1^{surprise}_{JPY,t}$
SNB	LIFFE 3-Month Euroswiss Franc	$MP_{SWZ,t} = \Delta f1^{surprise}_{SWZ,t}$
Federal Reserve	Fed Funds Rate futures 1-Month	$\mathrm{MP}_{US,t} = \frac{D_0}{D_0-d_0}\Delta f_t$

Note: This table lists the interest rate futures of the underlying central bank rate for the central banks ECB, BOJ, SNB and Federal Reserve. Source for interest rate futures is CQG Financial Data. For non-U.S. central banks, the 90 day rate is used. For the U.S. the immediate 1 month futures is used, and therefore the monetary surprise is multiplied by the scaling factor $\frac{D_0}{D_0-d_0}$, where D_0 is the number of days in the month of the FOMC meeting, and d_0 is the day of the meeting within the month.

Table 2: Descriptive statistics, monetary shocks

	Mean	SD	p-5	p-25	p-50	p-75	p-95	Obs	Contract Period
MP_{US}	-0.012	0.076	-0.121	-0.010	0.000	0.040	0.210	168	07/95 - 06/18
MP_{SWZ}	-0.029	0.101	-0.180	-0.060	-0.010	0.010	0.080	90	02/91 - 06/18
MP_{UK}	-0.006	0.063	-0.090	-0.020	0.000	0.010	0.080	232	06/97 - 06/18
MP_{EU}	0.001	0.042	-0.060	-0.015	0.000	0.020	0.068	240	01/99 - 06/18

Note: This table provides summary statistics of the surprise change in interest rate futures around scheduled monetary announcements of the Federal Reserve, ECB, BOJ and SNB. All values in percentage points. Source for interest rate futures is CQG Financial Data.

Table 3: Response of Euro/$, Chf/$ and Yen/$ CIP Deviations to ECB, SNB and BOJ Monetary Announcements

	(1)	(2)	(3)	(4)	(5)	(6)
	Libor basis			Treasury Basis		
	eur/usd	chf/usd	yen/usd	eur/usd	chf/usd	yen/usd
MP	-0.086	0.154***	-1.055*	0.080	0.198***	-1.434*
	(0.049)	(0.044)	(0.463)	(0.058)	(0.046)	(0.587)
MP × $\mathbb{1}[U_{\text{MP}}]$	0.652***	0.466**	1.826***	0.256	0.448**	2.208**
	(0.124)	(0.161)	(0.530)	(0.147)	(0.165)	(0.673)
δ	.566***	.62***	.771***	.336***	.646***	.774***
	(.114)	(.155)	(.259)	(.135)	(.159)	(.329)
R^2	0.049	0.125	0.027	0.012	0.097	0.013
observations	596	241	700	840	343	987

*** p<0.01, ** p<0.05 *p<0.1, robust standard errors in parantheses.

Note: This table regresses the change in the Libor and Treasury CIP deviation on monetary surprises of domestic central banks. For the euro/$ pair, I use monetary surprises of the ECB based on 90 day futures. For the chf/$ pair, we use monetary surprises of the SNB. For the yen/$ pair, we use monetary surprises of the BOJ. The LIBOR basis is the CIP deviation measured based on LIBOR, and is obtained from Bloomberg. The Treasury basis is the CIP deviation measured based on Treasury yields, and is obtained from Du et al. (2018b). CIP deviations are calculated for maturities ranging from 3 months to 10 year tenor. I use the following specification, where for a scheduled monetary announcement on day t, the daily change in the CIP deviation for tenor i is computed as the difference between the end of day price on days t and $t-1$.

$$CIP_{i,t} - CIP_{i,t-1} = \alpha_i + \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t$$

The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement. The indicator $\mathbb{1}[U_{\text{MP}}]$ takes a value of one when the central bank practices unconventional monetary policy. The marginal effect of the period of unconventional monetary policy is captured by δ, which is the sum of the coefficients on MP and $MP \times \mathbb{1}[U_{\text{MP}}]$. Sample period is from 01/2007 to 12/2017.

Table 4: Response of Euro/\$, Chf/\$ and Yen/\$ CIP Deviations to Federal Reserve Announcements

	(1)	(2)	(3)	(4)	(5)	(6)
	Libor basis			Treasury Basis		
	eur/usd	chf/usd	jpy/usd	eur/usd	chf/usd	jpy/usd
MP	-0.105*	-0.058	-0.059	-0.967***	-0.227**	-0.798***
	(0.044)	(0.045)	(0.047)	(0.117)	(0.080)	(0.104)
MP $\times$ $\mathbb{1}[U_{\text{MP}}]$	0.010	0.303**	-0.163	-0.625*	-0.348	-0.256
	(0.108)	(0.112)	(0.117)	(0.289)	(0.197)	(0.258)
δ	-.095	.245**	-.222**	-1.592***	-.575***	-1.054***
	(.099)	(.102)	(.107)	(.265)	(.18)	(.236)
R^2	0.017	0.026	0.015	0.164	0.038	0.124
observations	404	397	405	567	567	567

*** p<0.01, ** p<0.05 *p<0.1, robust standard errors in parantheses.

Note: This table regresses the change in the Libor and Treasury CIP deviation on monetary surprises of the Federal Reserve. For monetary surprises, we use the change in the nearest month Federal Fund Futures around scheduled monetary announcements. The LIBOR basis is the CIP deviation measured based on LIBOR, and is obtained from Bloomberg. The Treasury basis is the CIP deviation measured based on Treasury yields, and is obtained from Du et al. (2018b). CIP deviations are calculated for maturities ranging from 3 months to the 10 year tenor. I use the following specification, where for a scheduled monetary announcement on day t, the daily change in the CIP deviation for tenor i is computed as the difference between the end of day price on days t and $t-1$.

$$CIP_{i,t} - CIP_{i,t-1} = \alpha_i + \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t$$

The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement. The indicator $\mathbb{1}[U_{\text{MP}}]$ takes a value of one when the central bank practices unconventional monetary policy. The marginal effect of the period of unconventional monetary policy is captured by δ, which is the sum of the coefficients on MP and $MP \times \mathbb{1}[U_{\text{MP}}]$. Sample period is from 01/2007 to 12/2017.

Table 5: Response of Euro/\$, Chf/\$ and Yen/\$ CIP Deviations to changes in credit spreads

	(1)	(2)	(3)	(4)	(5)	(6)
	Libor basis			Libor Basis		
	eur/usd	chf/usd	jpy/usd	eur/usd	chf/usd	jpy/usd
Δcs	-0.033	0.074	0.005	0.657	0.968	-1.495
	(0.006)***	(0.015)***	(0.025)	(0.537)	(0.336)**	(0.561)**
$\Delta cs \times \mathbb{1}[U_{\mathrm{MP}}]$	0.083	0.142	0.212	-0.172	0.414	2.427
	(0.024)***	(0.021)***	(0.028)***	(0.553)	(0.531)	(0.647)***
δ	.05**	.216***	.217***	.485***	1.382***	.932***
	(.023)	(.016)	(.012)	(.131)	(.411)	(.322)
R^2	0.003	0.017	0.022			
observations	12975	12875	13803	570	229	691
IV	No	No	No	Yes	Yes	Yes

*** p<0.01, ** p<0.05 *p<0.1, robust standard errors in parentheses.

Note: This table regresses the change in the Libor CIP deviation on credit spreads. The LIBOR basis is the CIP deviation measured based on LIBOR, and is obtained from Bloomberg. CIP deviations are calculated for maturities ranging from 3 months to 10 year tenor. I use the following specification, where for a scheduled monetary announcement on day t, the daily change in the CIP deviation for tenor i is computed as the difference between the end of day price on days t and $t-1$.

$$CIP_{i,t} - CIP_{i,t-1} = \alpha_i + \mathbb{1}[U_{MPt}] + \beta \Delta cs_t + \gamma \Delta cs_t \times \mathbb{1}[U_{\mathrm{MP}}] + u_t$$

The explanatory variable is the concurrent daily change in the credit spread cs_t. The indicator $\mathbb{1}[U_{\mathrm{MP}}]$ takes a value of one when the central bank practices unconventional monetary policy. The marginal effect of the period of unconventional monetary policy is captured by δ, which is the sum of the coefficients on Δcs_t and $\Delta cs_t \times \mathbb{1}[U_{\mathrm{MP}}]$. Columns (4) to (6) instrument credit spreads using monetary surprises on scheduled policy announcements. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement of the central banks ECB, SNB and BOJ, for the regressions based on CIP deviations for the euro/\$, chf/\$ and yen/\$ respectively. Sample period is from 01/2007 to 12/2017.

Table 6: Share of Interoffice Funding to Total Dollar Assets, Call Reports

Bank	Region	2007-2013		2014-2017	
		$A_\$$	$\frac{x_\$}{A_\$}$	$A_\$$	$\frac{x_\$}{A_\$}$
DEUTSCHE BK AG	EUR	\$145.8 B	0.13	\$156.9 B	0.51
BANK TOK-MIT UFJ	JPY	\$88.6 B	0.17	\$148.1 B	0.15
BANK OF NOVA SCOTIA	CAD	\$101.8 B	0.27	\$142.6 B	0.21
NORINCHUKIN BK	JPY	\$75.7 B	0.00	\$123.7 B	0.00
SUMITOMO MITSUI BKG	JPY	\$58.7 B	0.26	\$110.4 B	0.12
SOCIETE GENERALE	EUR	\$84.1 B	0.08	\$76.6 B	0.11
CREDIT SUISSE	CHF	\$57.3 B	0.02	\$68.9 B	0.00
RABOBANK NEDERLAND	EUR	\$74.8 B	0.02	\$57 B	0.05
STANDARD CHARTERED BK	GBP	\$30.4 B	0.09	\$53.2 B	0.16
TORONTO-DOMINION BK	CAD	\$40.9 B	0.00	\$52.1 B	0.00
NORDEA BK FINLAND PLC	EUR	\$26.8 B	0.06	\$37.1 B	0.22
DEXIA CREDIT LOCAL	EUR	\$41.8 B	0.12	\$32.5 B	0.11
NATIONAL AUSTRALIA BK	AUD	\$20.7 B	0.02	\$25.5 B	0.02
AUSTRALIA & NEW ZEALAND	AUD	\$10.7 B	0.26	\$21.9 B	0.02
MITSUBISHI UFJ TR & BKG	JPY	\$11.5 B	0.04	\$21.1 B	0.08
LANDESBK BADEN WUERTTEMB	EUR	\$11.5 B	0.22	\$18.2 B	0.05
LLOYDS TSB BK PLC	GBP	\$24.3 B	0.14	\$17 B	0.31
COMMONWEALTH BK OF AUS	AUD	\$8 B	0.00	\$16.2 B	0.00
DZ BK AG DEUTSCHE ZENTRA	EUR	\$8.8 B	0.00	\$14.7 B	0.01
WESTPAC BKG CORP	AUD	\$15.4 B	0.02	\$13.7 B	0.06
BAYERISCHE LANDESBANK	EUR	\$19.8 B	0.34	\$11.2 B	0.19
CREDIT INDUS ET CMRL	EUR	\$11.9 B	0.17	\$10.7 B	0.27
NATIONAL BK OF CANADA	CAD	\$12 B	0.00	\$10.1 B	0.10
LANDESBANK HESSEN-THURIN	EUR	\$11.5 B	0.65	\$9.4 B	0.65
COMMERZBANK AG	EUR	\$14.2 B	0.37	\$6.5 B	0.55
BANCO BILBAO VIZCAYA ARG	EUR	\$20.3 B	0.18	\$5.2 B	0.16
KBC BANK NV	EUR	\$8 B	0.31	\$4.7 B	0.16
NORDDEUTSCHE LANDESBANK	EUR	\$5.7 B	0.13	\$4.2 B	0.45
HSH NORDBK AG	EUR	\$10.3 B	0.49	\$3.8 B	0.77
SHOKO CHUKIN BK	JPY	\$0.6 B	0.73	\$0.7 B	0.26
ALLIED IRISH BKS	EUR	\$4.3 B	0.32	\$0.7 B	0.63
BANCA MONTE DEI PASCHI	EUR	\$1.3 B	0.00	\$0.5 B	0.07
BANCO ESPIRITO SANTO	EUR	\$0.1 B	0.77	\$0.2 B	0.92

Note: This table reports total dollar assets, $A_\$$, and the share of interoffice flows to total dollar assets, $\frac{x_\$}{A_\$}$, for U.S. branches of foreign (non U.S.) banks. Data is obtained from the FFIEEC 002 form and Call Reports of Chicago Federal Reserve. Dollar assets are quoted in Billions of USD. Country labels indicate the currency of domicile of the parent bank. EUR=Euro Zone, JPY=Japan, CHF=Switzerland, AUD=Australia, CAD=Canada, GBP=United Kingdom.

Table 7: Determinants of the fraction of synthetic dollar funding for U.S. subsidiaries of European, Japanese and Swiss banks

	(1)	(2)	(3)	(4)	(5)
	S_{ijt}	S_{ijt}	S_{ijt}	S_{ijt}	S_{ijt}
$i_{d,ois} - i_{\$,ois}$	-0.0928***			-0.0474	
	(0.0333)			(0.0316)	
$i_{d,ois} - i_{\$,ois} \times \mathbb{1}[U_{\text{MP}}]$	0.0127				
	(0.272)				
cs_d		-0.0983***	-0.133***		-0.0454
		(0.0257)	(0.0403)		(0.0340)
$\text{cs}_d \times \mathbb{1}[U_{\text{MP}}]$		-0.111*	-0.0803		
		(0.0582)	(0.0980)		
Constant	0.156***	0.252***	0.147**	0.210	0.351*
	(0.0442)	(0.0725)	(0.0658)	(0.151)	(0.185)
Observations	2,379	2,460	2,011	759	775
Number of bankid	39	39	39	12	12
Country Group	Treatment	Treatment	Treatment	Control	Control
Bank FE	Yes	Yes	Yes	Yes	Yes
Year Quarter FE	Yes	Yes	Yes	Yes	Yes
IV	No	No	Yes	No	No

*** p<0.01, ** p<0.05 *p<0.1, robust standard errors in parentheses.

Note: This table regresses the fraction of synthetic dollar funding to total dollar assets, using Chicago Federal Reserve Call Reports. Data is obtained from the FFIEEC 002 form requiring foreign subsidiaries of non U.S. banks to report their balance sheet activities.

$$S_{ijt} = \alpha_j + \gamma_t + \beta X_{it} + \gamma X_{it} \times \mathbb{1}[U_{MPt}] + \epsilon_t$$

The dependent variable S_{ijt} is then calculated as the ratio of interoffice flows to total dollar assets, for bank j with headquarters in country i and period t. Standard errors are clustered at the bank level, and data is quarterly and sample period is from 2007 Q1 to 2017 Q4. Explanatory variables X_{it} include the interest rate differential, which is the domestic OIS rate less the USD OIS rate, and the domestic credit spread, which is calculated as the difference between the corporate and government bond index at all tenors. Interest rates and bond indices are obtained from Bloomberg. These variables are interacted with an indicator for the period of monetary policy, $\mathbb{1}[U_{MPt}]$. Columns (1) and (2) test the effect of the interest rate differential and credit spread on U.S. subsidiaries of Euro Area, Japanese and Swiss Banks. Column (3) instruments credit spreads with a lagged measure of central bank asset growth. Columns (4) and (5) conduct a placebo test by looking at control group countries (Australia, Canada, UK) that did not practice unconventional monetary policy.

Appendices

A: Model Proofs

Proof of Proposition 1: QE

Unconstrained Bank

From equation 19, an unconstrained bank has $\xi_t = 0$. The expression for CIP deviations as a function of credit spreads (equation 16 can then be re-expressed in equation 29. Note that we drop time subscripts as the equilibrium is static. This condition states that the synthetic and direct dollar funding costs are equalised for an unconstrained bank.

$$F'(x_\$^D) = \ell_\$ - (\bar{\ell}_d G(M) + \Delta) \tag{29}$$

In equilibrium, arbitrageurs set a price Δ such that in equilibrium, $x_\$^D = N\frac{\Delta}{\rho\theta^2\sigma_s^2}$. Substituting in the equilibrium condition in equation 29 and taking the derivative with respect to M gives us equation 30.

$$\frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\frac{\partial\Delta}{\partial M} = -\bar{\ell}_d G'(M) - \frac{\partial\Delta}{\partial M} \tag{30}$$

Rearranging terms, I obtain an expression for the effect of central bank asset purchases M on the equilibrium CIP deviation in equation 31.

$$\frac{\partial\Delta}{\partial M} = -\frac{\bar{\ell}_d G'(M)}{1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}} > 0 \tag{31}$$

Constrained Bank

For a constrained bank, direct dollar funding is fixed, and demands for synthetic dollar funding are given by $x_\$^D = A_\$ - \gamma K$. In equilibrium, $x_\$^D = N\frac{\Delta}{\theta\rho\sigma_s^2}$. We express the equilibrium in equation 32.

$$N\frac{\Delta}{\rho\theta^2\sigma_s^2} = A_\$ - \gamma K \tag{32}$$

Taking the derivative with respect to M in equation 33.

$$\frac{N}{\theta\rho\sigma_s^2}\frac{\partial\Delta}{\partial M} = \frac{\partial A_\$}{\partial M} + \frac{\partial A_\$}{\partial\Delta}\frac{\partial\Delta}{\partial M} \tag{33}$$

Rearranging terms, I obtain an expression for the effect of central bank asset purchases M on the equilibrium CIP deviation in equation 34.

$$\frac{\partial \Delta}{\partial M} = \frac{\frac{\partial A_\$}{\partial M}}{\frac{N}{\rho\theta^2\sigma_s^2} - \frac{\partial A_\$}{\partial \Delta}} \tag{34}$$

To simplify the notation, denote $A_\$ = \frac{K}{\alpha}\frac{R_\$}{(R^T\Sigma R)^{\frac{1}{2}}}$, where $R = \begin{bmatrix} R_d & R_\$ \end{bmatrix}^T$. The domestic excess return is given by $R_d = y_d - c_d$ and the dollar excess return is given by $R_\$ = y_\$ - (l_d + r_\$^f + \Delta + F'(x_\$^D))$. The covariance matrix of returns $\Sigma = I_{2\times 2}$. for tractability.

Taking the derivative $\frac{\partial A_\$}{\partial M}$ in equation 35.

$$\frac{\partial A_\$}{\partial M} = -\bar{\ell}_d G'(M) A_\$ \left(\frac{1}{R_\$} + \frac{R_\$}{R^T R}\right) \tag{35}$$

Taking the derivative $\frac{\partial A_\$}{\partial \Delta}$ in equation 36,

$$\frac{\partial A_\$}{\partial \Delta} = -\left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right) A_\$ \left(\frac{1}{R_\$} + \frac{R_\$}{R^T R}\right) \tag{36}$$

Finally, substituting the expressions for $\frac{\partial A_\$}{\partial M}$ and $\frac{\partial A_\$}{\partial \Delta}$ gives the analytical solution for $\frac{\partial \Delta}{\partial M}$ in equation 37.

$$\frac{\partial \Delta}{\partial M} = -\frac{\bar{\ell}_d G'(M)}{1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2} + \frac{N}{\rho\theta^2\sigma_s^2 A_\$}\left(\frac{1}{\frac{1}{R_\$} + \frac{R_\$}{R^T R}}\right)} > 0 \tag{37}$$

Proof of Proposition 2: Negative interest rates

Constrained Bank

In contrast to QE, negative rates only has an effect on a constrained bank.[31] Bank demands for dollar funding are given by $x_\$^D = A_\$ - \gamma K$. In equilibrium, $x_\$^D = N\frac{\Delta}{\theta\rho\sigma_s^2}$, which I express in equation 38.

$$N\frac{\Delta}{\rho\theta^2\sigma_s^2} = A_\$ - \gamma K \tag{38}$$

Taking the derivative with respect to r_m in equation 39.

$$\frac{N}{\theta\rho\sigma_s^2}\frac{\partial \Delta}{\partial r_m} = \frac{\partial A_\$}{\partial r_m} + \frac{\partial A_\$}{\partial r_m}\frac{\partial \Delta}{\partial r_m} \tag{39}$$

Rearranging terms, I obtain an expression for the effect of central bank asset purchases r_m on the equilibrium CIP deviation in equation 40.

[31] For an unconstrained bank, synthetic dollar funding costs are equal to direct dollar funding costs. Therefore, any additional dollar assets are funded directly, as synthetic funding becomes more costly due to convex hedging costs.

$$\frac{\partial \Delta}{\partial r_m} = \frac{\frac{\partial A_\$}{\partial r_m}}{\frac{N}{\rho\theta^2\sigma_s^2} - \frac{\partial A_\$}{\partial \Delta}} \tag{40}$$

Lets simplify the notation. Denote $A_\$ = \frac{K}{\alpha}\frac{R_\$}{(R^T\Sigma R)^{\frac{1}{2}}}$, where $R = \begin{bmatrix} R_d & R_\$ \end{bmatrix}^T$. The domestic excess return is given by $R_d = y_d - c_d$ and the dollar excess return is given by $R_\$ = y_\$ - (l_d + r_\$^f + \Delta + F'(x_\$^D))$. The covariance matrix of returns $\Sigma = I_{2\times 2}$. for tractability.

Solving for the derivative $\frac{\partial A_\$}{\partial r_m}$ in equation 41.

$$\frac{\partial A_\$}{\partial r_m} = -\frac{R_d A_\$}{R^T R} \tag{41}$$

Solving for the derivative $\frac{\partial A_\$}{\partial \Delta}$ in equation 42.

$$\frac{\partial A_\$}{\partial \Delta} = -\left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right) A_\$ \left(\frac{1}{R_\$} + \frac{R_\$}{R^T R}\right) \tag{42}$$

Finally, substituting the expressions for $\frac{\partial A_\$}{\partial r_m}$ and $\frac{\partial A_\$}{\partial \Delta}$ gives the analytical solution for $\frac{\partial \Delta}{\partial r_m}$ in equation 43.

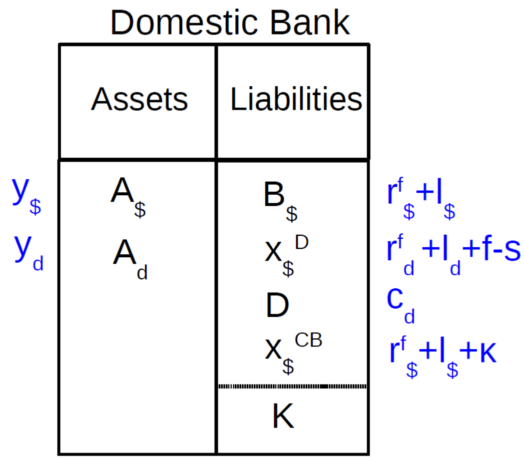
$$\frac{\partial \Delta}{\partial r_m} = -\frac{R_d}{\frac{NR^T R}{\rho\theta^2\sigma^2 A_\$} + \left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right)\left(\frac{R^T R}{R_\$} + R_\$\right)} < 0 \tag{43}$$

B: Model extension: Central Bank Swap Lines

During the financial crisis of 2008, rises in default risk in interbank markets led to a significant scarcity of dollar funding. Central bank swap lines are a tool in which the Federal Reserve engages in a currency swap, exchanging dollars for the domicile currency of the counterparty central bank. The counterparty central bank can then auction the dollar funds they receive to domestic banks. The terms of the auction are set so that any funds lent are at a premium to a risk-free interbank dollar borrowing rate.

I introduce central bank swap lines as an additional source of dollar funding for the bank. The consolidated balance sheet is presented in Figure 13. I model the swap line as an auction of dollar funds by the domestic central bank at a rate $\kappa + r_\$^f$, where κ is the premium on obtaining funds via the swap line.

Figure 13: Bank Balance Sheet



Note:Note: This figure illustrates a stylized balance sheet of a domestic bank with equity K. On the asset side, the bank invests in domestic and dollar assets A_d and $A_\$$, with returns y_d and $y_\$$ respectively. They fund their balance sheet with domestic deposits D with cost c_d. Now the bank has three sources of dollar funding. First, direct dollar borrowing $B_\$$ with cost $r^f_\$ + l_\$$, and synthetic dollar borrowings via FX swaps $x^D_\$$, with cost $r^f_d + l_d + f - s$. The additional source of dollar funding is via the swap line, which is at a penalty rate κ to direct dollar borrowing.

In addition to the penalty rate, I adjust the dollar borrowing constraint to include a liquidity shock ψ, $B_\$ \leq (\gamma - \psi)K$. The liquidity shock is a stylized way to capture the adverse dollar funding shock faced by European banks due to a reduction in wholesale funding sources, largely due to the retrenchment of U.S. money market funds in 2008 (Ivashina et al., 2015). In reality, central bank swap line funding are typically short-term. However, I'm assuming that a long-term swap line will having a funding cost equivalent to the direct dollar credit spread $l_\$$ with a premium equal to κ, which is the additional cost of obtaining funds via the auction.

The solution for the optimal demand for dollar funding via forex swaps and the central bank swap line, $x^D_\$$ and $x^{CB}_\$$, are given in equations 44 and 45. The optimal choice of synthetic dollar funding now depends on two factors. First, if the bank is unconstrained, the synthetic dollar cost is equal to the direct dollar borrowing cost, $\ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_\$$. An unconstrained bank therefore has no incentive to obtain funds from the swap line. In contrast, a constrained bank has saturated their level of direct dollar funding, and now must choose between synthetic dollar funding or bidding for funds at the swap line rate. In the event the swap line rate is too high, that is, $\ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) < \ell_\$ + \kappa$, the bank only chooses synthetic dollar funding.

$$x^D_{\$,t} = \begin{cases} F'^{-1}\left(\ell_\$ - (\ell_{d,t} + \Delta_t)\right) & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_\$ \\ A_{\$,t} - (\gamma - \psi)K & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) < \ell_\$ + \kappa \\ F'^{-1}\left(\ell_\$ + \kappa - (\ell_{d,t} + \Delta_t)\right) & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_\$ + \kappa \end{cases} \tag{44}$$

$$x^{CB}_{\$,t} = \begin{cases} 0 & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) < \ell_\$ + \kappa \\ A_{\$,t} - (\gamma - \psi)K - x^D_{\$,t} & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_\$ + \kappa \end{cases} \tag{45}$$

In summary, the effects of the central bank swap line are to reduce demand for synthetic funding for sufficiently dollar constrained banks, and is stated in proposition 3, where I formalize the effects of a funding shock to the direct dollar borrowing constraint.

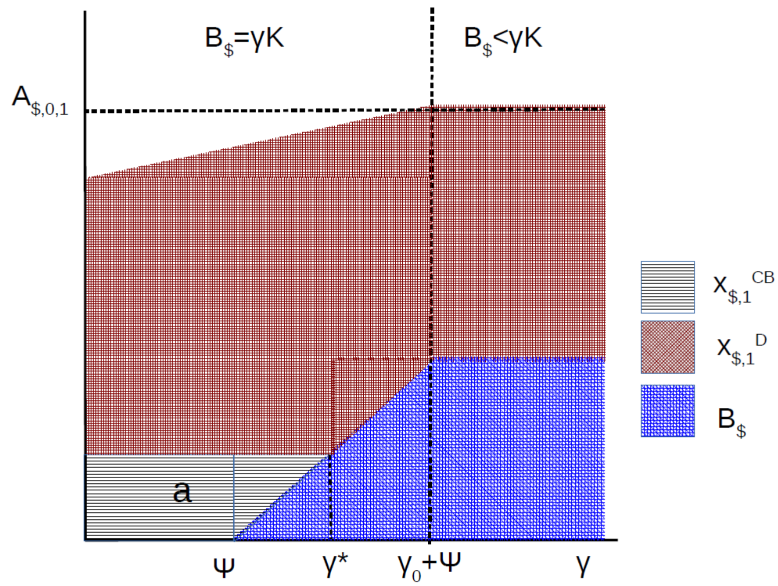
Proposition 3 [Swap Lines]: *Assume the bank operates in the constrained dollar borrowing region, and the bank is facing a crisis in dollar borrowing,* $B_\$ \leq (\gamma - \psi)K$. *Assume that in response to the crisis in dollar borrowing, the central bank extends dollar funding via a swap line with the Federal Reserve. This leads to:*

1. *A substitution from dollar funding in swap market to using the central bank swap line for banks with a sufficiently high synthetic dollar cost,*$\ell_{d,t} + \Delta_t + F'(x^D_{\$,0}) > \ell_\$ + \kappa$.

2. *A narrowing of the cross-currency basis in period 2 for banks that are sufficiently constrained with* $\gamma < \gamma^*$, *where* $\gamma^* = \frac{A_{\$,1} - F'^{-1}(\ell_\$ + \kappa - (\ell_d + \Delta))}{K} - \psi$
$$\frac{\partial \Delta}{\partial x^D_\$} = \begin{cases} 0 & , \gamma \geq \gamma^* \\ \frac{1}{\frac{1}{F''(x^D_\$)} + \frac{N}{\theta \rho \sigma^2_s}} > 0 & , \gamma < \gamma^* \end{cases}.$$

To further illustrate the effects of central bank swap lines on bank demands for direct and synthetic dollar funding, Figure 14 characterizes the bank's equilibrium allocation of dollar funding for different levels of γ. Central bank swap lines are used by a subset of banks that have a higher synthetic dollar funding cost than the rate at which they can obtain dollar funds via the swap line. This subset of banks is for a level of γ less than the threshold γ^* in Figure 14. The substitution from synthetic dollar funding toward the central bank swap lines is denoted by the area a in the diagram. The theoretical effects of swap lines have also been studied in Bahaj and Reis (2018), in which they study an exogenous decline in the penalty rate (κ in the model) on October 30, 2011, in which the penalty rate on Federal Reserve swap line auctions were reduced from 100 basis points above the inter bank dollar rate to a penalty of 50 basis points. They provide event study analysis showing a narrowing of CIP deviations following the announcement. This model is consistent with their findings, and a decline in κ causes a decline in the ceiling for CIP deviations in equilibrium.

Figure 14: Allocation of direct and synthetic dollar funding sources for a continuum of banks with varying γ. Both initial and final equilibrium after central bank swap line auctions is shown.



Note: This figure illustrates the effects of the swap line on the allocation of direct and synthetic dollar funding. For a bank that is sufficiently dollar constrained, with $\gamma < \gamma^*$, the bank finds it profitable to borrow dollars from the swap line. This is denoted by area a. For banks that are not as constrained in direct dollar borrowing, with $\gamma > \gamma^*$, the penalty rate on swap line funding is too high, and their optimal allocation of synthetic dollar funding is unchanged.

C: Model Quantitative Exercise

Calibration

I conduct a simple numerical exercise to test the validity of the model. I estimate the following set of parameters. First, I condense all supply side parameters into a constant Γ, which measures the elasticity of dealer supply to a change in the cross-currency basis.[32] The second parameter I calibrate is α, which constrains the risk-adjusted assets to a fraction of equity. Third, I assume a convex hedging cost $F(x_\$^D) = ax^2$, where a is a scaling factor to be estimated. I estimate these parameters by targeting three moments in the pre-crisis equilibrium. First, I set the pre-crisis CIP deviation to be 5 basis points. This roughly matches deviations prior to 2007, and captures transaction costs in arbitrage. Second, I set the bank's initial allocation of synthetic dollar funding to be 10% of total dollar assets. This is a rough estimate of the ratio of synthetic dollar funding to total dollar assets for Deutsche Bank in 2007.[33] Third, I set a ratio of total dollar assets to equity of one in the initial period.

[32]Recall the optimal supply of dollars by dealers is $Nx_\$^* = \frac{N\Delta}{\rho\theta\sigma^2}$. I rewrite optimal dealer supply as $x_\$^* = \frac{\Delta}{\Gamma}$, where $\Gamma = \frac{\rho\theta\sigma^2}{N}$.

[33]For details of data, please refer to empirical section 4 in which I calculate a proxy for the share of synthetic dollar funding to total dollar assets for U.S. subsidiaries of banks in Eurozone, Japan and Switzerland.

I normalize the monetary policy parameters r_m and M to a pre-crisis level of $M = 1$ and $r_m = 1\%$. For pass-through of the central bank rate to the deposit and lending rates, I assume simple functional forms, $r_d = r_m + 2\%$, and $c_d = min\{0, r_m\}$. This allows for a domestic interest rate margin of 2% when r_m is positive. Another critical parameter is the elasticity of credit spreads to central bank purchases, where I define the domestic credit spread $\ell_d = \bar{\ell}_d - \delta log M_t$. To estimate δ, the effects of the ECB Corporate asset purchase program is estimated to reduce bond yields by approximately 15 basis points. This program represents an approximate 5% increase in the size of the ECB balance sheet, yielding an elasticity of $\delta = 0.03$. I normalize $\gamma = 1$, and in the calibration set this to be the threshold at which the bank transitions from an unconstrained to constrained bank in direct dollar borrowing. Table 8 summarizes all relevant parameters in the calibration.

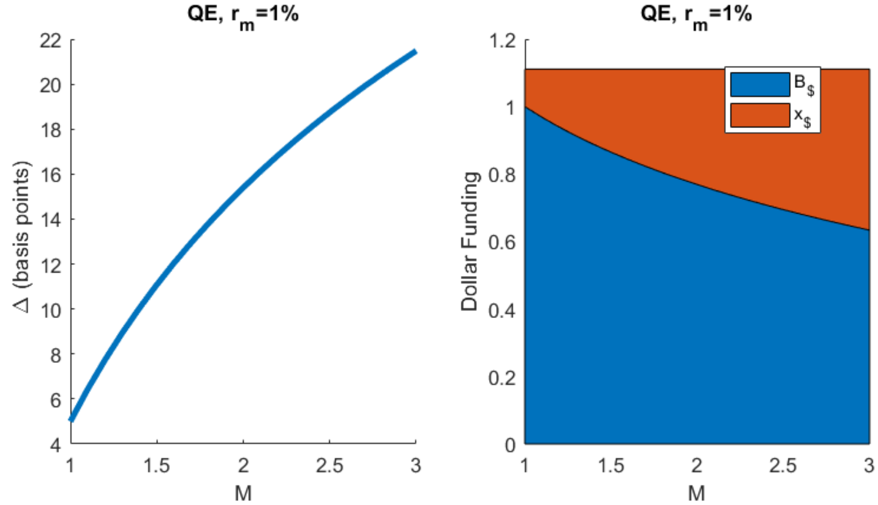
Table 8: **Calibration of Parameters: Initial equilibrium**

Parameter		
Dealer supply elasticity	Γ	0.0045
Value at Risk	α	4.02
Convex synthetic funding cost $F(x^D_\$) = ax^2$	a	0.085
Dollar borrowing constraint	γ	1
Credit spread elasticity to QE ($\ell_d = \bar{\ell}_d - \delta log M_t$)	δ	0.03
Dollar credit spread	$l_\$$	3%
Domestic credit spread	$\bar{\ell}_d$	2%
Dollar asset return	$y_\$$	4%
domestic asset return	y_d	3%
domestic deposit	c_d	1%

Results

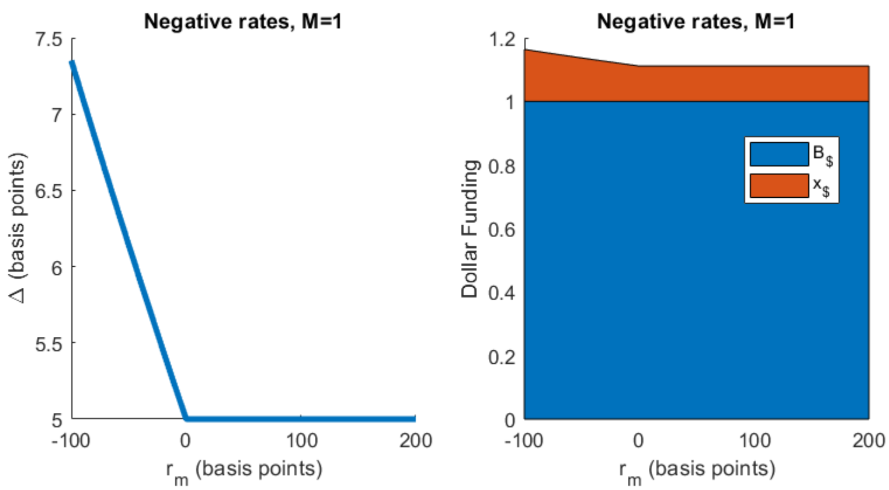
Figures 15 and 16 show the effect of QE and negative rates respectively. For QE, the pre-crisis CIP deviation of 5 basis points increases to approximately 15 basis points for $M = 2$. The decline in domestic credit spreads induced by QE causes a reallocation toward obtaining dollars via FX swaps. In response to negative interest rates, the bank portfolio rebalances to hold additional dollar assets. As the bank is constrained in direct dollar borrowing, they hedge the additional dollar assets via FX swaps. The effects of negative rates are relatively small compared to QE. This is because, for the given calibration, the convex hedging cost reduces the extent to which dollar assets rise in response to negative rates. A limitation of the model is the linear supply curve of dollars in the FX swap market. In the event dealer supply is fixed due to constraints on dealer leverage, the effects on CIP deviations will be much more acute.

Figure 15: Equilibrium Δ and allocation of dollar funding for a range of QE



Note: This figure plots the CIP deviation (in basis points) for different values of M which correspond to different values of the domestic credit spread. As M increases, so does the share of synthetic dollar funding, $x_\$ \uparrow$, and $B_\$ \downarrow$. The pre-crisis CIP deviation is calibrated to be 5 basis points, and the pre-crisis share of synthetic dollar funding is set at 10%.

Figure 16: Equilibrium Δ and allocation of dollar funding for a range of central bank rate r_m



Note: This figure plots the CIP deviation (in basis points) for different values of r_m. As r_m goes negative, CIP deviations widen, dollar assets are increased along with demands for synthetic funding. The pre-crisis CIP deviation is calibrated to be 5 basis points, and the pre-crisis share of synthetic dollar funding is set at 10%.