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

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January 14, 2020

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 microstructure of the foreign exchange 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 forex 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 forex swaps. Both policies thus lead to an increase in the excess demand for dollars in the forex swap market. To absorb the excess demand, financially constrained dealers 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 announcements. I also document a rising share of dollar funding via the forex 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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†I would like to thank Professors Pierre-Olivier Gourinchas, Barry Eichengreen, Yuriy Gorodnichenko and Andrew Rose for their continued guidance throughout this project. For useful comments and suggestions, I would like to thank Christian Jauregui, Arvind Krishnamurthy, Richard Lyons, Yusuf Mercan, David Murakami, Paul Goldsmith-Pinkham, Nicholas Sander, Jesse Schreger, Leslie Shen and Olav Syrstad. I would also like to thank discussants and seminar participants at Warwick Business School, UC Berkeley, Australasian Banking and Finance Conference, Reserve Bank of Australia Macroeconomics Conference and the Young Economist Symposium. I also thank Christian Jauregui for data collection of monetary announcements that we used in related work. I also thank Xinruo Hu for excellent research assistance. All errors are my own.

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 are systematically negative, indicating the existence of a dollar financing premium for Euro Area, Swiss and Japanese banks borrowing dollars on the foreign exchange swap market.That is to say, borrowing dollars synthetically is systematically more expensive than interest rates and forward premia otherwise suggest.

The initial deviation from CIP in 2008, also known as the cross-currency basis, 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 forex market is one of the deepest and most liquid financial markets and that forex swaps are among the most widely traded derivative instruments, with an estimated $250 B daily turnover (Figure 2). That markets in the specific currency pairs on which this paper focuses – the euro/$, chf/$ and yen/$ -- are especially liquid reinforces the point.

I propose an explanation focusing 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 3).[3] Recall that a European, Swiss or Japanese bank desiring long-term USD funding can borrow those dollars directly at the USD funding cost, or alternatively can obtain them by borrowing euros, Swiss francs or yen and swapping them into dollars, where in this case the cost is the domestic

[1] The euro/$, chf/$ and yen/$ will be the three bilateral pairs that I focus on this paper. However, in a following section, I identify a relationship between CIP deviations and the level of interest rates, and explains why the aud/$ cross-currency basis is positive in Figure 1. Another point to note is that all CIP deviations I discuss in the paper 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 forex swap, and the euro/$ and yen/$ accounting for over 50% of all forex 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).

[3] While the focus of the paper is on expansionary policies of the ECB, BOJ and SNB, the Federal Reserve has also pursued QE policies in the past. The last major expansion happened in 2012, with a tapering of QE beginning in late 2013.

funding cost plus the cross-currency basis. This is where QE arrives on the scene. QE programs entail purchases of privately-issued debt. They thereby cause a decline in domestic funding costs and reduce the cost of obtaining dollar funding via forex swaps. This leads to a reallocation of dollar funding toward forex swaps, which 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 forex 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 forex swaps. In Figure 4 I illustrate the effects of both policies – QE and negative interest rates -- on a stylized domestic (non U.S.) bank balance sheet. While both policies have an equivalent impact on bank demands for dollar funding in the forex swap market, the two channels have different implications for the balance sheet. QE works through the *liability* side, as the bank reallocates dollar funding toward borrowing dollars via the forex swap market. In contrast, negative interest rates operate through the *asset* side. As the relative return on dollar assets increases, a rise in dollar assets is matched by a rise in dollar funding via forex swaps.

Dealers are at the other end of these bank forex swap transactions. They provide the dollars that Euro Area, Swiss and Japanese banks seek in order to match their assets and liabilities. Dealers 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. To satisfy a growing demand for dollar funding from banks, dealers therefore raise the premium at which euros, yen and Swiss francs are swapped into dollars, causing a widening of the cross-currency basis.

To rationalize these two channels, I introduce a model with two agent types, banks that are customers in the forex swap market, and dealers who set the forward price and cross-currency basis. Non-U.S. banks have portfolios of domestic and dollar assets. They are funded by domestic deposits, dollar bonds and dollar funding obtained via forex swaps. Banks maximize returns in a standard portfolio choice problem, yielding a demand for dollars in the forex swap market.

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.[4] In turn this compresses domestic

[4]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

credit spreads, defined as domestic bond yields in excess of the risk-free rate. This causes banks to seek more dollar funding in the forex swap market. To absorb the excess demand for dollar funding, dealers therefore reset the forward rate, causing the cross-currency basis to widen.

To analyze the effects of negative rates, I assume differential 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. This results in an increased demand for dollars obtained via forex swaps, and dealers again respond by resetting the forward rate, causing the cross-country basis to widen still more. The effects on prices are thus directionally the same as in the case of QE.

I also consider the effect of central bank swap lines, like those implemented by the Federal Reserve in 2008 as a way of providing dollar liquidity to banks outside the United States. These are arrangements between the Federal Reserve and counterparty central banks to exchange dollars for foreign currencies at a specified rate. To the extent counterparty central banks channel the dollars thereby obtained to domestic banks, these swaps are an incremental source of dollar liquidity. I model swap lines as an auction of funds in periods when dollar borrowing is otherwise constrained. As banks substitute toward the dollar liquidity provided via the swap line, the model predicts a decline in bank demands for synthetic dollar funding, and a narrowing of the cross-currency basis. Figure 5 illustrates these mechanics.[5]

In the empirical part of the paper, I first provide narrative evidence of a significant widening of the cross-currency basis for the euro/$, yen/$ and chf/$ around the time of negative interest rate announcements. I then generalize this result using surprises to interest rate futures around scheduled monetary announcements by the ECB, BOJ and SNB. The identifying assumption is that changes in interest rate futures on announcement days respond only to monetary news. In response to expansionary monetary surprises, I detect a persistent widening of the cross-currency basis and a decline in domestic credit spreads.

A testable prediction of the model is that both QE and negative interest rates should lead banks in the Eurozone, Japan and Switzerland to substitute toward synthetic dollar funding. Therefore, I expect the fraction of synthetic dollar funding to total dollar assets should increase. Using data on interoffice funding of U.S. subsidiaries of Eurozone, Japanese and Swiss banks, I find that a decline in domestic credit spreads causes a rise in the share of synthetic dollar

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.

[5] In Figure 5, I simplify the analysis by considering a non-sterilized swap line, in which both the domestic central bank and Federal Reserve increase money supply to finance the currency swap.

funding. Moreover, consistent with the model prediction, the increase is especially evident in periods of unconventional monetary policy.

1.1 Related Literature

Since 2008, theories to explain rising CIP deviations have mainly focused on rising counterparty risk Baba and Packer (2009), rising balance sheet costs and regulatory requirements Du et al. (2018a); Liao (2018); Bräuning and Puria (2017), the strengthening of the dollarAvdjiev et al. (2016), and rising bid-ask spreads due to limited dealer capacity Pinnington and Shamloo (2016). All of these factors suggest CIP deviations are predominantly driven by constraints on supply of dollars available for forex swaps. In contrast, the role of this paper is to consider monetary policy as a potential demand side factor in explaining widening CIP deviations.

A series of papers provide evidence linking monetary policy to CIP deviations Iida et al. (2016); Borio et al. (2016); Dedola et al. (2017); Du et al. (2018a). I extend their evidence in three ways. 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 that U.S. subsidiaries of banks in the Euro area, Japan and Switzerland increase their share of synthetic dollar funding in response to a decline in domestic funding costs.

I also contribute to the literature on modeling CIP deviations Ivashina et al. (2015); Liao (2018); Gabaix and Maggiori (2015); Avdjiev et al. (2016); Sushko et al. (2017). Most papers focus on factors increasing limits to arbitrage, either by imposing an outside cost of capital, or by tightening balance sheet constraints of dealers supplying dollars in the forex swap market. The closest related paper examines a shock to credit quality of Euro area banks during the sovereign debt crisis in 2011Ivashina et al. (2015). The authors model the disruption to credit quality as causing a shortage of wholesale dollar funding, requiring banks to increase demands for dollar funding in the forex swap market. I add to this literature by formalizing the channels through which monetary policy can cause a rise in bank demands for dollar funding in the forex 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.

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). For example, Abidi and Flores (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.[6] This

[6] The threshold they exploit are conditions for the bond to be eligible for CSPP. 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

evidence motivates my assumption that the effects of QE are via reducing domestic credit spreads, which in turn causes the bank to substitute toward synthetic dollar funding. A series of papers also document that CIP deviations are a by product of differences in funding costs across currencies Syrstad (2018); Rime et al. (2017); Liao (2018); Kohler and Müller (2018). Liao (2018) uses detailed corporate bond issuance data to show that there is a clear parallel between CIP deviations and mispricing in the corporate bond market, and Syrstad (2018) documents a cointegrated relationship between relative funding costs and the cross-currency basis. Kohler and Mueller (2018) document a measure of CIP deviations based on cross-currency repo transactions. Cross-currency repos are transactions which a bank can use to exchange domestic currency collateral for a USD loan. By showing the existence of a funding liquidity premium of the USD, their refined measure of CIP deviations based on repos are much closer to parity. My paper adds to this literature by microfounding the relationship between the CIP deviation measured in a risk-free rate, and the relative funding costs across currencies.

A recent literature has emerged on identifying the impact of negative interest rates on bank profitability Altavilla et al. (2018); Borio and Gambacorta (2017); Lopez et al. (2018); Claessens et al. (2018). Borio et al (2017) explain this phenomenon as a retail deposit endowment effect. In times of moderate money market rates, the bank is able to have a sufficient markdown on retail deposit rates. However, this markdown becomes smaller as money market rates fall, causing net interest income to fall. Using cross-country evidence, all of these studies find that net interest income falls during a period of negative interest rates, and this effect is more concentrated for banks with a high deposit ratio.[7] Similar results are found when using the response of bank equities to scheduled monetary announcements. A related study by Ampudia and Van den Heuvel (2018) find that equity values fall more for high deposit banks in response to expansionary announcements during the period of negative interest rates.

The evidence of negative rates on causing a decline in net interest income supports the channel of negative interest rates in my paper. 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 forex swaps. To support this theory, recent papers have identified the impact of monetary policy on forex swap hedging demand Bräuning and Ivashina (2017); Iida et al. (2016). Bräuning and Ivashina (2017) examine the impact of the Federal Reserve increasing the rate on excess reserves (IOER). They find a rise in IOER cause subsidiaries of non U.S. banks to borrow dollars synthetically and then

identifying assumption is that the classification of bonds by credit standards are exogenous to macroeconomic conditions and other shocks that affect yields.

[7]While my paper does not focus on non net interest income, it is possible that banks can offset the decline in net interest income through a rise in bank fees or through capital gains from rising asset prices, and there is some evidence in Lopez et al (2018) supporting this claim. However, in the context of this paper, what matters is the effect of negative rates on net interest income.

deposit those dollars with the Federal Reserve. This is complementary to my paper, as the rise in IOER causes a rise in hedging demand for dollar funding via forex 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. (2018). In Bergant et al (2018), the authors provide evidence at a securities level that in response to asset purchase programs by the ECB in 2016, banks in the Eurozone significantly increased their exposure to US dollar denominated assets. They cite this as a portfolio rebalancing effect in response to declining yields of bonds with similar characteristics, as part of the asset purchase program.[8] Similarly, Maggori et al document a secular trend since 2008 of rising dollar issuance, and a tilting of mutual fund portfolios from euro denominated to dollar denominated securities.[9]

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

2 Stylized Facts on the Forex Swap Market

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 cross-currency basis. 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. Third, I show evidence that balance sheet constraints are a limiting factor in arbitrage. Before I outline the facts, I will briefly cover two important definitions, the cross-currency basis, and forex swaps.

Cross-currency basis

Define the spot rate S and forward rate F in dollars per unit of domestic currency, and dollar and domestic borrowing costs $r^f_\$$ and r^f_d respectively. Consider an investor that can borrow 1 dollar directly at cost $r^f_\$$. Alternatively, the investor can borrow dollars via the forex swap market. First, an investor borrows $\frac{1}{S}$ units of domestic currency at rate $1 + r^f_d$. They hedge

[8]Further evidence for the portfolio rebalancing effect in response to QE can be found in a similar study Goldstein et al. (2018). The authors find that in response to QE by the Fedearal Reserve, mutual funds reallocated their portfolios to hold Treasury bonds with similar characteristics to the bonds that were part of the asset purchase program.

[9]They use Morningstar data, which reports comprehensive mutual fund holdings at a security level. While mutual funds may include private investors as well as banks, their findings are complementary and provide a more general trend of portfolio rebalancing toward dollar assets in both the corporate and financial sector.

exchange rate risk with a forward contract, in which they re-convert the domestic currency into dollars at the forward rate F. The dollar borrowing cost via forex swaps, which I refer to as the synthetic dollar borrowing cost, is then equal to $\frac{F}{S}(1+r_d^f)$. I then define the cross-currency basis as the difference between the direct and synthetic dollar borrowing cost.

$$\Delta = \underbrace{1 + r_{\$}^f}_{\text{direct}} - \underbrace{\frac{F}{S}(1 + r_d^f)}_{\text{synthetic}}$$

Foreign exchange swaps

Foreign exchange swaps, also known as spot-forward contracts, are typically used at short maturities less than 1 month (Figure 6). Principals are first exchanged at the current spot rate. Both parties then agree to re-exchange the principals at maturity at a specified forward rate. At longer maturities of greater than 3 months, a variant of the forex swap, known as a cross-currency swap, is used (Figure 7). A cross-currency swap begins with an exchange of principals at a spot rate, followed by an interest rate swap in which the counterparties exchange 3 month LIBOR interest repayments in the respective currencies they hold until maturity. At maturity of the contract, the principals are then re-exchanged at the initial spot rate.

Stylized Fact #1 *In the cross-section, high interest rate currencies have a more positive cross-currency basis.*

Examining a set of advanced economies, countries with a higher interest rate typically have a more positive cross-currency basis (Figure 8).[10] Consider an example of a bank pursuing a carry trade strategy, in which banks borrow in a low interest rate currency, the yen, and go long in the dollar. This strategy yields a positive return given the tendency for high interest rate currencies to appreciate on average. But if banks pursue an extensive carry trade strategy, the build up of dollar assets require dollar funding via forex swaps to hedge forex risk. In the event hedging demands by banks for dollars in the forex swap market cannot be fully absorbed by dealers, this results in an increase in the premium at which yen is swapped into dollars.

The non-zero slope in Figure 8 is also an indication that limits to arbitrage matter. For example, to conduct CIP arbitrage, an agent would borrow 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/$ cross-currency basis. Without limits to

[10] The relationship in Figure 8 is positive for the period since 2008, however it is a stronger correlation for the period since 2014.

arbitrage, dealers will fully absorb the hedging demands of banks, and the slope should be zero.[11]

Stylized 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. Given bank funding costs are typically higher in USD, a measure of CIP deviations that takes into account funding costs should be much closer to parity. In Figure 9, I compare a measure of the 5 year cross-currency basis for the euro/$ and yen/$ pairs, against a measure that includes the differences in funding costs. 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. Credit spreads measure the excess of the bond yield above a risk-free rate, and provide a measure of the relative cost of funding across currencies.Once the CIP deviation is adjusted for differences in funding costs, these deviations are smaller in magnitude and closer to parity.[12] 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, 2018; Kohler and Müller, 2018)..

Stylized Fact #3 *Dealers are constrained in supply of dollars in the forex swap market*

Since 2015, there have been increasing limits to arbitrage in financial markets through regulations on bank leverage. Basel 3 requires a minimum risk-adjusted capital to assets ratio, and quarter-end reporting obligations of financial institutions require these conditions to be met. Therefore, at quarter-ends, a dealer cannot leverage significantly to conduct an arbitrage trade of borrowing dollars directly and then lend those dollars via forex swaps. The most compelling evidence that balance sheet constraints in arbitrage matter are 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). Taking the absolute difference of 1 month and 12 month deviations for the euro/$, yen/$ and chf/$ currency pairs, there is a significant rise in CIP deviations at short-term maturities (Figure 10). As the authors in Du et al (2017) note, the spikes in short-term CIP deviations have been more prevalent since 2015. These findings suggest that balance

[11] Indeed, the slope of Figure 8 is zero for the pre-2008 period.

[12] Mathematically, I account for credit spreads by constructing the following measure: $\Delta + \ell_{\$} - \ell_d$, where Δ is the cross-currency basis, $\ell_{\$}$ is the dollar credit spread, and ℓ_d is the domestic credit spread.

sheet constraints play a role, and the supply of dollars in the forex swap market by dealers is constrained. While the paper focuses on channels that affect bank demands for dollars in the forex swap market, these findings suggest that demand imbalances may only be absorbed through dealers adjusting the forward premium.[13]

figuresection

3 Model

I introduce a model with two agents, a domestic (non U.S.) bank and dealers. To simplify the setting, I consider a bank with headquarters domiciled outside the U.S, and a subsidiary located in the U.S. The bank at headquarters invests in domestic assets and holds domestic deposits. Meanwhile, the U.S. subsidiary manages the dollar balance sheet position of the bank, and invests in dollar assets, and obtains direct dollar funding. In addition, headquarters can lend in domestic currency to its U.S subsidiary, which are then swapped into dollars. The U.S. subsidiary then has two ways of borrowing dollars. They can borrow directly via wholesale funding or issuing dollar denominated debt, or alternatively, by borrowing dollars synthetically from headquarters. In equilibrium the bank chooses a level of domestic and dollar assets that maximizes a risk-adjusted return. The bank also chooses an allocation of direct and synthetic dollar funding such that marginal costs of each funding source are equalized.

Dealers are the intermediaries through which banks settle transactions in the forex swap market. As they take the other end of the swap, they supply dollars in exchange for the domestic currency. Dealers 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 rate, and therefore increase the premium banks pay to swap domestic currency into dollars. In the baseline model, I assume that dealers set a forward rate such that they fully absorb the demands for dollar funding by banks. This yields a static equilibrium in which the dealer sets the cross-currency basis at which the supply of dollars in the forex swap market exactly match bank demands for dollar funding. I relax this assumption in a subsequent section in which I allow for delayed price-setting.

3.1 Dealer

Following Sushko et al (2017), I model a dealer that has expected exponential utility over next period wealth W_{t+1}. Formally, I define $U_t = E_t\left[-e^{-\rho W_{t+}}\right]$, where ρ is a measure of risk aversion. Dealer wealth in period $t+1$ is equal to the dollar asset return on prior period

[13] For more micro-level evidence that leverage matters, I refer the reader to Cenedse et al (2018) that shows dealer leverage plays a role in forward pricing. The authors find dealers that are more leveraged are more sensitive to a rise in market demand and are more likely to raise the forward premium of the contract.

wealth, and a return on lending dollars in the swap market. The dealer exchanges principals 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 dealer bears exchange rate risk. In the event of a default with a given probability θ, the dealer 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}.

$$W_{t+1} = W_t(1 + r^f_\$) + (1 - \theta)x_{\$,t}(f_t - s_t + r^f_d - r^f_\$) + \theta x_{\$,t}(s_{t+1} - s_t + r^f_d - r^f_\$) \tag{1}$$

The cross-currency basis, Δ_t, is defined as the excess of the forward premium over the interest rate differential, $\Delta_t = f_t - s_t - (r^f_\$ - r^f_d)$. I can rewrite equation 1 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.

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

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[14].

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

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

$$x^*_{\$t} = \frac{\Delta_t}{\rho\theta^2\sigma^2} \tag{3}$$

Taking the cross-currency basis as given, a rise in counterparty risk, exchange rate risk and risk aversion lead to a lower supply of dollars.[15]

3.2 Bank

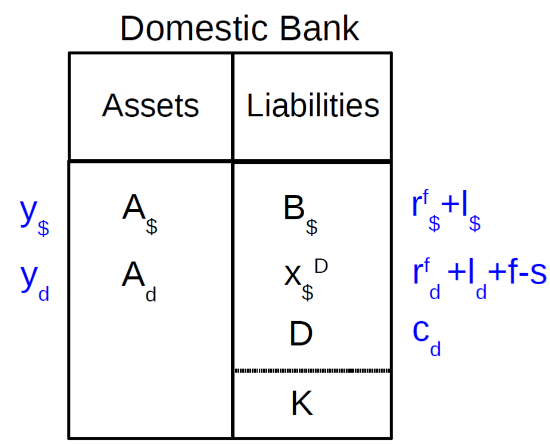
I consider an International bank with headquarters domiciled outside the U.S. At headquarters, the bank operates the domestic currency side of the balance sheet, and invests in domestic

[14]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, $E_t e^{-\rho\theta x_{\$,t}s_{t+1}} = e^{-\rho\theta x_{\$,t}-\frac{1}{2}\rho\theta^2 x^2_{\$,t}\sigma^2}$. Taking logs and simplifying yields the expression in equation 2.

[15]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/\$ cross-currency basis during the financial crisis of 2008, and subsequently in the euro crisis.

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 $A_\$$ on behalf of headquarters. Headquarters also provide domestic currency funding to its U.S. subsidiary, which are then swapped into dollars. I denote this as the level of synthetic dollar funding $x_\$^D$. A stylized representation of the consolidated balance sheet is illustrated in Figure [1].[16]

Figure 1: Bank Balance Sheet



The asset returns are stochastic with distributions $\tilde{y}_d \sim N(y_d, \sigma_d^2)$ 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_d^f. It then engages in a forex 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 forex swaps.

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

Empirical evidence in support of convex hedging costs is found in Abbassi and Bräuning (2018). Using detailed forex swap trades for a set of German banks, they find that banks that have to pay a dollar borrowing premium that is increasing in the size of their dollar funding gap, which is the amount of dollars obtained via forex swaps to hedge currency exposure. They

[16]The balance sheet reports the assets and liabilities of headquarters and its U.S. subsidiary.

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. Other reasons for a convex hedging cost include the cost of providing dollar collateral. As the size of the swap position increases, the bank is required to post an increasing amount of dollar collateral for the dealer to accept the transaction. Regulations on interoffice funding of US branches of foreign (non U.S.) banks may also be a factor. For example, a tax on interoffice flows, such as the BEAT tax implemented in 2018, makes synthetic dollar funding more costly, all else equal.[17] The convex hedging cost has the additional property of creating an imperfect substitution between the direct and synthetic sources of dollar funding. This is consistent with banks in practice, as U.S. subsidiaries typically have a mix of direct and synthetic dollar funding.[18]

Portfolio Problem

The bank maximizes the value of the portfolio after the realization of asset returns, subject to equations 5,6,7 and 8. Equation 5 is a value at risk constraint which determines the optimal risk-adjusted weights of domestic and dollar assets. This constraint is also seen in Adjiev et al (2016).[19] Equation 6 states that bank equity K is the difference between total assets and total liabilities. Equation 7 states that the balance sheet of the bank is currency neutral, and dollar assets are entirely funded by direct or synthetic dollar funding. This is consistent with banking regulations that are designed to impose capital charges on banks that have unhedged currency exposure Abbassi and Bräuning (2018). Equation 8 is a constraint on dollar denominated debt to be within a fraction γ of bank capital. To justify this constraint, in practice, non U.S. banks direct dollar borrowing is relatively uninsured compared to domestic currency liabilities for a non U.S. bank.[20]

[17] For more details on the BEAT tax, please refer to a recent Financial Times article, https://ftalphaville.ft.com/2018/03/23/1521832181000/Cross-currency-basis-feels-the-BEAT/. The article clearly states that as U.S. subsidiaries now have to pay a tax on interoffice funding they obtain from headquarters. This also has the indirect effect of causing a substitution toward commercial paper markets as a direct consequence of interoffice flows being taxed.

[18] For details of U.S. subsidiaries of foreign (non U.S.) banks share of synthetic dollar funding, please refer to Table 8 for more details. I find that for the majority of U.S. subsidiaries, there is typically a mix of synthetic and direct dollar funding.

[19] In Avdjiev et al. (2016) the authors consider a setup of a bank that is engaged in supplying dollars in the forex 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 dealer arms. In my model, the bank is demanding dollars via forex swaps, and the dealer is supplying dollars.

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

$$\max_{A_{d,t},A_{\$,t},x^D_{\$,t},B_{\$,t},D_{d,t}} V_{t+1} = \tilde{y}_d A_{d,t} + \tilde{y}_\$ A_{\$,t} - (\ell_\$ + r^f_\$)B_{\$,t} - (\ell_{d,t} + r^f_d + f_t - s_t)x^D_{\$,t,} - c_d D_{d,t} - F(x^D_{\$,t}) \tag{4}$$

Subject to

$$a^T \Sigma a \leq \left(\frac{K}{\alpha}\right)^2, a = \begin{bmatrix} A_{d,t} & A_{\$,t} \end{bmatrix}^T \Sigma = \begin{bmatrix} \sigma^2_d & \sigma_{d,\$} \\ \sigma_{d,\$} & \sigma^2_\$ \end{bmatrix} \leq \left(\frac{K}{\alpha}\right)^2 \tag{5}$$

$$K = A_{d,t} + A_{\$,t} - D_{d,t} - B_{\$,t} - x^D_{\$,t} \tag{6}$$

$$A_{\$,t} = x^D_{\$,t} + B_{\$,t} \tag{7}$$

$$B_{\$,t} \leq \gamma K \tag{8}$$

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 9 to 12, where the Lagrangian for constraints 5,6,7 and 8 are given by ϕ_t, μ_t λ_t and ξ_t.

$$\begin{matrix} A_{d,t}: \\ A_{\$,t}: \end{matrix} \quad \begin{bmatrix} y_d \\ y_\$ \end{bmatrix} - 2\phi_t \Sigma \begin{bmatrix} A_{d,t} \\ A_{\$,t} \end{bmatrix} - \begin{bmatrix} \mu_t \\ \mu_t + \lambda_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{9}$$

$$x^D_{\$,t}: \quad -(\ell_{d,t} + r^f_d + f_t - s_t) - F'(x^D_{\$,t}) + \lambda_t + \mu_t = 0 \tag{10}$$

$$D_{d,t}: \quad -c_d + \mu_t = 0 \tag{11}$$

$$B_{\$,t}: \quad -\ell_\$ - r^f_\$ + \mu_t + \lambda_t - \xi_t = 0 \tag{12}$$

Using equations 10 and 12, I can express the relation between direct and synthetic dollar borrowing costs in equation 13.

$$\underbrace{\ell_{d,t} + r^f_d + f_t - s_t + F'(x^D_{\$,t})}_{\text{synthetic dollar cost}} = \underbrace{\ell_{\$,t} + r^f_\$ + \xi_t}_{\text{direct dollar cost}} \tag{13}$$

This condition can be interpreted as a law of one price in bond issuance, after covering exchange rate risk with a forward contract. Recall that the cross-currency basis is defined as the excess of the forward premium over the interest rate differential, $\Delta_t = f_t - s_t + r^f_d - r^f_\$$. The cross-currency basis can then be expressed as the difference between dollar and domestic credit spreads. In other words, CIP deviations (measured in a risk-free rate) reflect differences in funding costs across currencies. [21]

[21] The relationship between covered interest rate parity deviations and law of one price deviations in bond pricing has been studied in the following papers Liao (2018); Rime et al. (2017); Kohler and Müller (2018).

$$\Delta_t = \ell_{\$,t} - \ell_{d,t} + \xi_t - F'(x^D_{\$,t}) \tag{14}$$

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 15). The solution for the optimal allocation of direct and synthetic dollar funding is dependent on whether the bank is in the constrained or unconstrained regions of dollar borrowing (equation 16). Dollar borrowing is similarly defined as a fraction of equity if the bank is constrained, or alternatively the difference between dollar assets and the optimal level of swap funding in the event the bank is unconstrained.

$$\begin{bmatrix} A_{d,t} \\ A_{\$,t} \end{bmatrix} = \frac{K}{\alpha\sqrt{R^T\Sigma^{-1}R}}\Sigma^{-1}R \tag{15}$$

$$x^D_{\$,t} = \begin{cases} F'^{-1}\left(\ell_\$ - (\ell_d + \Delta)\right) & \xi_t = 0 \text{ [unconstrained]} \\ A_{\$,t} - \gamma K & \xi_t \neq 0 \text{ [constrained]} \end{cases} \tag{16}$$

$$B^D_{\$,t} = \begin{cases} A_{\$,t} - \frac{\ell_\$ - (\ell + \Delta)}{\ell'_d(x^D_{\$,t})} & \xi_t = 0 \text{ [unconstrained]} \\ \gamma K & \xi_t \neq 0 \text{ [constrained]} \end{cases} \tag{17}$$

Equilibrium

In a market of N dealers, each dealer will receive orders from the bank, $x^D_{j,\$}$, where $[j= 1]N\sum x^D_{j,\$} = x^D_\$$. Assuming dealers are symmetric, and have the same risk aversion and capacity to supply dollars in the market. Each dealer supplies an optimal level of dollars x^* determined in equation 3.

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

1. *Dealers supply $x^*_{\$,t}$ dollars, optimizing mean-variance preferences over wealth (equation 3).*

2. *A representative bank demands $x^D_{\$,t}$ dollars, optimizing the value of their portfolio (equation 16).*

3. *The Dealer sets Δ_t such that bank demands for dollar funding are directly met by dealer supply. $x^D_{\$,t}(\Delta_t) = Nx^*_{\$,t}(\Delta_t)$*

3.3 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 Vayanos and Vila (2009); Williamson et al. (2017). Central bank purchases of private sector debt reduce the effective market supply of private debt. Preferred habitat theory suggests that the relative decline in the supply of private bonds raises prices and lowers yields. This compresses domestic credit spreads, defined as the difference between the bond yield and a risk-free rate.[22]

I capture the effects of QE as causing a decline in the domestic credit spread. This creates a wedge between synthetic and direct dollar borrowing costs, causing the bank to reallocate dollar funding toward forex swaps. To absorb excess demand for dollar funding. dealers raise the premium to swap domestic currency into dollars. A formal statement of the effects of QE is provided in proposition 1.

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.*

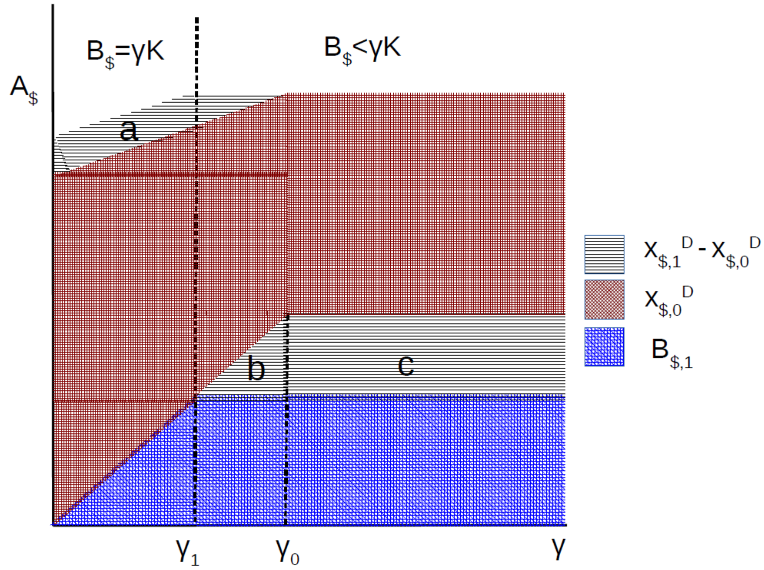
2. *In equilibrium, dealers increase the premium at which domestic currency is swapped into dollars. The cross-currency basis widens for banks in both the unconstrained and constrained regions of direct dollar borrowing,*

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

Proof: See Appendix

[22]Mathematically, let us keep the level of demand for private-sector bonds fixed. Then, a decline in market supply requires a fall in bond yields to induces banks to increase supply to the market.

Figure 2: Allocation of direct and synthetic dollar funding sources for banks with varying γ. Both initial and final equilibrium after QE is shown.



To further illustrate the effects of QE on bank demands for direct and synthetic dollar funding, Figure 2 characterizes the bank's new equilibrium allocation of dollar funding for varying levels of γ . The threshold γ^* is the boundary at which a bank transitions from the unconstrained to constrained regions of direct dollar borrowing.

$$\gamma^* = \frac{A_\$ - F'^{-1}(\ell_\$ - (\ell_d + \Delta))}{K} \tag{18}$$

The total increase in bank demands for dollar funding after QE is denoted by the area $x^D_{\$,1} - x^D_{\$,0}$. The area $b + c$ in the diagram denotes a reallocation of dollar funding toward forex swaps for banks in the region of unconstrained dollar borrowing, with $\gamma \geq \gamma_1^*$. In contrast, for constrained banks with $\gamma \geq \gamma_1^*$, the channel of increased demand for dollar funding works through QE causing an increase in the excess return on dollar assets. [23] This causes a portfolio rebalancing to hold more dollar assets, which can only be hedged by dollar funding via forex swaps. The increase in synthetic dollar funding by constrained banks is denoted by area a in the Figure.

3.4 Negative interest rates

An unanticipated decline in the central bank rate leads to a differential rate of pass-through to loan rates and deposit rates at the zero lower bound. Mathematically, I impose simple functional forms for domestic loan and deposit rates. $y_d = r_m + \mu_A$, and $c_d = min\{0, r_m\}$.

[23]Recall the excess return on dollar assets is equal to $R_{\$,t} = y_\$ - (\ell_{d,t} + r^f_\$ + \Delta_t + F'(x^D_\$))$. A decline in domestic credit spreads, all else equal, causes a rise in the dollar excess return.

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.[24]

A decline in r_m in the region $-\mu_A < r_m < 0$ reduces the excess return on domestic assets. To hedge the dollar asset position, the bank raises its demand for dollars via forex swaps. Dealers absorb the increase in demand by raising the premium banks pay to swap domestic currency into dollars. In the new equilibrium, the bank now has a higher share of dollar assets in its portfolio. This is formally stated in proposition 2.

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 forex swaps.*

2. *In equilibrium, dealers increase the premium at which domestic currency is swapped into dollars. The cross-currency basis widens for banks in the constrained region of dollar borrowing,*

$$\frac{\partial \Delta}{\partial r_m} = \begin{cases} 0 & , \xi_t = 0 \text{ [unconstrained]} \\ -\frac{R_d}{\frac{NR^TR}{\rho\theta\sigma^2 A_\$} + \left(1 + \frac{NF''(x^D_\$)}{\theta\rho\sigma_s^2}\right)\left(\frac{R^TR}{R_\$} + R_\$\right)} < 0 & , \xi_t \neq 0 \text{ [constrained]} \end{cases}$$

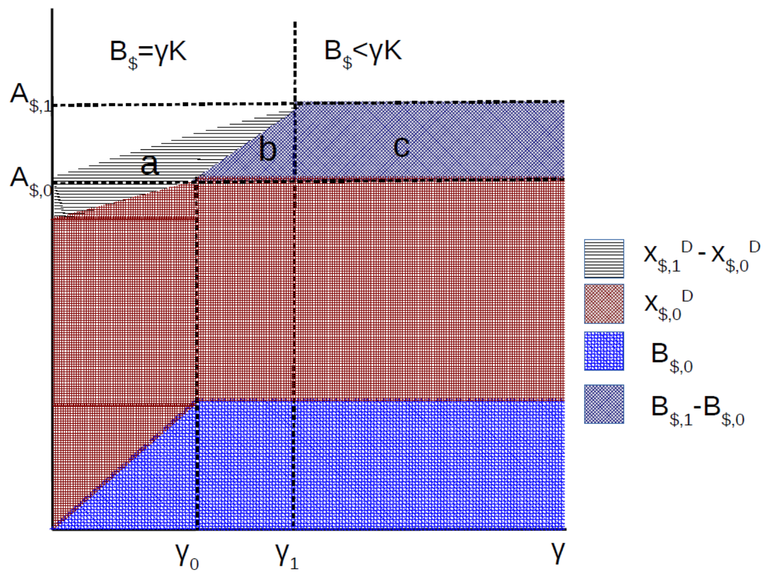
Proof: See Appendix

To further illustrate the effects of negative interest rates on bank demands for direct and synthetic dollar funding, Figure 3 characterizes the bank's new equilibrium allocation of dollar funding for varying levels of γ . Negative interest rates reduce the excess return on domestic

[24]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), for more details refer to the literature review at the end of section 1.1. The assumption of differential pass-through to loan and deposit rates has also been used in theoretical banking models Ulate (2018); Brunnermeier and Koby (2016). While these models focus on the general equilibrium effects of negative interest rates on lending and leverage of financial intermediaries, I also document a decline in domestic lending, and a rebalancing to hold more dollar assets.

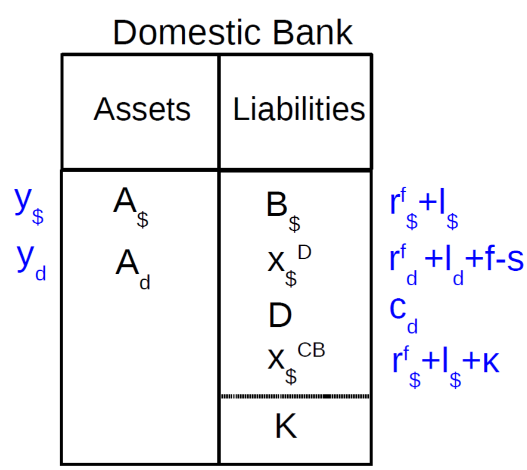
assets, causing a portfolio rebalancing to hold more dollar assets. Banks in the unconstrained region can fund additional dollar assets by borrowing dollars directly, this is denoted by area $b + c$ in the diagram.[25] In contrast, only constrained banks hedge the additional demand for dollar assets by borrowing dollars synthetically, this increase is denoted by area a.

Figure 3: Allocation of direct and synthetic dollar funding sources for banks with varying γ. Both initial and final equilibrium after negative rates is shown.



3.5 Central Bank Swap Lines

Figure 4: Bank Balance Sheet



[25]In the initial equilibrium, an unconstrained bank has equal costs of direct and synthetic dollar funding, $\underbrace{\ell_{d,t} + \Delta_t + F'(x^D_{\$,t})}_{\text{synthetic dollar cost}} = \underbrace{\ell_{\$,t}}_{\text{direct dollar cost}}$ .Therefore, as synthetic dollar funding cost is convex, $F''(.) > 0$, at the margin, an unconstrained bank will choose direct dollar funding.

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 were a policy tool used in 2008, in which the Federal Reserve engaged 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.

To formalize the effect of central bank swap lines, 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 2008Ivashina et al. (2015). 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. The revised balance sheet of the bank is provided in Figure 4[26].

The solution of the bank portfolio is now characterized by the same equations. 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 19 and 20. 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.

$$x^D_{\$,t} = \begin{cases} F'^{-1}\left(\ell_{\$} - (\ell_{d,t} + \Delta_t)\right) & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_{\$} \\ A_{\$,t} - (\gamma - \psi)K & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) < \ell_{\$} + \kappa \\ F'^{-1}\left(\ell_{\$} + \kappa - (\ell_{d,t} + \Delta_t)\right) & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_{\$} + \kappa \end{cases} \tag{19}$$

$$x^{CB}_{\$,t} = \begin{cases} 0 & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) < \ell_{\$} + \kappa \\ A_{\$,t} - (\gamma - \psi)K - x^D_{\$,t} & \ell_{d,t} + \Delta_t + F'(x^D_{\$,t}) = \ell_{\$} + \kappa \end{cases} \tag{20}$$

[26] 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.

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:*

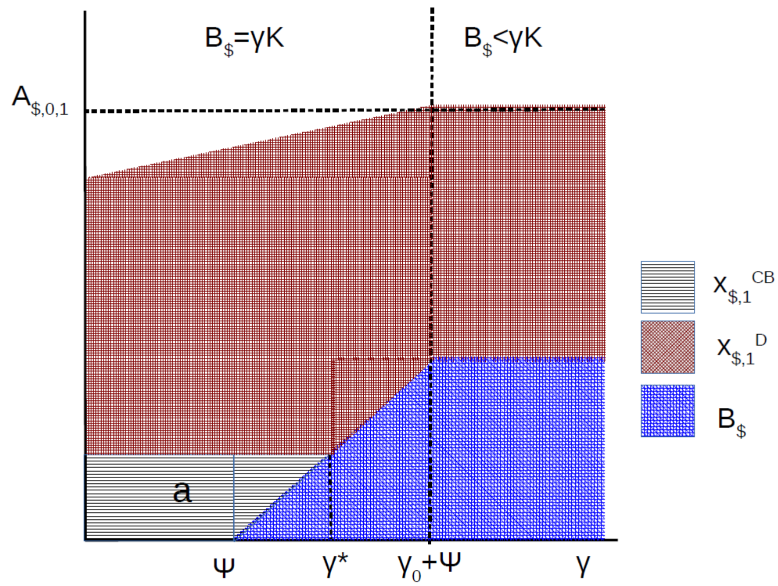
1. *A substitution from dollar funding in swap market to using the central bank swap line for banks with a sufficiently high synthetic dollar cost,*$\ell_{d,t} + \Delta_t + F'(x^D_{\$,0}) > \ell_\$ + \kappa$*.*

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

Figure 5 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^*. 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) . [27]

[27] They study an exogenous decline in κ to model the effects of a Federal Reserve announcement on October 30, 2011, in which the penalty rate on swap line auctions were reduced from 100 basis points above an interbank dollar rate to 50 basis points. They provide event study analysis showing a decline in CIP deviations following 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 5: 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.



3.6 Numerical 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.[28] 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.[29] Third, I set a ratio of total dollar assets to equity of one in the initial period.

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

[28] 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 $\Gamma = \frac{\rho\theta\sigma^2}{N}$.

[29] For details of data, please refer to empirical section 4.3 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.

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 1 summarizes all relevant parameters in the calibration.

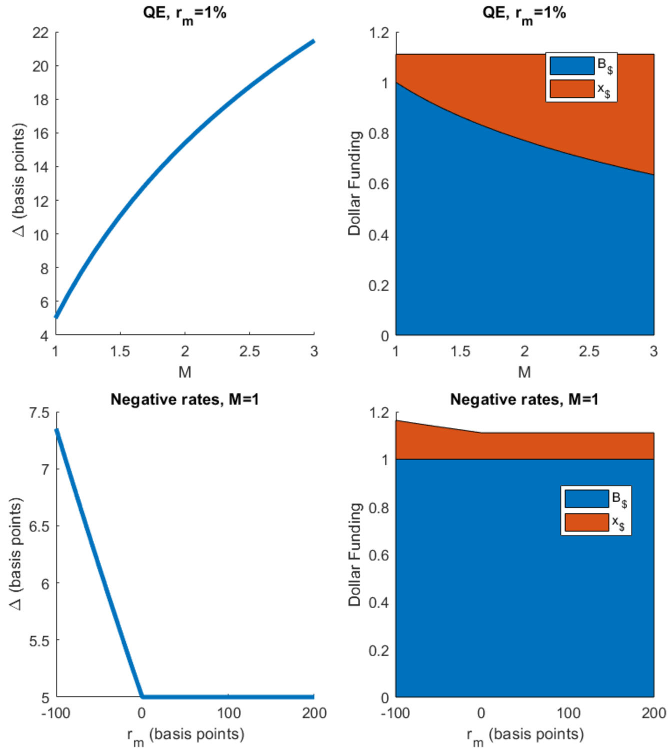
Table 1: **Calibration of Parameters: Initial equilibrium**

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

Figure 6 shows the effect of QE and negative interest rates on the equilibrium cross-currency basis. 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 forex 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 forex 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 preceding results is the linear supply curve of dollars in the forex 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 6: Top: equilibrium Δ and allocation of dollar funding for a range of QE
Bottom: Equilibrium Δ and allocation of dollar funding for a range of central bank rate r_m



To conclude, the model has provided a rationale for the effects of QE and negative interest rates on the forex 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 forex swaps. Negative interest rates increase the relative return on dollar assets, causing the bank to increase dollar funding via forex swaps to hedge exchange rate risk. In times of crisis, swap line auctions provide an incremental source of dollar funding that banks substitute towards, mitigating bank demands for dollar funding, with a consequent narrowing of the cross-currency basis.

figuresection

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 forex swap market increase, dealers absorb this excess demand by raising the premium at which euros, Swiss francs and yen are swapped into dollars, causing a widening of the cross-currency basis. To identify the effects of monetary policy on the cross-currency basis, I examine the change in interest rate futures in a high-frequency window around scheduled monetary announcements of the ECB, BOJ and SNB. I document a widening of the cross-currency basis for the euro/$, yen/$ and chf/$ around negative interest rate announcements, and show this effect is robust to CIP deviations at maturities across the term structure.

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 forex swap market. Therefore, the share of synthetic dollar funding to total dollar assets should increase. To test this, I use data on interoffice funding of U.S. subsidiaries of banks in the Euro area, Japan and Switzerland as a proxy for the level of synthetic dollar funding. In response to a decline in domestic credit spreads, I document an increase in the share of synthetic dollar funding, all else equal.

4.1 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 other papers Ranaldo and Rossi (2010); Brusa et al. (2016).

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. [30]A summary

[30]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

of interest rate futures for the central bank policy rate is provided in Table 2. Descriptive statistics for the foreign monetary shocks, including contract length, are provided in Table 3.

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

Cross-currency basis

At long maturities of greater and equal to 1 year, I use the cross-currency basis available at Bloomberg. At short maturities less than or equal to 3 months, I calculate CIP deviations using Bloomberg spot rates and forward swap points. Forward swap points, denoted sp, are quoted as the difference between spot and forward rates, $F = S + \frac{sp}{10^4}$. I compute deviations for a tenor of 1 month and 3 month using LIBOR as the benchmark rate[31]. I calculate spot and forward rates expressed in dollars per unit of domestic currency. The CIP deviation is then calculated as the difference between the local dollar borrowing rate less the synthetic dollar borrowing rate, where i_q is the US LIBOR, i_b is the domestic (non U.S.) interest rate in LIBOR, S_a is the ask spot rate and F_b is the bid forward rate. A negative Δ indicates that synthetic dollar borrowing costs exceed local borrowing costs.

$$\Delta = 1 + i_q \frac{tenor}{360} - \frac{F_b}{S_a}(1 + i_b \frac{tenor}{360})$$

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. To infer credit spreads, 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. [32]

day of the month, and D_0 is the number of days in that month.

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

[31] When the US dollar is the base currency, we calculate the synthetic dollar premium as follows: Where i_b and i_q are the base and quoting currency interest rates, S_b and F_a are the spot bid and forward rates.

$$\Delta = 1 + i_b \frac{tenor}{360} - \frac{S_b}{F_a}(1 + i_q \frac{tenor}{360}) \quad (21)$$

[32] 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

4.2 Monetary Surprises and CIP Deviations

4.2.1 HF 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 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. The deposit facility rate was then 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. The SNB implemented a negative rate on sight balances of 25 basis points on 18th December, 2014.[33] 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.[34] 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 cross-currency basis 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.

4.2.2 HF 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. However, the only example of 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 3, August 10 and August 17 of 2011 increased the level of sight deposits from 30B Chf to 80B Chf on August 3rd, which was subsequently increased to 120B Chf on August 10th,

[33] 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%.

[34] https://www.boj.or.jp/en/announcements/release_2016/k160129a.pdf

and finally 200B Chf on August 17. The SNB then decided to set of a floor of 1.20 Chf per Euro on September 6th, and proposed to intervene in forex 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 in response to these policies. Examining the cross-currency basis of the Chf/$ around these announcements at a high frequency, there is evidence of a significant widening of deviations shortly after each announcement. Deviations widen by 10 basis points on August 3 and August 10, and by 30 basis points on August 17 (Figure 12).

4.2.3 Interest rate future shocks

To more formally test for a contemporaneous response of the cross-currency basis to monetary surprises, I regress daily changes of the cross-currency basis 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 cross-currency basis.[35]

$$CIP_t - CIP_{t-1} = \alpha + \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t \tag{22}$$

In equation 22, I hypothesize that expansionary monetary surprises cause the cross-currency basis of the euro/$, chf/$ and yen/$ pairs to become more negative in the regime of unconventional monetary policy. Formally, I test if the effect γ is greater than zero. In contrast, deviations prior to the period of unconventional policy should be unresponsive to monetary policy, $\beta = 0$. The starting date for unconventional monetary policy in Japan is August of 2010. This is 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 for unconventional monetary policy is June of 2014. This is when the deposit facility rate first became negative 10 basis points.

I test for the effects on the cross-currency basis at maturities of 1m, 3m, 1Y, 5Y and 10Y. Results for each currency pair are shown in Tables 4,5 and 6. The effects on the cross-currency basis are consistent with the model. There is a sensitivity to monetary surprises at all maturities, and the estimates are typically higher at shorter maturities.

To examine whether there are more persistent effects, I use the method of local projections to trace an impulse response of the monetary shock at a horizon h. The specification is shown in equation 23, and uses additional explanatory variables, including lags of the outcome variable,

[35] I define the cross-currency basis as the difference between the direct and synthetic dollar borrowing rate, which are how deviations are expressed in Figure 1.

as well as a set of controls X_t which includes the trade weighted dollar exchange rate, VIX volatility index and the USD LIBOR-OIS spread. I regress the change in the outcome variable at horizon h, the cross-currency basis and credit spread, on the monetary shock MP_t.

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_i + \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + \sum_{l=1}^{L} A_l Y_{i,t-l} + X_t + \epsilon_t, \;\; h = 0, 1, 2, ...10 \tag{23}$$

I present results for a 1 basis point expansionary shock of the ECB, BOJ and SNB in the period of unconventional monetary policy in Figure 13. I find evidence of a permanent widening of cross-currency basis and a decline in domestic credit spreads for the euro, Swiss franc and yen, consistent with the predictions of the model.

4.2.4 Robustness tests

The empirical results so far have used a measure of CIP deviations based on the LIBOR rate as the benchmark rate with which to compare domestic and dollar borrowing costs. This 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 in the interbank market. However, the model makes a prediction about mispricing of the *forward premium* in response to an excess demand for dollar funding in the forex swap market. If this is so, then this should theoretically affect CIP deviations based on a variety of benchmark rates.

I now test the specification in equation 23, where the measure of the CIP deviation is now based on the Treasury yield as the benchmark rate. Data construction and regression results are provided in the Appendix section 5. Consistent with the model prediction, I find an expansionary monetary surprise in the period of unconventional monetary policy cause a widening of the Treasury basis, and the result is stronger at longer maturities, and of a similar magnitude to the effects on the LIBOR basis. This suggests that it is the common element, the forward premium, that dealers are adjusting in response to monetary announcements. As well as domestic monetary announcements, I also observe that monetary announcements of the Federal Reserve in the period 2008-2012 has an effect of narrowing the Treasury basis. This is intuitive, as the model predicts an expansionary QE announcement by the Federal Reserve should have an equal and opposite effect.[36]

[36] One can also interpret the Treasury basis as a liquidity and safety premium an investor earns on a U.S. Treasury bond. The idea of a safety or liquidity premium afforded to Treasuries has been seen in the following papers Du et al. (2018b); Jiang et al. (2018). Given the Treasury basis measures a relative scarcity of safe assets, QE by the Federal Reserves results in an increase in the relative supply of safe Treasury assets. This will cause a decline in Treasury yields, and a decline in the safety and liquidity premium associated with holding U.S. treasuries, all else equal.

4.3 Bank Holdings of Forex Swaps: Cross-Sectional Evidence

A testable prediction of the model is that both QE and negative interest rates lead banks in the Eurozone, Japan and Switzerland to substitute toward synthetic dollar funding. Therefore, I expect the fraction of synthetic dollar funding to total dollar assets should increase. While there is no official data on forex swap holdings at a bank level, 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.[37] The key variables I use from the call reports are total dollar assets and net flows due to the head office.[38] Interoffice flows measure funding U.S. subsidiaries of foreign (non U.S) banks receive from head quarters. I use this as an approximation of the bank's amount of dollar funding via forex swaps. This is a valid approximation under two assumptions. First, I assume the head quarters of the non U.S. bank only has access to domestic currency funding sources. Second, the U.S. subsidiary's balance sheet only consists of dollar assets. When these conditions are met, all interoffice flows are domestic funding swapped into dollars. [39]

Table 7 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 7). 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.

To formally test for the effect of unconventional monetary policy on the share of synthetic funding, I use the specification in equation 24.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

[37]The relevant form for non-U.S. bank balance sheet items is the FFIEEC 002.

[38]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".

[39]Even if those assumptions are met, interoffice flows can still be misrepresentative of the actual level of dollar funding the bank obtains via forex swaps. Suppose the bank headquarters directly manages the dollar asset position of the bank. In this case, they can tap into its domestic sources and swap into dollars without requiring the U.S. subsidiary. Second, suppose the U.S. subsidiary can directly issue a domestic currency bond, and can then swap their domestic funding into dollars. In both instances, interoffice flows are an understatement of the true level of dollar funding via forex swaps.

headquarters in country i, and period t is quarterly.[40] Explanatory variables X_{it} include the difference between the domestic and US dollar risk-free rates, and the domestic corporate credit spread.[41] In the former, I use one month OIS rates obtained from Bloomberg. These rates are a fixed-floating interest rate swap, and are a measure of a risk-free interbank rate. To test for a difference across periods of conventional and unconventional monetary policy, I interact the explanatory variable with U_{MP}, which is equal to 1 for the period in which the central bank implemented negative interest rates or QE. In addition, I incorporate time, country 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. Bank and country fixed effects absorb idiosyncratic factors such as differences in corporate structure, and country-specific funding shocks.[42] I choose 2007 as the starting period 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.

$$S_{ijt} = \alpha_i + \lambda_j + \gamma_t + \beta X_{it} + \delta X_{it} \times U_{MP,it} + \epsilon_t \tag{24}$$

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. In particular, the model predicts the effects should be stronger in the period of unconventional monetary policy. I therefore hypothesize that the net effect of unconventional monetary policy, $\beta + \delta$, should be negative. This indicates a decline in domestic interest rates and credit spreads cause a rise in the share of synthetic dollar funding, all else equal.

Results for U.S. subsidiaries with head quarters in the Euro area, Japan and Switzerland support these predictions (Table 8). In specification 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 specification 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 by approximately 20 basis points during this period. The higher sensitivity of synthetic dollar

[40] 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.

[41] I construct a proxy for the corporate credit spread, using Bloomberg corporate bond indices for 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. See data section for more details on construction.

[42] 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. Some banks may prefer to manage its dollar balance sheet activities at headquarters, in which case interoffice flows are negligible.

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 forex swaps.

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. Specification 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.

I conduct regressions for a set of banks with headquarters in control 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 specifications 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. These deviations are suggestive of a dollar financing premium for banks swapping euros, Swiss francs and yen into dollars.

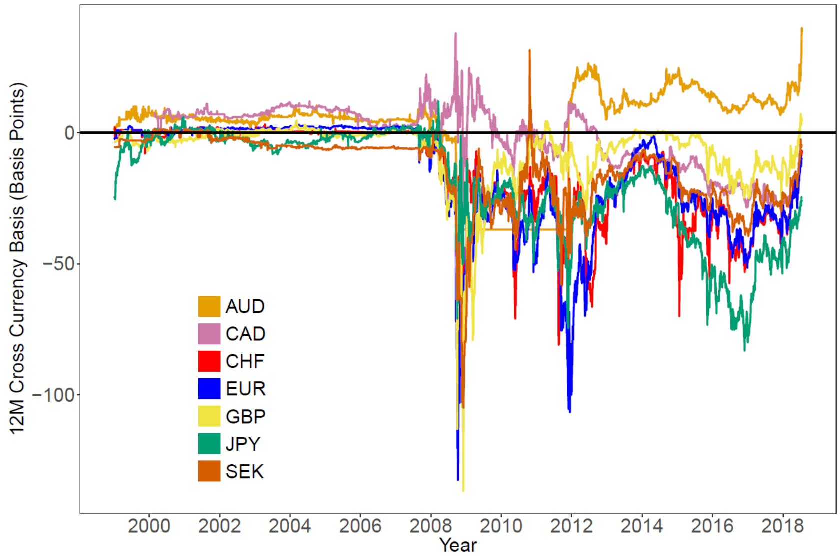
I propose a theory in which the unconventional monetary policies of the ECB, BOJ and SNB are the key factor explaining the persistence of CIP deviations. I model QE as central bank purchases of privately-issued debt. In reducing the market supply of privately-issued debt, QE compresses domestic credit spreads. This reduces the cost of swapping euros, Swiss francs and yen into dollars. Banks therefore reallocate dollar funding toward forex 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 forex swaps. Both policies therefore increase bank demands for swapping euros, Swiss francs and yen into dollars. Dealers, who are intermediaries that take the other end of the forex swap, supply dollars in exchange for those currencies. Because dealers are risk averse, they face balance sheet risk proportional to the size of the swap position. To absorb the excess demand for dollar funding, they therefore raise the premium at which banks swap domestic currency into dollars, widening the cross-currency basis.

I then provide empirical evidence to support the predictions of the model. First, I observe a significant widening of the cross-currency basis for the euro/$, yen/$ and chf/$ around the negative interest rate announcements. The model also predicts, in response to a decline in domestic credit spreads induced by QE, a rise in bank demands for dollar funding. Using a proxy for holdings of forex swaps by U.S. subsidiaries of banks in the Euro area, Japan and Switzerland, I document a rise in the share of synthetic dollar funding to total dollar assets in response to a decline in domestic credit spreads.

This paper has implications for policy and suggestions for future work. First, CIP deviations can be interpreted as a tax on dollar funding for non U.S. banks. While a deviation of 50 basis points may be small, the daily turnover in forex swap markets amounts to $250B, and pairs of the euro/$ and yen/$ account for almost half of the turnover in all forex swaps. This suggests a sizable hedging cost to bank balance sheets that may cause inefficiencies in the bank's portfolio and erode bank profits. This implication can be tested formally using data. If verified the policy implications will need to be taken on board by policy makers concerned with the profitability and stability of their banking systems. In addition, this paper considers policies that can be implemented to correct dollar imbalances in global banking. Central bank swap lines have been shown to reduce CIP deviations by providing an incremental source of dollar funding. However, swap lines have typically only been drawn when banks endure a severe rollover crisis in dollar funding markets. But negotiating permanent swap lines might be undesirable for various reasons. For example, the domestic central bank may be forced to take a large amount of balance sheet risk. As the domestic central bank is now providing dollar liquidity, this may act against the macroeconomic policy platform of the domestic central bank in supporting domestic lending. All of this suggests that to the extent unconventional monetary policies of the Eurozone, Japan and Switzerland remain, there will be a structural imbalance in bank demands for dollar funding in the forex swap market. This means CIP deviations will continue to persist. This naturally implies that 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.

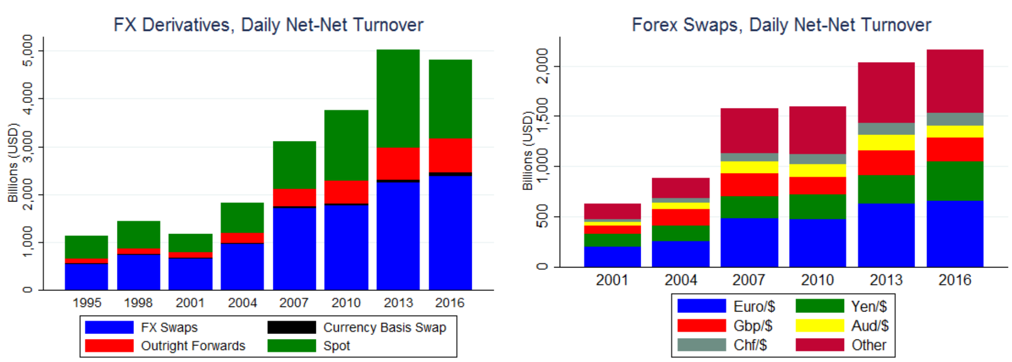
Figures

Figure 1: The puzzle of persistent CIP deviations



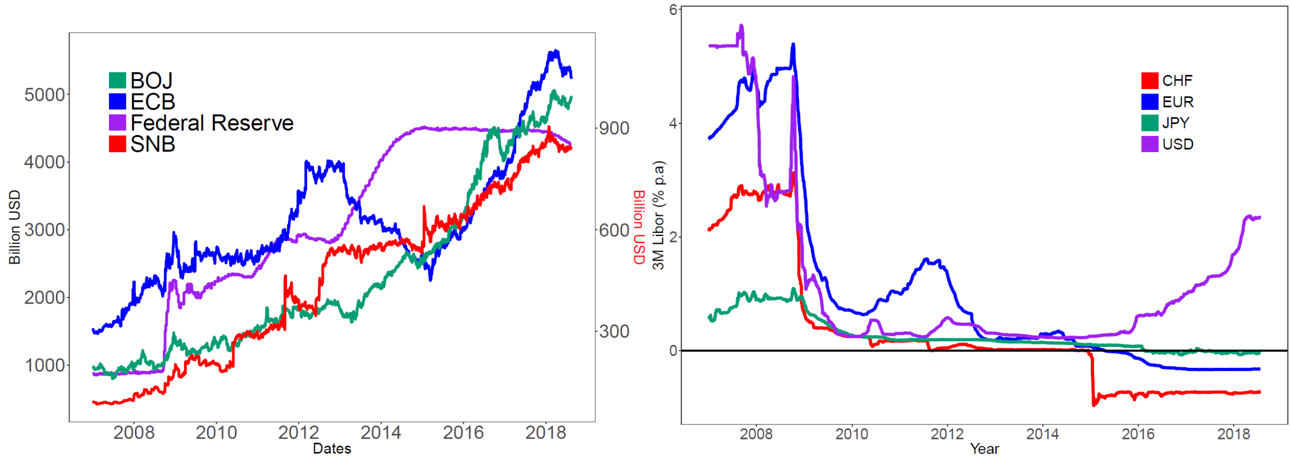
Note: 12M Cross-Currency Basis measured in basis points, obtained from Bloomberg. This provides a measure of CIP deviations based on a LIBOR benchmark rate. Negative deviations indicate a dollar borrowing premium for the euro/\$, chf/\$ and yen/\$ pairs. Formally, the CIP deviation Δ in this figure is given by the following formula, $\Delta = 1 + r^f_\$ - \frac{F}{S}(1 + r^f_d)$, where $r^f_\$$ and r^f_d are LIBOR rates in dollars and domestic currency, and S, F are the spot and forward rates expressed as dollars per unit of domestic currency.

Figure 2: BIS Triennial Survey: Daily Net-Net turnover in FX Derivatives and Spots (left) and currency allocation of Forex Swaps with USD as one of the swap legs.



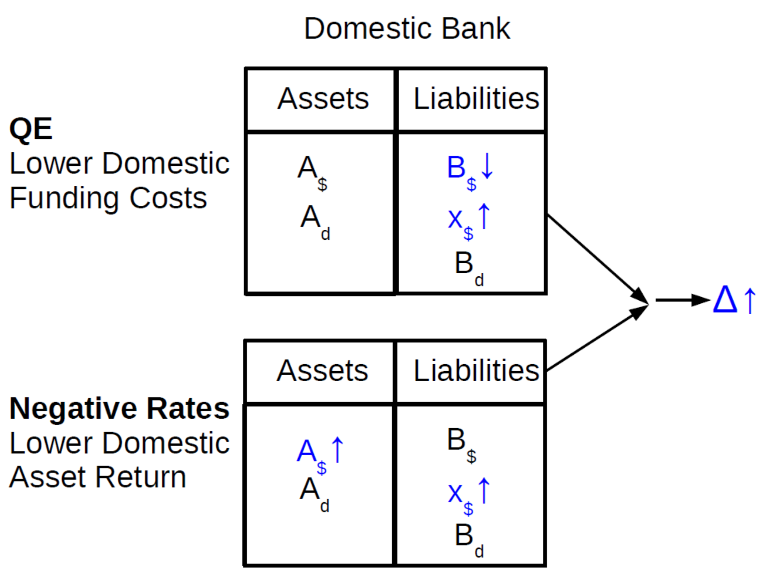
Note: Left: Total breakdown of FX derivatives daily net-net turnover, using BIS triennial survey. Right: Breakdown of Forex swaps by bilateral pairs involving one leg that is the USD.

Figure 3: Negative rate policies and QE implemented by ECB, BOJ and SNB



Note: Left is total assets of ECB, Federal Reserve, BOJ and SNB. SNB scale is on right-axis. Right: 3m LIBOR rates from Bloomberg.

Figure 4: Effects of negative rates and quantitative easing on the domestic bank balance sheet

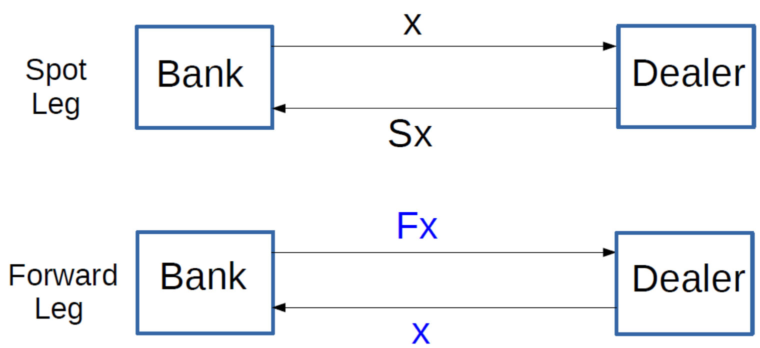


Note: This schematic illustrates the two theories of how unconventional monetary policy can affect the demand for swaps. QE works on the liability side of a domestic bank (where domestic refers to a bank domiciled in the Eurozone, Japan and/or Switzerland). As domestic funding costs decline, swaps $S_\$^{FX}$ become a cheaper source of funding than direct dollar borrowing $B_\$$, causing a reallocation of funding towards swaps. Negative rates work on the asset side, by reducing the relative return on domestic assets, the bank tilts towards holding dollar assets $A_\$$, which require increased swap funding. Both policies lead to an increase in bank demands for dollar funding via forex swaps. Dealer are financially constrained, and increase the dollar borrowing premium. This results in a widening of the cross-currency basis Δ.

Figure 5: Effects of a Federal Reserve swap line on a recipient bank balance sheet

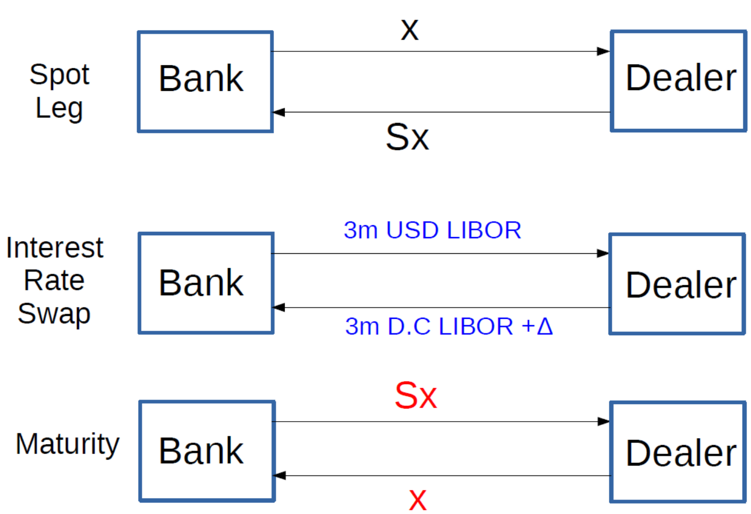
Note: This schematic illustrates the effects of swap lines. First, swap lines are an arrangement between the domestic central bank (domestic refers to banks from the Eurozone, Japan and Switzerland) and the US Federal Reserve to swap an amount S_d^{CB} for dollars at a specified exchange rate. The domestic central bank then uses the dollar liquidity to then lend to domestic banks. As they no longer need dollar funding from the swap market, dealers reduce the dollar borrowing premium, and the cross-currency basis narrows.

Figure 6: Foreign exchange swap



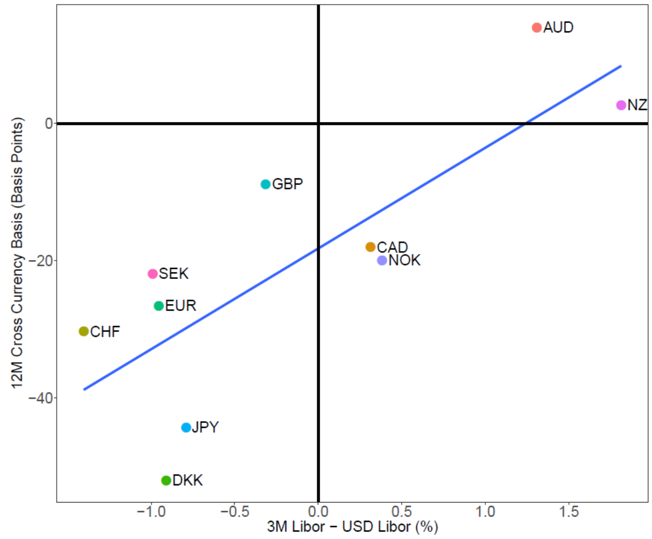
Note: Forex swap is typically for maturities at less than 3m. At the spot leg, domestic currency and dollars are swapped at the prevailing spot rate. At maturity, the principals are then re-exchanged at the forward rate.

Figure 7: Cross-currency swap



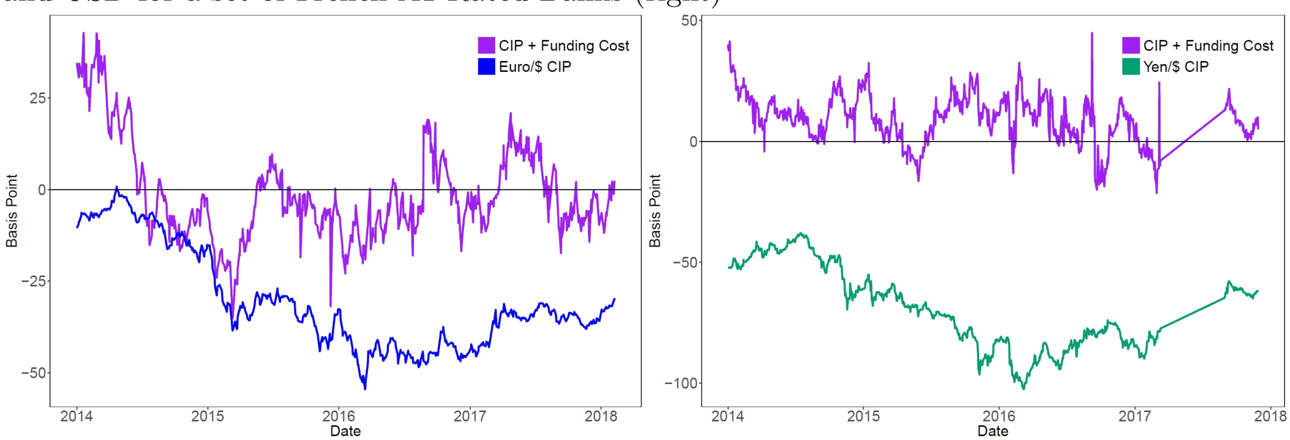
Note: The Cross-Currency Swap is typically for maturities >3m. In the spot leg, dollars are exchanged at spot. The bank and dealer then engages in an interest rate swap, in which the bank pays 3m USD LIBOR, and the dealer pays 3m LIBOR in domestic currency with the addition of the cross-currency basis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

Figure 8: Cross currency basis and LIBOR interest rate differential, advanced economies, 2014-present



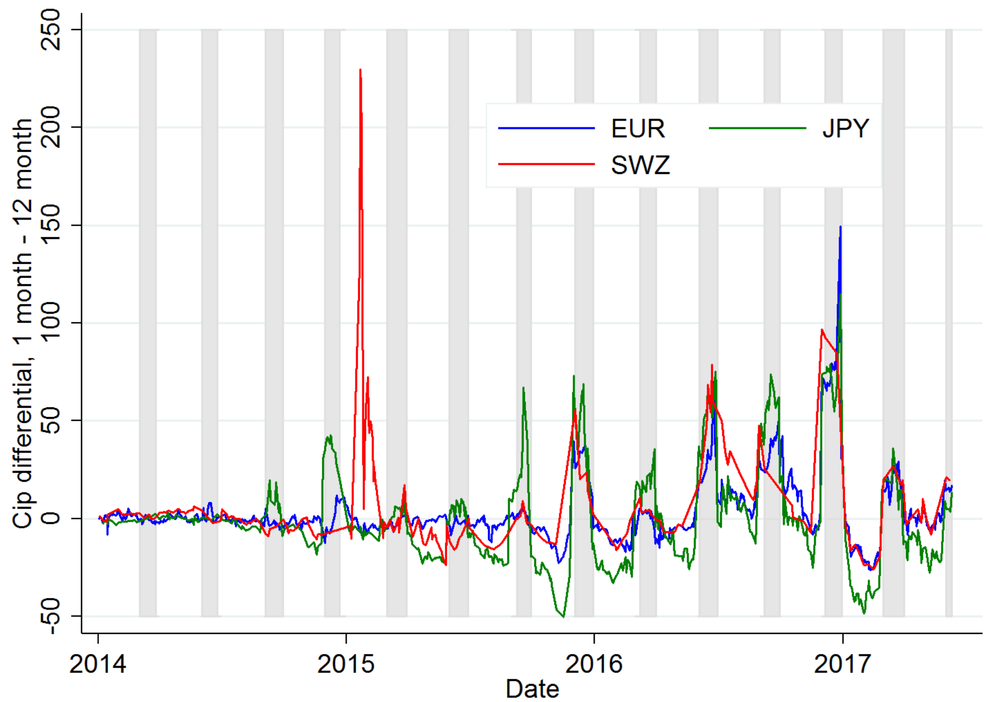
Note: This plot takes the average of the cross-currency basis and LIBOR interest rate differential in the period since 2014. Cross-currency basis is with respect to USD. Source: Bloomberg

Figure 9: Credit Spreads in Yen and USD for a set of Japan A1 Rated Banks (left) and Euros and USD for a set of French A1 Rated Banks (right)



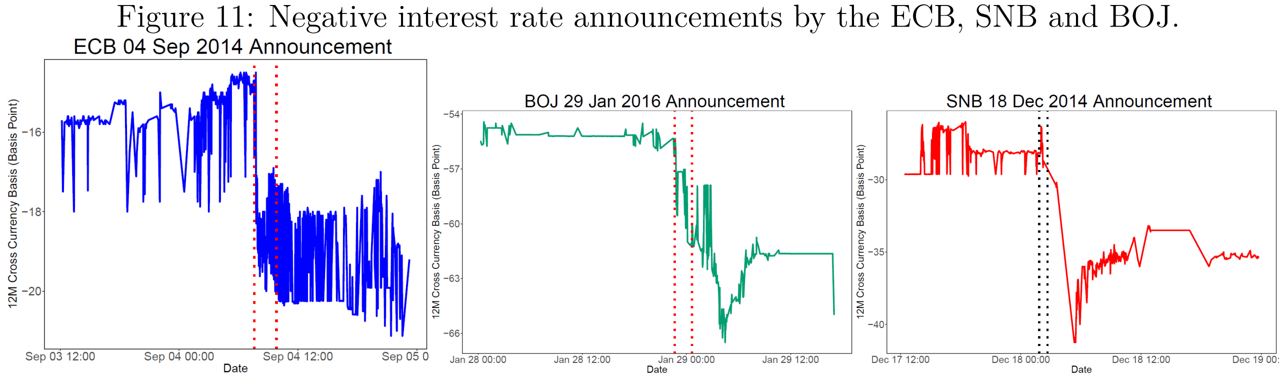
Note: This is a plot showing CIP deviations for the euro/$ (left) and yen/$ deviations, as well as a measure that takes into account funding costs across currencies. The CIP deviation used is the 5 year cross-currency basis.

Figure 10: Absolute CIP deviations of 1 month less 12 month spike at quarter-ends since 2015



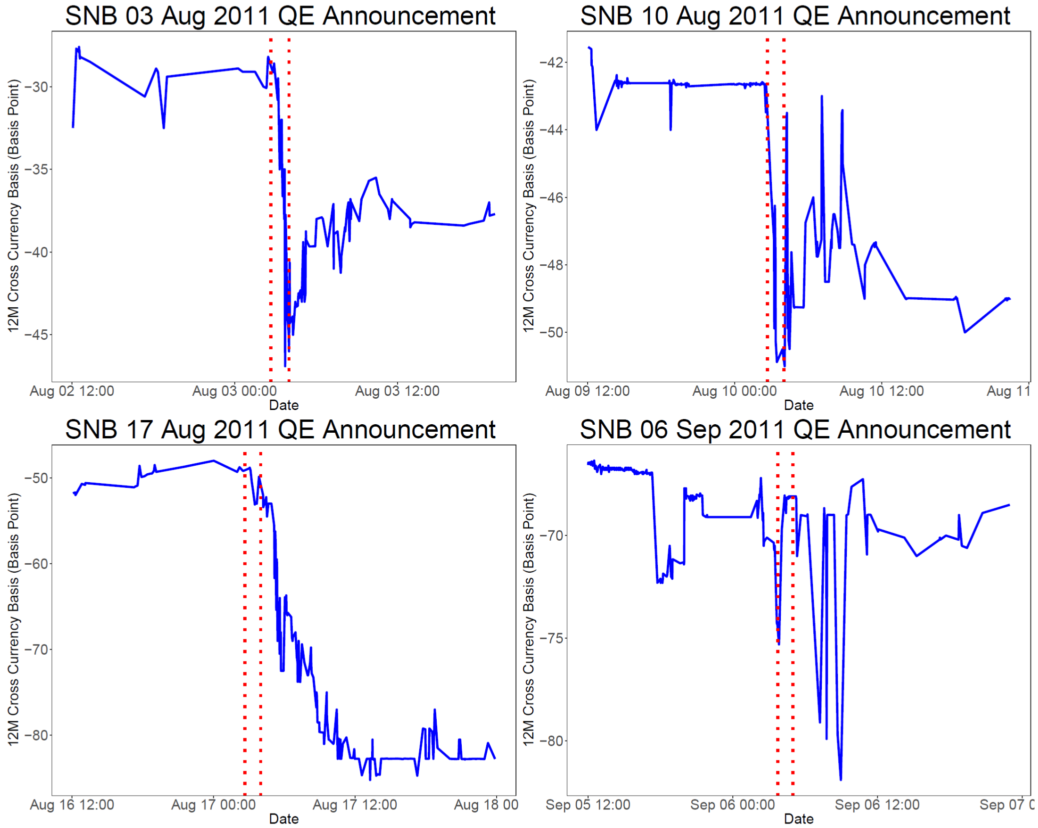
Note: This is a plot of absolute differences between 1 month and 12 month cross-currency basis. 1 month deviations are calculated using LIBOR as the benchmark rate. 12 month deviations is the cross-currency basis obtained from Bloomberg. Shaded areas indicate months preceding quarter-ends, March, June, September and December.

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



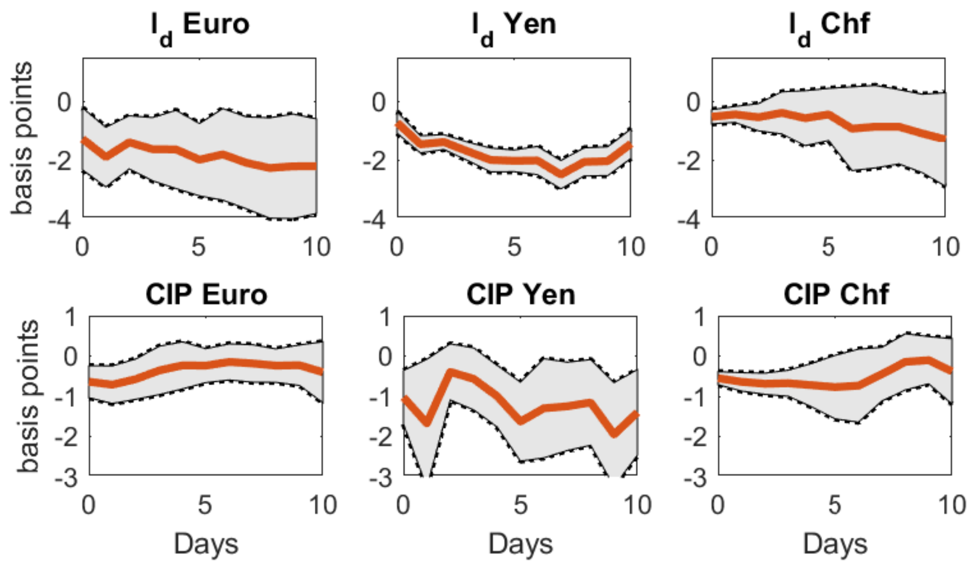
Note: Response of 12m cross-currency basis of the euro/$, chf/$ and yen/$ to negative interest rate announcements by the ECB, SNB and BOJ respectively. Source: Thomson Reuters Tick History

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



Note: Response of 12m cross-currency basis of the chf/$ around key announcements of the SNB in August and September of 2011. Source: Thomson Reuters Tick History

Figure 13: Response of 1y+ cross-currency basis and credit spreads in response to an expansionary monetary announcement



Note: I conduct local projections of 1m cross-currency basis, and 5 year credit spreads in response to a -1 basis point shock to the interest rate futures for the 90 day interbank rate.

Tables

Table 2: 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 3: Descriptive statistics, monetary shocks

	Mean	SD	p-5	p-25	p-50	p-75	p-95	Obs	Contract Period
$MP1_{\mathrm{US}}$	-0.012	0.076	-0.121	-0.010	0.000	0.040	0.210	168	07/95 - 09/16
MP_{SWZ}	-0.029	0.101	-0.180	-0.060	-0.010	0.010	0.080	90	02/91 - 09/16
MP_{UK}	-0.006	0.063	-0.090	-0.020	0.000	0.010	0.080	232	06/97 - 09/16
MP_{EU}	0.001	0.042	-0.060	-0.015	0.000	0.020	0.068	240	01/99 - 09/16

All values in percentage points

Table 4: Response of Euro/$ Cross-Currency Basis around ECB announcements

	1m	3m	1y	5y	10y
MP	-0.308	-0.115	-0.007	-0.126	-0.052
	(0.568)	(0.354)	(0.104)	(0.123)	(0.070)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	1.893	1.493	0.496	0.479	0.344
	(0.766)*	(0.590)*	(0.167)**	(0.157)**	(0.119)**
δ	1.585	1.378	0.489	0.353	0.293
	(.515)***	(.473)***	(.131)***	(.097)***	(.096)***
R^2	0.037	0.073	0.050	0.103	0.110
observations	117	117	119	121	121

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

Note: This table regresses the change in the Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled ECB monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 5: Response of Chf/$ Cross-Currency Basis around SNB announcements

	1m	3m	1y	5y	10y
MP	0.639	0.679	0.052	0.012	0.008
	(0.245)*	(0.225)**	(0.050)	(0.010)	(0.006)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.992	1.029	0.595	0.190	0.145
	(0.668)	(0.410)*	(0.099)***	(0.043)***	(0.038)***
δ	1.631	1.709	0.646	0.202	0.153
	(.622)***	(.342)***	(.085)***	(.042)***	(.037)***
R^2	0.292	0.356	0.490	0.353	0.247
observations	47	47	49	48	49

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

Note: This table regresses the change in the cross-currency basis at maturities of 1,2,5,7 and 10Y following a scheduled SNB monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 6: Response of Yen/$ Cross-Currency Basis around BOJ announcements

	1m	3m	1y	5y	10y
MP	-9.877	-3.831	-0.474	-0.406	-0.046
	(6.916)	(3.783)	(0.801)	(0.406)	(0.252)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	10.443	4.810	1.167	1.134	0.779
	(6.928)	(3.792)	(0.821)	(0.480)*	(0.334)*
δ	0.567	0.979	0.693	0.729	0.732
	(.408)	(.263)***	(.18)***	(.256)***	(.219)***
R^2	0.058	0.049	0.049	0.128	0.157
observations	136	136	142	142	142

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

Note: This table regresses the change in the cross-currency basis at maturities of 1,2,5,7 and 10Y following a scheduled BOJ monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 7: Share of Interoffice Funding to Total Dollar Assets, Call Reports

Bank	Region	2007-2013 $A_\$$	2007-2013 $\frac{x_\$}{A_\$}$	2014-2017 $A_\$$	2014-2017 $\frac{x_\$}{A_\$}$
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. Reported data are averages taken over periods 2007-2013 and 2014-2017, and excludes banks which do not have data for both periods. 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 8: 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
Country FE	Yes	Yes	Yes	Yes	Yes
Year Quarter FE	Yes	Yes	Yes	Yes	Yes
IV	No	No	Yes	No	No

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

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. Dependent variable is then calculated as the ratio of interoffice flows to total dollar assets. Standard errors are clustered at the bank level, and data is quarterly and starts in 2007. Explanatory variables 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.

References

Abbassi, Puriya and Falk Bräuning, "The Pricing of FX Forward Contracts: Micro Evidence from Banksâ Dollar Hedging," 2018.

Abidi, Nordine, I Miquel Flores, and Nicolas A Eterovic, "Who Benefits from the ECB's Corporate Sector Purchase Programme? A Difference-in-Discontinuities Approach," Technical Report, Working Paper 2017.

Aizenman, Joshua and Gurnain Kaur Pasricha, "Selective swap arrangements and the global financial crisis: Analysis and interpretation," *International Review of Economics & Finance*, 2010, *19* (3), 353–365.

Akram, Q Farooq, Dagfinn Rime, and Lucio Sarno, "Arbitrage in the foreign exchange market: Turning on the microscope," *Journal of International Economics*, 2008, *76* (2), 237–253.

Altavilla, Carlo, Miguel Boucinha, and José-Luis Peydró, "Monetary policy and bank profitability in a low interest rate environment," *Economic Policy*, 2018, *33* (96), 531–586.

Ampudia, Miguel and Skander Van den Heuvel, "Monetary policy and bank equity values in a time of low interest rates," 2018.

Avdjiev, Stefan, Wenxin Du, Catherine Koch, and Hyun Song Shin, "The dollar, bank leverage and the deviation from covered interest parity," 2016.

Baba, Naohiko and Frank Packer, "Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08," *Journal of Banking & Finance*, 2009, *33* (11), 1953–1962.

_ **and Ilhyock Shim**, "Policy responses to dislocations in the FX swap market: the experience of Korea," 2010.

Bahaj, Saleem, Ricardo Reis et al., "Central Bank Swap Lines," Bank of England Working Paper 2018.

Bergant, Katharina, Michael Fidora, and Martin Schmitz, "International capital flows at the security level-evidence from the ECBâs asset purchase programme," 2018.

Bordo, Michael D, Owen F Humpage, and Anna J Schwartz, "The Evolution of the Federal Reserve Swap Lines," *IMF Economic Review*, 2015, *63* (2), 353–372.

Borio, Claudio and Leonardo Gambacorta, "Monetary policy and bank lending in a low interest rate environment: diminishing effectiveness?," *Journal of Macroeconomics*, 2017, *54*, 217–231.

Borio, Claudio EV, Robert N McCauley, Patrick McGuire, and Vladyslav Sushko, "Covered interest parity lost: understanding the cross-currency basis," 2016.

Bräuning, Falk and Kovid Puria, "Uncovering covered interest parity: the role of bank regulation and monetary policy," 2017.

_ and Victoria Ivashina, "Monetary policy and global banking," Technical Report, National Bureau of Economic Research 2017.

Brunnermeier, Markus K and Yann Koby, "The reversal interest rate: An effective lower bound on monetary policy," *Unpublished paper, Princeton University*, 2016.

Bruno, Valentina and Hyun Song Shin, "Cross-Border Banking and Global Liquidity*," *The Review of Economic Studies*, 2014, p. rdu042.

_ and _ , "Capital flows and the risk-taking channel of monetary policy," *Journal of Monetary Economics*, 2015, *71*, 119–132.

Brusa, Francesca, Pavel G Savor, and Mungo Ivor Wilson, "One central bank to rule them all," 2016.

Cenedese, Gino, Pasquale Della Corte, and Tianyu Wang, "Limits to Arbitrage in the Foreign Exchange Market: Evidence from FX Trade Repository Data," *Unpublished working paper*, 2017.

Chamon, Marcos, Márcio Garcia, Laura Souza, and Itaú Unibanco, "FX interventions in Brazil: a synthetic control approach," *Textos para discussão*, 2015, *630.*

Chang, Roberto and Andres Velasco, "A model of financial crises in emerging markets," *Quarterly Journal of Economics*, 2001, pp. 489–517.

Christensen, Jens HE, Signe Krogstrup et al., "Swiss unconventional monetary policy: lessons for the transmission of quantitative easing," in "in" Citeseer 2014.

Christensen, Jens Henrik Eggert and Signe Krogstrup, "A portfolio model of quantitative easing," 2016.

Claessens, Stijn, Nicholas Coleman, and Michael Donnelly, "âLow-For-Longâ interest rates and banksâ interest margins and profitability: Cross-country evidence," *Journal of Financial Intermediation*, 2018, *35*, 1–16.

Dedola, Luca, Georgios Georgiadis, Johannes Gräb, and Arnaud Mehl, "Does a Big Bazooka Matter? Central Bank Balance-Sheet Policies and Exchange Rates," 2017.

Diamond, Douglas W and Philip H Dybvig, "Bank runs, deposit insurance, and liquidity," *The journal of political economy*, 1983, pp. 401–419.

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

_ **and Jesse Schreger**, "Local currency sovereign risk," *The Journal of Finance*, 2016, *71* (3), 1027–1070.

_ **, Joanne Im, and Jesse Schreger**, "The US Treasury Premium," *Journal of International Economics*, 2018, *112*, 167–181.

Evans, Martin DD and Richard K Lyons, "Order flow and exchange rate dynamics," *Journal of political economy*, 2002, *110* (1), 170–180.

_ **and** _ , "Do currency markets absorb news quickly?," *Journal of International Money and Finance*, 2005, *24* (2), 197–217.

Fleming, Michael J and Nicholas Klagge, "The Federal Reserve foreign exchange swap lines," 2010.

Gabaix, Xavier and Matteo Maggiori, "International liquidity and exchange rate dynamics," 2015.

Gertler, Mark, Nobuhiro Kiyotaki et al., "Financial intermediation and credit policy in business cycle analysis," *Handbook of monetary economics*, 2010, *3* (3), 547–599.

Goldberg, Linda S, Craig Kennedy, and Jason Miu, "Central bank dollar swap lines and overseas dollar funding costs," Technical Report, National Bureau of Economic Research 2010.

Goldstein, Itay, Jonathan Witmer, Jing Yang et al., "Following the Money: Evidence for the Portfolio Balance Channel of Quantitative Easing," *Bank of Canada Staff Working Papers*, 2018, (18-33).

Griffoli, T Mancini and A Ranaldo, "Deviations from Covered Interest Parity during the crisis: A story of funding liquidity constraint," Technical Report, Working Paper, Swiss National Bank 2009.

Gurkaynak, Refet S, "Using federal funds futures contracts for monetary policy analysis," 2005.

_ , Brian P Sack, and Eric T Swanson, "Do actions speak louder than words? The response of asset prices to monetary policy actions and statements," 2004.

Hasbrouck, Joel, "Measuring the information content of stock trades," *The Journal of Finance*, 1991, *46* (1), 179–207.

He, Zhiguo, Arvind Krishnamurthy, Konstantin Milbradt et al., "A model of the reserve asset," Technical Report 2015.

Heider, Florian, Farzad Saidi, and Glenn Schepens, "Life below zero: Bank lending under negative policy rates," 2018.

Iida, Tomoyuki, Takeshi Kimura, Nao Sudo et al., "Regulatory reforms and the dollar funding of global banks: Evidence from the impact of monetary policy divergence," Technical Report, Bank of Japan 2016.

Ito, Hiroyuki and Cesar Rodriguez, "Clamoring for Greenbacks: Explaining the resurgence of the US dollar in international debt," Technical Report, Research Institute of Economy, Trade and Industry (RIETI) 2015.

Ivashina, Victoria, David S Scharfstein, and Jeremy C Stein, "Dollar Funding and the Lending Behavior of Global Banks," *The Quarterly Journal of Economics*, 2015, *130* (3), 1241–1281.

Jiang, Zhengyang, Arvind Krishnamurthy, and Hanno Lustig, "Foreign Safe Asset Demand and the Dollar Exchange Rate," Working Paper 24439, National Bureau of Economic Research March 2018.

Kohler, Daniel and Benjamin Müller, "Covered interest rate parity, relative funding liquidity and cross-currency repos," 2018.

Koijen, Ralph SJ, François Koulischer, Benoît Nguyen, and Motohiro Yogo, "Euro-area quantitative easing and portfolio rebalancing," *American Economic Review*, 2017, *107* (5), 621–27.

Kuttner, Kenneth N, "Monetary policy surprises and interest rates: Evidence from the Fed funds futures market," *Journal of monetary economics*, 2001, *47* (3), 523–544.

Liao, Gordon Y, "Credit Migration and Covered Interest Rate Parity," Technical Report 2018.

Lopez, Jose A, Andrew K Rose, and Mark M Spiegel, "Why Have Negative Nominal Interest Rates Had Such a Small Effect on Bank Performance? Cross Country Evidence," Technical Report, National Bureau of Economic Research 2018.

Maggiori, Matteo and Emmanuel Farhi, "A Model of the International Monetary System," Working Paper. Paper.

_ , Brent Neiman, and Jesse Schreger, "International currencies and capital allocation," Working Paper, National Bureau of Economic Research 2018.

Moessner, Richhild and William A Allen, "Central bank swap line effectiveness during the euro area sovereign debt crisis," *Journal of International Money and Finance*, 2013, *35*, 167–178.

Pinnington, James and Maral Shamloo, "Limits to arbitrage and deviations from covered interest rate parity," Technical Report, Bank of Canada staff discussion paper 2016.

Ranaldo, Angelo and Enzo Rossi, "The reaction of asset markets to Swiss National Bank communication," *Journal of International Money and Finance*, 2010, *29* (3), 486–503.

Rime, Dagfinn, Andreas Schrimpf, and Olav Syrstad, "Segmented Money Markets and Covered Interest Parity Arbitrage," *Working Paper*, 2016.

_ , _ , and _ , "Segmented money markets and covered interest parity arbitrage," 2017.

Sushko, Vladyslav, Claudio EV Borio, Robert N McCauley, and Patrick McGuire, "The failure of covered interest parity: FX hedging demand and costly balance sheets," 2017.

Swanson, Eric T, "Measuring the effects of unconventional monetary policy on asset prices," Technical Report, National Bureau of Economic Research 2015.

Syrstad, Olav, "Covered Interest Rate Parity in Bond Markets," 2018.

Ulate, Mauricio, "Going Negative at the Zero Lower Bound, The Effects of Negative Rates on Bank Profitability," 2018.

Vayanos, Dimitri and Jean-Luc Vila, "A preferred-habitat model of the term structure of interest rates," Technical Report, National Bureau of Economic Research 2009.

Williamson, Stephen D et al., "Quantitative Easing: How Well Does This Tool Work?," *The Regional Economist*, 2017, *25* (3).

6 Appendices

A: Model Proofs

Proof of Proposition 1: QE

Unconstrained Bank

From equation 16, an unconstrained bank has $\xi_t = 0$. The first order condition can then be rewritten as follows. Note that we drop time subscripts as the equilibrium is static.

$$F'(x_\$^D) = \ell_\$ - (\bar{\ell}_d G(M) + \Delta) \tag{6.25}$$

In equilibrium, dealers set a price Δ such that in equilibrium, $x_\$^D = N\frac{\Delta}{\rho\theta^2\sigma_s^2}$. Taking the derivative of equation 6.25 with respect to M,

$$F''(x_\$^D)N\frac{\Delta}{\rho\theta^2\sigma_s^2}\frac{\partial\Delta}{\partial M} = -\bar{\ell}_d G'(M) - \frac{\partial\Delta}{\partial M} \tag{6.26}$$

Rearranging terms, I obtain an expression for the effect of central bank asset purchases M on the equilibrium cross-currency basis..

$$\frac{\partial\Delta}{\partial M} = -\frac{\bar{\ell}_d G'(M)}{1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}} > 0 \tag{6.27}$$

Constrained Bank

The effects on a constrained bank is different. Now, bank demands for dollar funding are given by $x_\$^D = A_\$ - \gamma K$. In equilibrium, $x_\$^D = N\frac{\Delta}{\theta\rho\sigma_s^2}$.

$$N\frac{\Delta}{\rho\theta^2\sigma_s^2} = A_\$ - \gamma K \tag{6.28}$$

Taking derivative with respect to M,

$$\frac{N}{\theta\rho\sigma_s^2}\frac{\partial\Delta}{\partial M} = \frac{\partial A_\$}{\partial M} + \frac{\partial A_\$}{\partial\Delta}\frac{\partial\Delta}{\partial M} \tag{6.29}$$

Rearranging terms, I obtain an expression for the effect of central bank asset purchases M on the equilibrium cross-currency basis.

$$\frac{\partial\Delta}{\partial M} = \frac{\frac{\partial A_\$}{\partial M}}{\frac{N}{\rho\theta^2\sigma_s^2} - \frac{\partial A_\$}{\partial\Delta}} \tag{6.30}$$

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

$$\frac{\partial A_\$}{\partial M} = -\bar{\ell}_d G'(M) A_\$ \left(\frac{1}{R_\$} + \frac{R_\$}{R^T R}\right) \tag{6.31}$$

$$\frac{\partial A_\$}{\partial \Delta} = -\left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right) A_\$ \left(\frac{1}{R_\$} + \frac{R_\$}{R^T R}\right) \tag{6.32}$$

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

$$\frac{\partial \Delta}{\partial M} = -\frac{\bar{\ell}_d G'(M)}{1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2} + \frac{N}{\rho\theta^2\sigma_s^2 A_\$}\left(\frac{1}{\frac{1}{R_\$} + \frac{R_\$}{R^T R}}\right)} > 0 \tag{6.33}$$

Proof of Proposition 2: Negative interest rates

Constrained Bank

Bank demands for dollar funding are given by $x_\$^D = A_\$ - \gamma K$. In equilibrium, $x_\$^D = N\frac{\Delta}{\theta\rho\sigma_s^2}$.

$$N\frac{\Delta}{\rho\theta^2\sigma_s^2} = A_\$ - \gamma K \tag{6.34}$$

Taking the derivative with respect to r_m,

$$\frac{N}{\theta\rho\sigma_s^2}\frac{\partial \Delta}{\partial r_m} = \frac{\partial A_\$}{\partial r_m} + \frac{\partial A_\$}{\partial r_m}\frac{\partial \Delta}{\partial r_m} \tag{6.35}$$

Rearranging terms, I obtain an expression for the effect of central bank asset purchases r_m on the equilibrium cross-currency basis.

$$\frac{\partial \Delta}{\partial r_m} = \frac{\frac{\partial A_\$}{\partial r_m}}{\frac{N}{\rho\theta^2\sigma_s^2} - \frac{\partial A_\$}{\partial \Delta}} \tag{6.36}$$

Similar to analyzing the effects of QE on a central bank, lets simplify the notation. Denote $A_\$ = \frac{K}{\alpha}\frac{R_\$}{(R^T\Sigma R)^{\frac{1}{2}}}$, where $R = \begin{bmatrix} R_d & R_\$ \end{bmatrix}^T$.$R_d$ is the domestic excess return $y_d - c_d$, and $R_\$$ is the dollar excess return $y_\$ - (l_d + r_\$^f + \Delta + F'(x_\$^D))$. Σ is the covariance matrix of returns, and for tractability, I assume $\Sigma = I_{2\times 2}$. Solving for the derivatives $\frac{\partial A_\$}{\partial M}$ and $\frac{\partial A_\$}{\partial \Delta}$, we obtain:

$$\frac{\partial A_\$}{\partial r_m} = -\frac{R_d A_\$}{R^T R} \tag{6.37}$$

$$\frac{\partial A_\$}{\partial \Delta} = -\left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right) A_\$ \left(\frac{1}{R_\$} + \frac{R_\$}{R^T R}\right) \tag{6.38}$$

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

$$\frac{\partial \Delta}{\partial r_m} = -\frac{R_d}{\frac{NR^T R}{\rho\theta^2\sigma^2 A_\$} + \left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right)\left(\frac{R^T R}{R_\$} + R_\$\right)} \tag{6.39}$$

C: Monetary shocks and CIP Deviations: Effects on the Treasury Basis

In this section, I test for the effects of monetary surprises on the Treasury basis. The model makes a prediction about mispricing of the forward premium in response to an excess demand for dollar funding in the forex swap market. If this is so, then this should theoretically affect CIP deviations based on a variety of benchmark rates, not just LIBOR. Secondly, the model makes a prediction about CIP deviations as reflecting the difference between domestic and dollar credit spreads. To the extent that domestic QE compresses spreads on Treasury bonds, the model predicts an equivalent widening of the Treasury basis.

I use a dataset which computes the Treasury basis for a select group of advanced and emerging economies, provided in Du and Schreger (2016); Du et al. (2018b). I provide a brief exposition of how the authors construct the Treasury basis. It is calculated as the difference between the direct and synthetic dollar borrowing rates, where are the U.S. and domestic treasury rates, and the difference between the forward and spot rates expressed in dollars per units of domestic currency.[43]

$$CIP_t^T = \underset{\text{direct}}{y_{\$,t}^T} - \underbrace{\left(y_{d,t}^T + f_t - s_t\right)}_{\text{synthetic}} \tag{6.40}$$

At maturities of greater or equal to 1 year, the forward premium can be expressed as a relationship between the interest rate swaps in the two currencies and the LIBOR cross-currency basis. To swap domestic currency into dollars, the bank engages in a cross-currency swap, in which it receives domestic currency LIBOR payments with the addition of the cross-currency basis Δ, and pays USD LIBOR. As the interest payments are floating, the bank hedges interest rate risk by swapping the floating domestic currency LIBOR for fixed, and paying a fixed USD

[43] To be consistent with the main body of the paper, I construct the basis as the difference between the direct and synthetic dollar borrowing rate. In the original dataset, in contrast, the authors calculate the difference between the synthetic and direct rates.

LIBOR to obtain floating LIBOR. The forward premium, which is the net cost of engaging in the cross-currency swap, is expressed in equation 6.41, where $IRS_{\$,t}$ and $IRS_{d,t}$ are the fixed-floating interest rate swaps in USD and domestic currency respectively.

$$f_t - s_t = IRS_{\$t} - \Delta_t - IRS_{d,t} \tag{6.41}$$

Finally, substituting the formula for the forward premium in equation 6.42, I obtain a formula for the Treasury basis.[44]

$$CIP_t^T = y_{\$,t}^T - y_{d,t}^T - (IRS_{\$,t} + \Delta_t - IRS_{d,t}) \tag{6.42}$$

The specification I test is in equation 6.43, where CIP^T is now the deviation from covered interest rate parity based on the Treasury yield as the benchmark rate, as opposed to the LIBOR rate in the main body of the paper.[45]Regression results for the specification in equation 6.43 are provided in Tables 9, 10 and 11. Consistent with the model prediction, an expansionary monetary surprise in the period of unconventional monetary policy cause a widening of the Treasury basis. This is most significant at maturities of 5,7 and 10 years, with quantitatively similar to effects on the LIBOR basis.

$$CIP_t^T - CIP_{t-1}^T = \alpha + \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t \tag{6.43}$$

QE programs implemented by the Federal Reserve in the period 2008-2012 should have an equal and opposite effect. [46] To measure the effect of U.S. monetary policy surprises, I compute the change in Fed funds futures around scheduled monetary announcements of the Federal Reserve. The period of unconventional monetary policy is characterized by 3 QE programs, which involves 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. Regression results are reported in Tables 12, 13 and 14. The results are consistent with the model prediction, and suggest that following an expansionary QE announcement by the Federal Reserve, there is a narrowing of the Treasury basis. The effects are stronger at longer maturities, and the coefficient estimates are approximately equal and of the opposite sign to the effect of domestic monetary

[44]If the benchmark rate becomes LIBOR instead of the treasury rate, the CIP deviation collapses to the LIBOR basis Δ_t. $CIP_t^T = IRS_{\$,t} - IRS_{d,t} - (IRS_{\$,t} + \Delta_t - IRS_{d,t}) = \Delta_t$

[45]In contrast, I use the LIBOR cross-currency basis for the results in the main body of the paper, as this is typically the more important dollar borrowing premium for banks borrowing dollars via forex swaps.

[46]One can also interpret the Treasury basis as a liquidity and safety premium an investor earns on a U.S. Treasury bond. Given the Treasury basis measures a relative scarcity of safe assets, an increase in the relative supply of safe assets by the U.S. government will cause a decline in Treasury yields, and a decline in the safety and liquidity premium associated with holding U.S. treasuries, all else equal.

surprises.

Table 9: Response of Euro/$ Treasury Basis around ECB announcements

	1y	2y	5y	7y	10y
MP	-0.101	0.046	0.194	0.328	0.130
	(0.104)	(0.131)	(0.156)	(0.170)	(0.116)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.101	0.137	0.266	0.168	0.533
	(0.252)	(0.248)	(0.256)	(0.269)	(0.352)
δ	-0.001	0.183	0.460	0.495	0.663
	(.23)	(.211)	(.203)**	(.209)**	(.332)**
R^2	0.005	0.001	0.017	0.031	0.021
observations	253	253	253	253	252

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

Note: This table regresses the change in the Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled ECB monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 10: Response of Chf/$ Treasury Basis around SNB announcements

	1y	2y	5y	7y	10y
MP	0.258	0.151	0.065	0.281	-0.054
	(0.128)*	(0.069)*	(0.080)	(0.105)**	(0.066)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.294	0.533	0.337	0.101	0.423
	(0.292)	(0.124)***	(0.136)*	(0.141)	(0.127)**
δ	0.552	0.684	0.402	0.382	0.368
	(.262)**	(.103)***	(.11)***	(.094)***	(.108)***
R^2	0.059	0.140	0.043	0.134	0.026
observations	105	117	117	117	117

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

Note: This table regresses the change in the Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled SNB monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 11: Response of Yen/$ Treasury Basis around BOJ announcements

	1y	2y	5y	7y	10y
MP	0.196	0.432	0.248	0.755	0.472
	(0.810)	(0.299)	(0.260)	(0.497)	(0.265)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.762	0.621	0.474	-0.171	0.237
	(0.845)	(0.392)	(0.486)	(0.593)	(0.390)
δ	0.958	1.053	0.722	0.584	0.709
	(.242)***	(.255)***	(.411)*	(.324)*	(.286)**
R^2	0.011	0.029	0.018	0.025	0.034
observations	261	261	261	261	261

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

Note: This table regresses the change in the Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled BOJ monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 12: Response of Euro/$ Treasury Basis around Federal Reserve announcements

	1y	2y	5y	7y	10y
MP	-0.784	-0.395	-0.077	-0.084	-0.046
	(0.324)*	(0.137)**	(0.126)	(0.106)	(0.080)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.792	-0.528	-2.121	-4.307	-1.796
	(0.367)*	(0.210)*	(0.304)***	(0.203)***	(0.266)***
δ	0.008	-0.922	-2.197	-4.390	-1.843
	(.223)	(.171)***	(.277)***	(.175)***	(.253)***
R2	0.160	0.149	0.227	0.630	0.198
observations	144	144	144	144	144

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

Note: This table regresses the change in the euro/$ Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled Federal Reserve monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 13: Response of Chf/$ Treasury Basis around Federal Reserve announcements

	1y	2y	5y	7y	10y
MP	-0.289	0.000	0.100	0.043	0.073
	(0.159)	(0.103)	(0.069)	(0.058)	(0.057)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.348	0.301	-0.411	-2.836	-1.039
	(0.174)*	(0.125)*	(0.096)***	(0.170)***	(0.097)***
δ	0.059	0.301	-0.311	-2.794	-0.966
	(.084)	(.079)***	(.07)***	(.161)***	(.079)***
R2	0.036	0.004	0.022	0.287	0.058
observations	165	183	183	183	183

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

Note: This table regresses the change in the chf/$ Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled Federal Reserve monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.

Table 14: Response of Yen/$ Treasury Basis around Federal Reserve announcements

	1y	2y	5y	7y	10y
MP	-0.710	-0.190	-0.129	-0.141	-0.039
	(0.213)**	(0.103)	(0.104)	(0.102)	(0.065)
MP $\times$ $\mathbb{1}[U_{\mathrm{MP}}]$	0.915	-0.162	-0.486	-2.870	-0.498
	(0.238)***	(0.146)	(0.120)***	(0.207)***	(0.106)***
δ	0.205	-0.352	-0.616	-3.011	-0.537
	(.139)	(.11)***	(.071)***	(.186)***	(.084)***
R2	0.158	0.041	0.035	0.286	0.016
observations	165	184	184	184	184

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

Note: This table regresses the change in the yen/$ Treasury basis at maturities of 1,2,5,7 and 10Y following a scheduled Federal Reserve monetary announcement, on the surprise change in interest rate futures. For an announcement on day t, the daily change is computed as the difference between the end of day price on days t and $t-1$. The monetary shock is computed as the change in interest rate futures computed within a wide window around the monetary announcement.