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# Essays in International Finance

by

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# Abstract

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Since the beginning of my graduate studies at Berkeley, I have had a deep interest in foreign exchange. This is naturally at the heart of international finance, however recently a surge of research papers have been investigating not the market for spot contracts, which is conventionally what most people refer to when talking about foreign exchange, but rather derivative markets, including forwards and forex swaps. This transition in interest has largely occurred because of recent post-crisis developments in forex swap markets. Since 2008, we have witnessed persistent deviations of covered interest rate parity. This is an arbitrage condition, and states that the costs of borrowing local and foreign currency should be equal after eliminating exchange rate risk using a forward contract. The focus of the first chapter of my thesis is largely to propose an explanation to explain the violation of this arbitrage condition,

In the first chapter, I interpret the puzzle as a persistent dollar financing premium for banks in the Euro area, Japan and Switzerland. While prior literature has typically focused on explaining the dollar borrowing premium as stemming from limits to arbitrage and the supply of dollars in the forex swaps, I provide an alternative explanation, that is centered on unconventional monetary policies of the European Central Bank, Bank of Japan and Swiss National Bank. Using a model of the foreign exchange swap market, I explore two channels through which the unconventional monetary policies, namely Quantitative Easing (QE) and negative interest rates, can create an excess demand for dollar funding. In the first, QE 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. To support model predictions, 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.

In the second chapter (coauthored with Olav Syrstad), we investigate in more detail price-setting in the forex swap market. Given the pricing of forwards no longer obeys the iron law of covered interest rate parity, this paper examines the information content of order flow. Order flow is measured as the net of buyer initiated transactions in the forex swap interdealer market, and can be used by dealers as a measure of underlying imbalances in forex swaps. This is important for price-setting as dealers typically keep flat positions on a day-to-day basis. An unexpected rise in order flow therefore cause the interdealer market to reset prices to restore order flow, resulting in an increase in the forward premium customers pay to swap into dollars, widening CIP deviations.

We provide evidence that an unconditional shock to order flow causes a widening of CIP deviations. We then test two sources of shocks to customer demands for forex swaps. First, we test whether there is an increase in order flow around expansionary unconventional monetary announcements. We find limited evidence that a rise in order flow following expansionary monetary announcements, supporting the contemporaneous price-setting. In contrast, we find evidence in support of price-setting via order flow when examining Federal Reserve Swap line allotments during 2008-2010. This caused a decline in order flow and a narrowing of the cross-currency basis. The results are consistent in a framework in which monetary surprises represent publicly available information that is wholly contained in the dealer information set. Swap line allotments are made to a subset of banks, and so act as italicidiosyncratic shocks to order flow that are unanticipated by dealers result in price-setting following a rise in order flow. Finally, we show that dealer leverage matters: around quarter-ends, there is evidence that order flow of short-term swaps rises, leading to a widening of cross-currency basis. This is due to dealers offloading holdings of short-term swaps in order to meet regulations on leverage.

In the third chapter (coauthored with Christian Jauregui), I examine the international effects of monetary policy. Much has been written on the domestic effects of the U.S. Federal Reserve's actions, but what about its effects across borders? In this paper, we document the international spillovers of major central banks policies' through their indirect effect on a set of base asset prices, by using high-frequency identification of monetary policy announcements. We implement a gross domestic product (GDP)-tracking approach to identify real spillovers of monetary policy, by mimicking real GDP news based on our asset returns around monetary announcements. This reflects news regarding real GDP growth due to monetary policy. Using our approach, we find in response to positive, domestic monetary shocks, real GDP-tracking news becomes negative for Australia, Canada, and the United States. Our methodology indicates significant spillovers of U.S. monetary policy to asset prices in periphery countries, such as Australia and Canada, with a U.S. monetary contraction leading to a decrease in both of these countries' real GDP-tracking news.

To my parents

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I would also like to thank my class mates Christian Jauregui and Nicholas Sander for their excellent feedback, help in obtaining data and in preparing presentations. I have also had the opportunity to work with Olav Syrstad, an economist at Norges Bank, on my chapter investigating order flow in the forex swap market. I thank Olav for sharing his expertise on forex swaps, in particular on the institutional background of forex swaps and global banking, and for giving me the opportunity to visit the Norges Bank. I would also like to thank my undergraduate friends David Murakami and Robert Nguyen for their feedback, guidance and support during my final year in applying to jobs. I have also had the chance to mentor students through the undergraduate Research assistance program, and I thank Sarah Hu for her dedicated contributions to the empirical part of my first chapter.

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# Chapter 1

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

## 1.1 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 1.1). 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

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[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 1.1. 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).

forex swaps are among the most widely traded derivative instruments, with an estimated \$250 B daily turnover (Figure 1.2). 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 1.3).[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 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 1.4 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

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[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.

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 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 1.5 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

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[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 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 1.5, 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.

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

## 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 dollar Avdjiev 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., 2017a; 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, Ivashina et al. (2015) examines a shock to credit quality of Euro area banks during the sovereign debt crisis in 2011. 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 et al. (2017) find that the corporate asset purchase program (CSPP) implemented by the ECB in 2016 led to a decline in yields of approximately 15 basis points for bonds that satisfied the conditions for purchase.[6] This evidence motivates my assumption that the effects of QE are via reducing domestic credit spreads, which in turn causes the bank to substitute toward 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 Müller (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 and Gambacorta (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

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[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 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.

synthetically and then 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, Maggiori et al. (2018) 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.

## 1.2 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 $r_{d}^{f}$ 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 $1 + r_{d}^{f}$. They hedge 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

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[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.

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 2.13). 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 1.7 ). 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 1.8).[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 1.8 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 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

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[10] The relationship in Figure 1.8 is positive for the period since 2008, however it is a stronger correlation for the period since 2014.

[11] Indeed, the slope of Figure 1.8 is zero for the pre-2008 period.

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 1.9, 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 1.10). As the authors in Du et al. (2018a) note, the spikes in short-term CIP deviations have been more prevalent since 2015. These findings suggest that balance 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]

## 1.3 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

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

[13] For more micro-level evidence that leverage matters, I refer the reader to Cenedese et al. (2017) 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.

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.

## 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 $\rho$ is a measure of risk aversion. Dealer wealth in period $t+1$ is equal to the dollar asset return on prior period 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 $\theta$, 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 $s_{t+1}$.

$$W_{t+1} = W_t(1 + r^f_{\$}) + (1-\theta)x_{\$,t}(f_t - s_t + r^f_d - r^f_{\$}) + \theta x_{\$,t}(s_{t+1} - s_t + r^f_d - r^f_{\$}) \tag{1.1}$$

The cross-currency basis, $\Delta_t$, 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 2.2.1 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].

$$\max_{x_{\$,t}} \rho \left( W_t(1 + r^f_\$) + x_{\$,t}\Delta_t - \frac{1}{2}\rho\theta^2 x^2_{\$,t}\sigma^2 \right) \tag{1.2}$$

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

$$x^*_{\$t} = \frac{\Delta_t}{\rho\theta^2\sigma^2} \tag{1.3}$$

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]

## 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 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 1.11.[16]

The asset returns are stochastic with distributions $\tilde{y}_d \sim N(y_d, \sigma^2_d)$ and $\tilde{y}_\$ \sim N(y_\$, \sigma^2_\$)$ , and with covariance $\sigma_{d,s}$. The borrowing cost on domestic deposits $c_d$ is assumed fixed. The cost of direct dollar borrowing is the sum of the dollar credit spread $l_\$$ and the risk-free rate in dollar borrowing, $r^f_\$$. To obtain dollars synthetically, the bank first issues a domestic currency bond with a yield equal to the addition of the credit spread $l_d$ and a risk-free rate $r^f_d$. It then engages in a 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

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[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, $E_t e^{-\rho\theta x_{\$,t}s_{t+1}} = e^{-\rho\theta x_{\$,t}f_t-\frac{1}{2}\rho^2\theta^2 x^2_{\$,t}\sigma^2}$. Taking logs and simplifying yields the expression in equation 1.2.

[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.

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

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 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 1.5,1.6,1.7 and 1.8. Equation 1.5 is a value at risk constraint which determines the optimal risk-adjusted weights of domestic and dollar assets. This constraint is also seen in Avdjiev et al. (2016).[19] Equation 1.6 states that bank equity $K$ is the difference between total assets and total liabilities. Equation 1.7 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 1.8 is a constraint on dollar denominated debt to be within a fraction $\gamma$ 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]

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[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 1.8 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.

$$\max_{A_{d,t},A_{\$,t},x^D_{\$,t},B_{\$,t},D_{d,t}} V_{t+1} = \tilde{y}_d A_{d,t} + \tilde{y}_\$ A_{\$,t} - (\ell_\$ + r^f_\$)B_{\$,t} \tag{1.4}$$

$$- (\ell_{d,t} + r^f_d + f_t - s_t)x^D_{\$,t,} - c_d D_{d,t} - F(x^D_{\$,t})$$

Subject to

$$a^T \Sigma a \leq \left(\frac{K}{\alpha}\right)^2, a = \begin{bmatrix} A_{d,t} & A_{\$,t} \end{bmatrix}^T \Sigma = \begin{bmatrix} \sigma^2_d & \sigma_{d,\$} \\ \sigma_{d,\$} & \sigma^2_\$ \end{bmatrix} \leq \left(\frac{K}{\alpha}\right)^2 \tag{1.5}$$

$$K = A_{d,t} + A_{\$,t} - D_{d,t} - B_{\$,t} - x^D_{\$,t} \tag{1.6}$$

$$A_{\$,t} = x^D_{\$,t} + B_{\$,t} \tag{1.7}$$

$$B_{\$,t} \leq \gamma K \tag{1.8}$$

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 1.9 to 1.12, where the Lagrangian for constraints 1.5,1.6,1.7 and 1.8 are given by $\phi_t$, $\mu_t$ $\lambda_t$ and $\xi_t$.

$$\begin{matrix} A_{d,t}: \\ A_{\$,t}: \end{matrix} \quad \begin{bmatrix} y_d \\ y_\$ \end{bmatrix} - 2\phi_t \Sigma \begin{bmatrix} A_{d,t} \\ A_{\$,t} \end{bmatrix} - \begin{bmatrix} \mu_t \\ \mu_t + \lambda_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{1.9}$$

$$x^D_{\$,t}: \quad - (\ell_{d,t} + r^f_d + f_t - s_t) - F'(x^D_{\$,t}) + \lambda_t + \mu_t = 0 \tag{1.10}$$

$$D_{d,t}: \quad - c_d + \mu_t = 0 \tag{1.11}$$

$$B_{\$,t}: \quad - \ell_\$ - r^f_\$ + \mu_t + \lambda_t - \xi_t = 0 \tag{1.12}$$

Using equations 1.10 and 1.12, I can express the relation between direct and synthetic dollar borrowing costs in equation 1.13.

$$\underbrace{\ell_{d,t} + r^f_d + f_t - s_t + F'(x^D_{\$,t})}_{\text{synthetic dollar cost}} = \underbrace{\ell_{\$,t} + r^f_\$ + \xi_t}_{\text{direct dollar cost}} \tag{1.13}$$

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]

$$\Delta_t = \ell_{\$,t} - \ell_{d,t} + \xi_t - F'(x^D_{\$,t}) \tag{1.14}$$

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 1.15).

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[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).

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 1.16). 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.

$$\begin{bmatrix} A_{d,t} \\ A_{\$,t} \end{bmatrix} = \frac{K}{\alpha\sqrt{R^T\Sigma^{-1}R}}\Sigma^{-1}R \tag{1.15}$$

$$x^D_{\$,t} = \begin{cases} F'^{-1}\left(\ell_\$ - (\ell_d + \Delta)\right) & \xi_t = 0 \text{ [unconstrained]} \\ A_{\$,t} - \gamma K & \xi_t \neq 0 \text{ [constrained]} \end{cases} \tag{1.16}$$

$$B^D_{\$,t} = \begin{cases} A_{\$,t} - \frac{\ell_\$ - (\ell + \Delta)}{\ell'_d(x^D_{\$,t})} & \xi_t = 0 \text{ [unconstrained]} \\ \gamma K & \xi_t \neq 0 \text{ [constrained]} \end{cases} \tag{1.17}$$

**Equilibrium**

In a market of N dealers, each dealer will receive orders from the bank, $x^D_{j,\$}$, where $\sum_{j=1}^N x^D_{j,\$} = x^D_\$$. 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 2.2.3.

**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 2.2.3).*
2. *A representative bank demands $x^D_{\$,t}$ dollars, optimizing the value of their portfolio (equation 1.16).*
3. *The Dealer sets $\Delta_t$ such that bank demands for dollar funding are directly met by dealer supply. $x^D_{\$,t}(\Delta_t) = Nx^*_{\$,t}(\Delta_t)$*

## 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 $\ell_d$ 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* $\ell_d$, *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,*

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

*Proof: See Appendix*

To further illustrate the effects of QE on bank demands for direct and synthetic dollar funding, Figure 1.12 characterizes the bank's new equilibrium allocation of dollar funding for varying levels of $\gamma$ . The threshold $\gamma^*$ is the boundary at which a bank transitions from the unconstrained to constrained regions of direct dollar borrowing.

$$\gamma^* = \frac{A_\$ - F'^{-1}(\ell_\$ - (\ell_d + \Delta))}{K} \tag{1.18}$$

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

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[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.

[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.

via forex swaps. The increase in synthetic dollar funding by constrained banks is denoted by area $a$ in the Figure.

## 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 $c_d = min\{0, r_m\}$. 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 $\mu_A$. 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,*

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

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[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.

*Proof: See Appendix*

To further illustrate the effects of negative interest rates on bank demands for direct and synthetic dollar funding, Figure 1.13 characterizes the bank's new equilibrium allocation of dollar funding for varying levels of $\gamma$ . Negative interest rates reduce the excess return on domestic 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 $a$.

## Central Bank Swap Lines

During the financial crisis of 2008, rises in default risk in interbank markets led to a significant scarcity of dollar funding. Central bank swap lines 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 $\psi$, $B_\$ \leq (\gamma - \psi)K$. The liquidity shock is a stylized way to capture the adverse dollar funding shock faced by European banks due to a reduction in wholesale funding sources, largely due to the retrenchment of U.S. money market funds in 2008 (Ivashina et al., 2015). I model the swap line as an auction of dollar funds by the domestic central bank at a rate $\kappa + r^f_\$$, where $\kappa$ is the premium on obtaining funds via the swap line. The revised balance sheet of the bank is provided in Figure 1.14.[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 1.19 and 1.20. 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.

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[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.

[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 $\kappa$, which is the additional cost of obtaining funds via the auction.

$$x_{\$,t}^{D} = \begin{cases} F'^{-1}\left(\ell_{\$} - (\ell_{d,t} + \Delta_t)\right) & \ell_{d,t} + \Delta_t + F'(x_{\$,t}^{D}) = \ell_{\$} \\ A_{\$,t} - (\gamma - \psi)K & \ell_{d,t} + \Delta_t + F'(x_{\$,t}^{D}) < \ell_{\$} + \kappa \\ F'^{-1}\left(\ell_{\$} + \kappa - (\ell_{d,t} + \Delta_t)\right) & \ell_{d,t} + \Delta_t + F'(x_{\$,t}^{D}) = \ell_{\$} + \kappa \end{cases} \tag{1.19}$$

$$x_{\$,t}^{CB} = \begin{cases} 0 & \ell_{d,t} + \Delta_t + F'(x_{\$,t}^{D}) < \ell_{\$} + \kappa \\ A_{\$,t} - (\gamma - \psi)K - x_{\$,t}^{D} & \ell_{d,t} + \Delta_t + F'(x_{\$,t}^{D}) = \ell_{\$} + \kappa \end{cases} \tag{1.20}$$

**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,*$\ell_{d,t} + \Delta_t + F'(x_{\$,0}^{D}) > \ell_{\$} + \kappa$*.*

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 1.15 characterizes the bank's equilibrium allocation of dollar funding for different levels of $\gamma$. 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 $\gamma$ less than the threshold $\gamma^*$. 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 et al. (2018). [27]

## 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 $\Gamma$, which measures the elasticity of dealer supply to a change in the cross-currency basis.[28] The second parameter I calibrate is $\alpha$, which constrains the risk-adjusted assets to a fraction of

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[27] They study an exogenous decline in $\kappa$ 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 $\kappa$ causes a decline in the ceiling for CIP deviations in equilibrium.

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

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 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 $\delta$, 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 1.1 summarizes all relevant parameters in the calibration.

### Results

Figure 1.16 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.

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.

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[29] For details of data, please refer to empirical section 1.4 in which I calculate a proxy for the share of synthetic dollar funding to total dollar assets for U.S. subsidiaries of banks in Eurozone, Japan and Switzerland.

## 1.4 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.

## 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 $\Delta f_t$ are calculated as the difference between futures $f_t$ $\delta^-$ minutes prior to the meeting and $\delta^+$ 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

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

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

of interest rate futures for the central bank policy rate is provided in Table 2.1. Descriptive statistics for the foreign monetary shocks, including contract length, are provided in Table 2.2.

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

### 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 $\Delta$ 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]

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[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.

$$\Delta = 1 + i_b \frac{tenor}{360} - \frac{S_b}{F_a}(1 + i_q \frac{tenor}{360}) \tag{1.21}$$

[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

## Monetary Surprises and CIP Deviations

### 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 1.17, 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.

### 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, 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

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[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

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 1.18).

### 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]

$$CIP_t - CIP_{t-1} = \alpha + \kappa \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t \tag{1.22}$$

In equation 1.22, 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 $\gamma$ 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 1.4,1.5 and 1.6. 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 1.23, and uses additional explanatory variables, including lags of the outcome variable, 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 $MP_t$.

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_i + \kappa \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + \sum_{l=1}^{L} A_l \Delta Y_{i,t-l} + X_t + \epsilon_t, \;\; h = 0, 1, 2, ....10 \tag{1.23}$$

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[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 1.1.

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 2.8. 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.

### 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 1.23, 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 1.5. 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]

## 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

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[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.

[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”.

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 1.7 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 1.7). 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 1.24.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 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

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[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.

[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.

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.

$$S_{ijt} = \alpha_i + \lambda_j + \gamma_t + \beta X_{it} + \delta X_{it} \times U_{MP,it} + \epsilon_t \tag{1.24}$$

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 1.8). 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 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.

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[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.

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.

## 1.5 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.

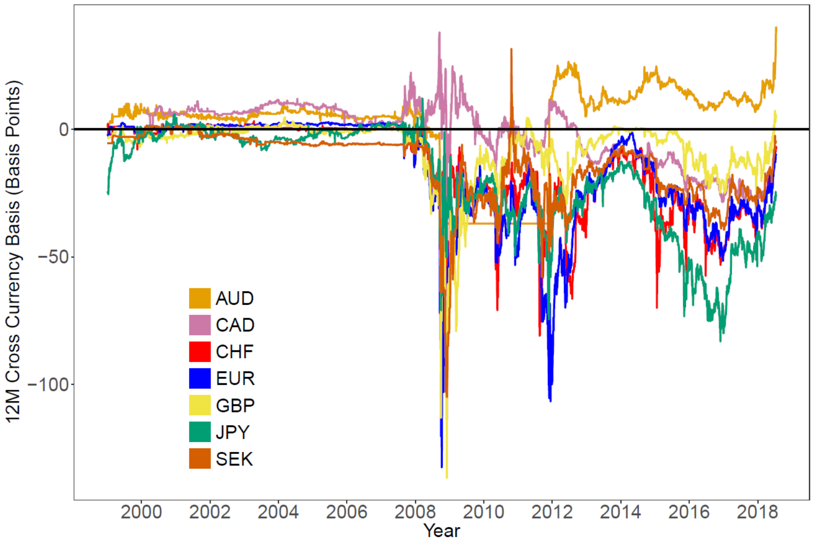
I propose a theory in which the unconventional monetary policies of the ECB, BOJ and SNB are the key factor explaining the persistence of CIP deviations. I model QE as central bank purchases of privately-issued debt. In reducing the market supply of privately-issued debt, QE compresses domestic credit 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.

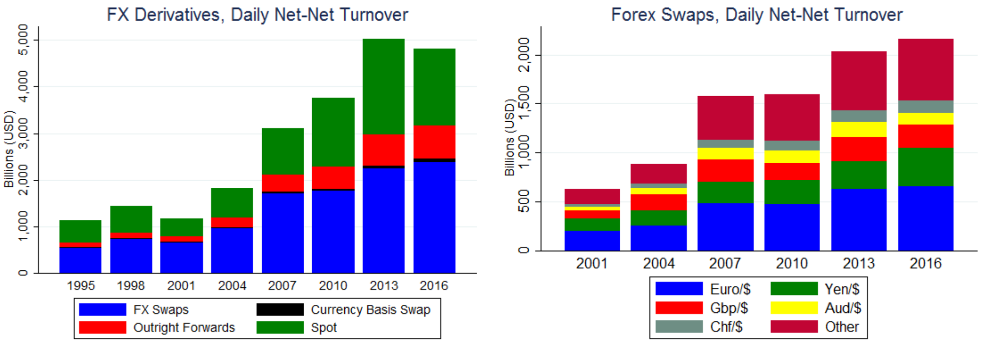
# Figures

Figure 1.1: The puzzle of persistent CIP deviations



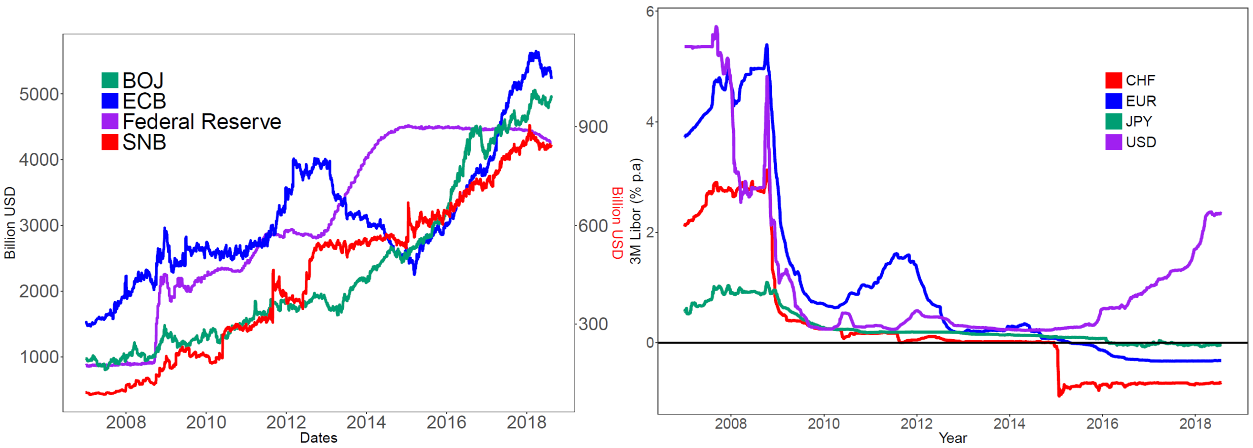
Note: 12M Cross-Currency Basis measured in basis points, obtained from Bloomberg. This provides a measure of CIP deviations based on a LIBOR benchmark rate. Negative deviations indicate a dollar borrowing premium for the euro/\$, chf/\$ and yen/\$ pairs. Formally, the CIP deviation $\Delta$ in this figure 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 1.2: 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.



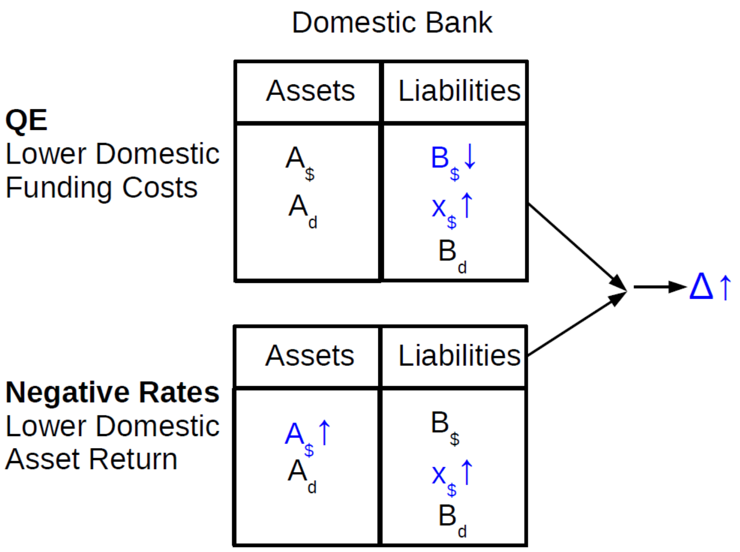
Note: Left: Total breakdown of FX derivatives daily net-net turnover, using BIS triennial survey. Right: Breakdown of Forex swaps by bilateral pairs involving one leg that is the USD.

Figure 1.3: Negative rate policies and QE implemented by ECB, BOJ and SNB



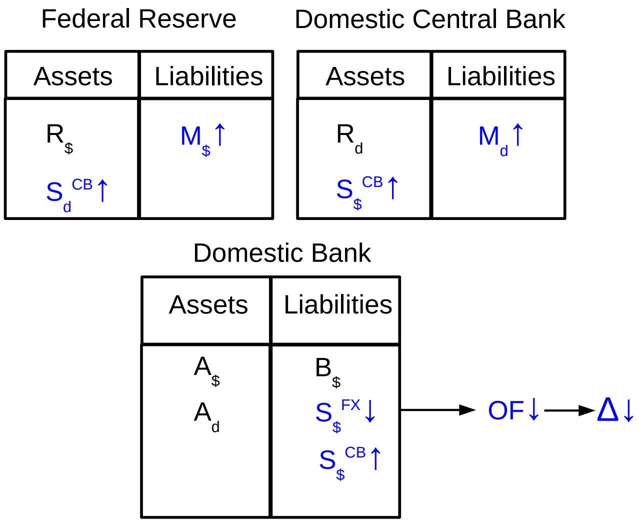
Note: Left is total assets of ECB, Federal Reserve, BOJ and SNB. SNB scale is on right-axis. Right: 3m LIBOR rates from Bloomberg.

Figure 1.4: Effects of negative rates and quantitative easing on the domestic bank balance sheet



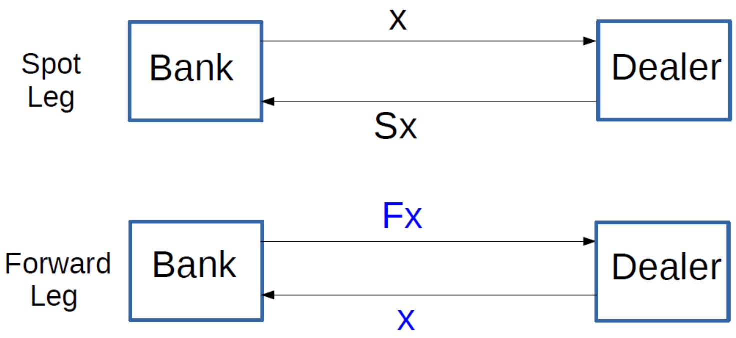
Note: This schematic illustrates the two theories of how unconventional monetary policy can affect the demand for swaps. QE works on the liability side of a domestic bank (where domestic refers to a bank domiciled in the Eurozone, Japan and/or Switzerland). As domestic funding costs decline, swaps $S_{\$}^{FX}$ 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 $\Delta$.

Figure 1.5: Effects of a Federal Reserve swap line on a recipient bank balance sheet



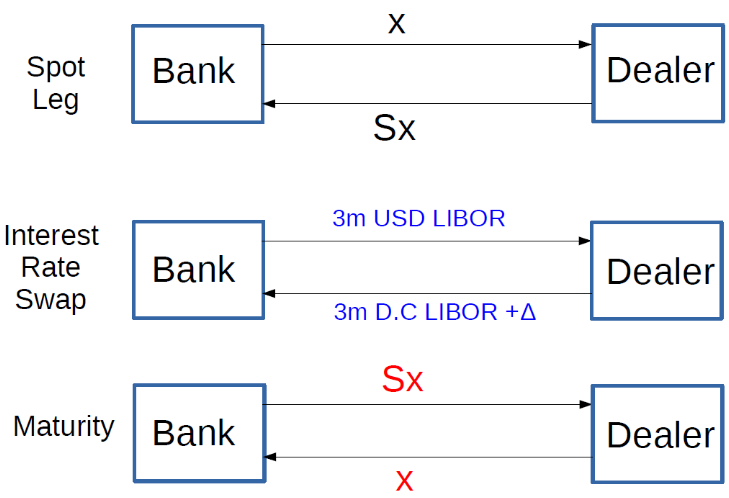
Note: This schematic illustrates the effects of swap lines. First, swap lines are an arrangement between the domestic central bank (domestic refers to banks from the Eurozone, Japan and Switzerland) and the US Federal Reserve to swap an amount $S_d^{CB}$ for dollars at a specified exchange rate. The 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 1.6: Foreign exchange swap



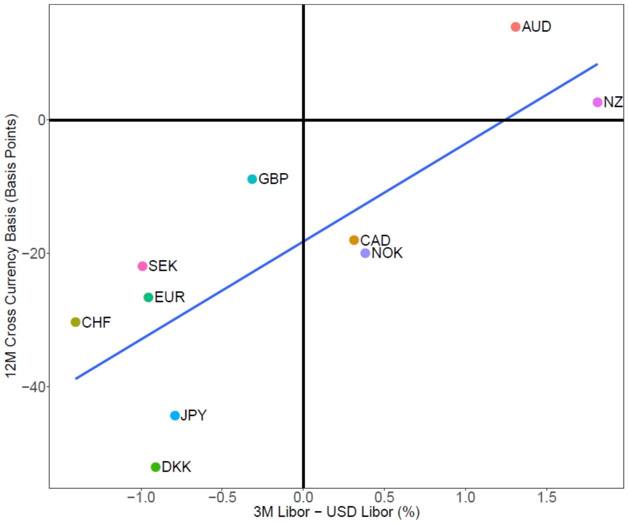
Note: Forex swap is typically for maturities at less than 3m. At the spot leg, domestic currency and dollars are swapped at the prevailing spot rate. At maturity, the principals are then re-exchanged at the forward rate.

Figure 1.7: Cross-currency swap



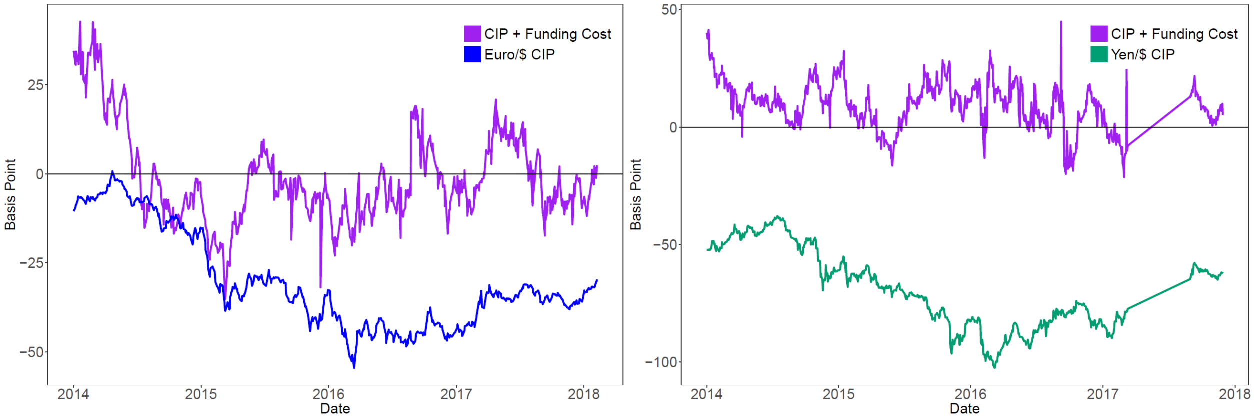
Note: The Cross-Currency Swap is typically for maturities >3m. In the spot leg, dollars are exchanged at spot. The bank and dealer then engages in an interest rate swap, in which the bank pays 3m USD LIBOR, and the dealer pays 3m LIBOR in domestic currency with the addition of the cross-currency basis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

Figure 1.8: Cross currency basis and LIBOR interest rate differential, advanced economies, 2014-present



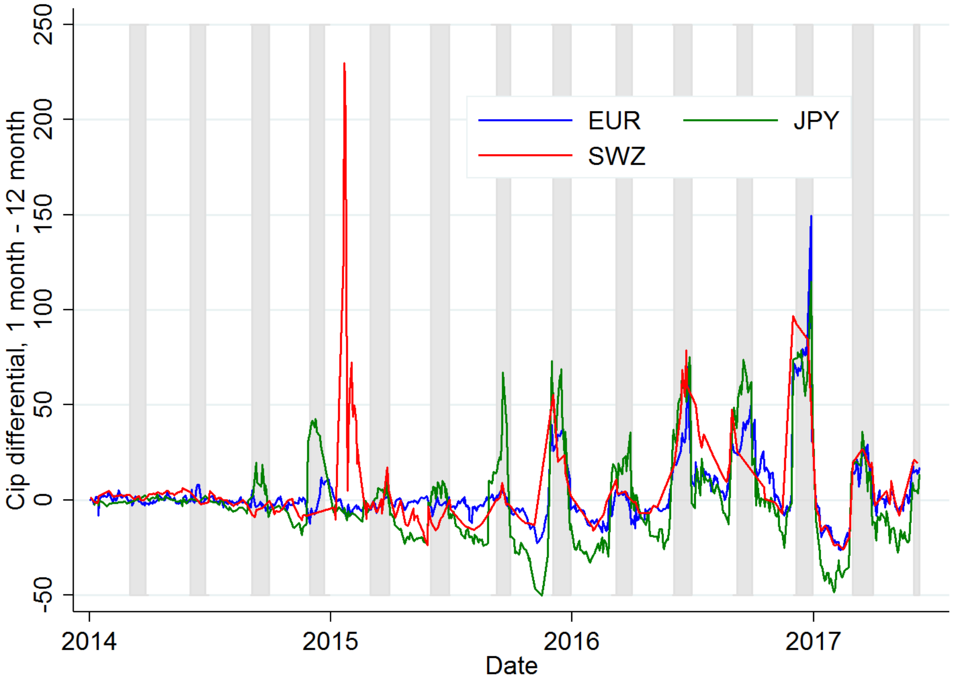
Note: This plot takes the average of the cross-currency basis and LIBOR interest rate differential in the period since 2014. Cross-currency basis is with respect to USD. Source: Bloomberg

Figure 1.9: 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 1.10: 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 1.11: Bank Balance Sheet

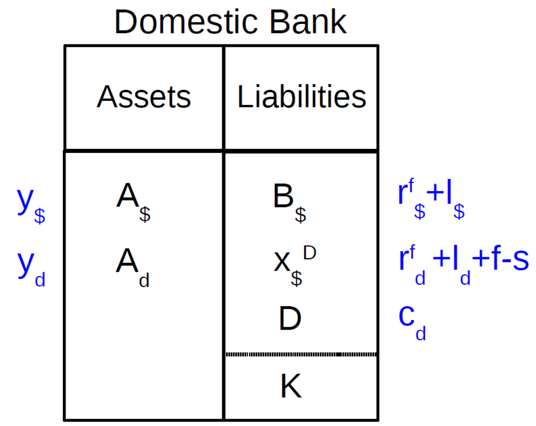


Figure 1.12: Allocation of direct and synthetic dollar funding sources for banks with varying $\gamma$. Both initial and final equilibrium after QE is shown.

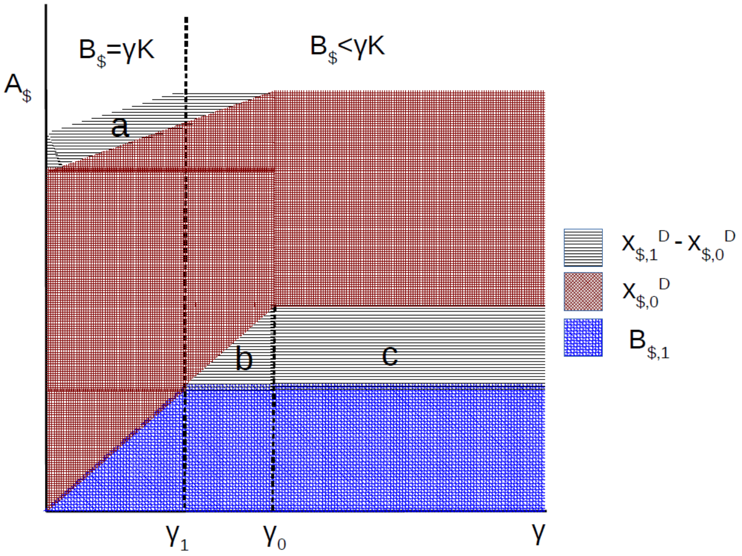


Figure 1.13: Allocation of direct and synthetic dollar funding sources for banks with varying $\gamma$. Both initial and final equilibrium after negative rates is shown.

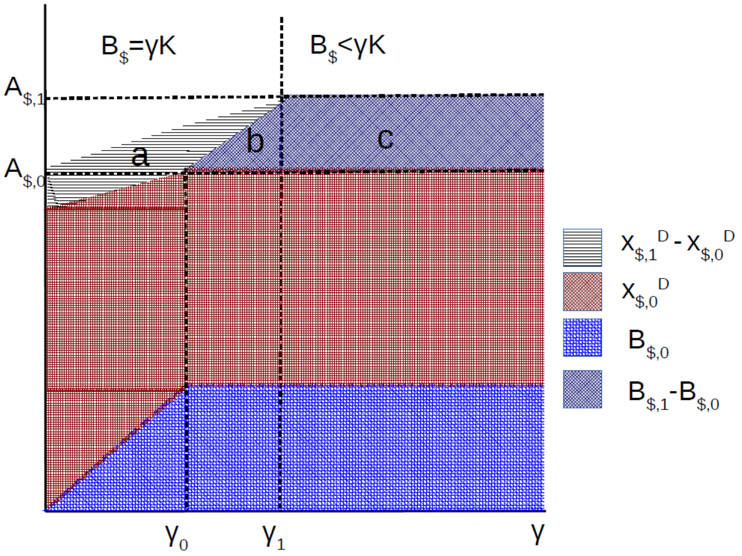


Figure 1.14: Bank Balance Sheet

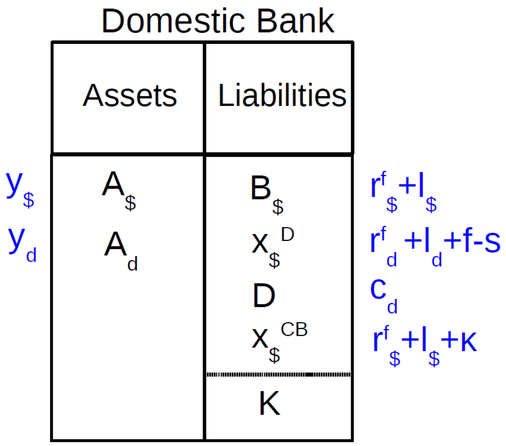


Figure 1.15: Allocation of direct and synthetic dollar funding sources for a continuum of banks with varying $\gamma$. Both initial and final equilibrium after central bank swap line auctions is shown.

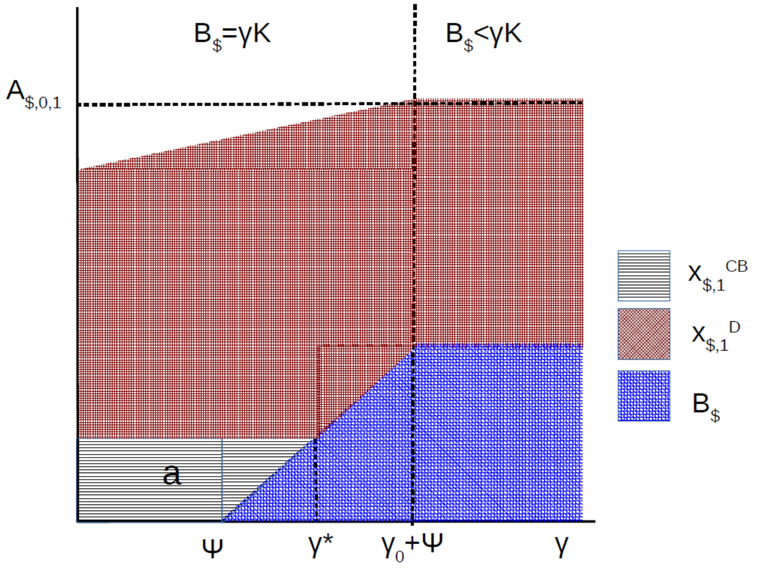


Figure 1.16: Top: equilibrium $\Delta$ and allocation of dollar funding for a range of QE
Bottom: Equilibrium $\Delta$ and allocation of dollar funding for a range of central bank rate $r_m$

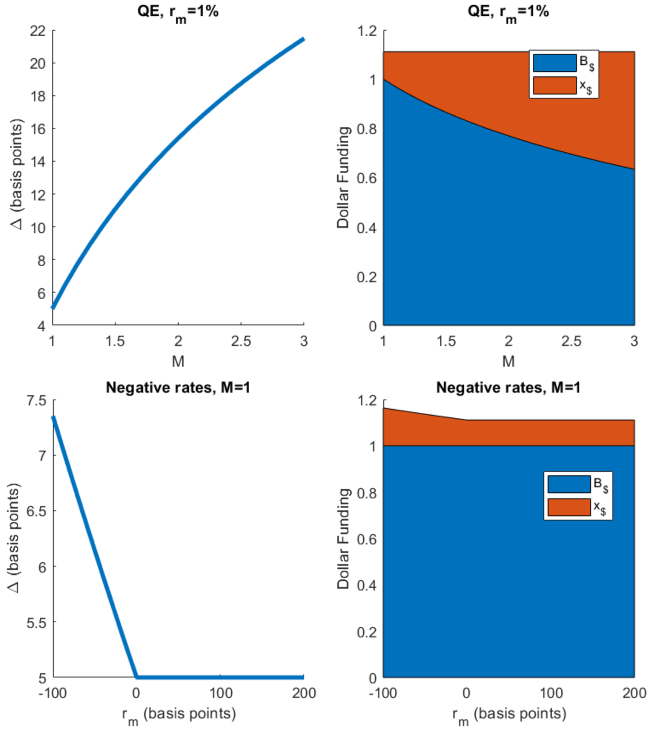
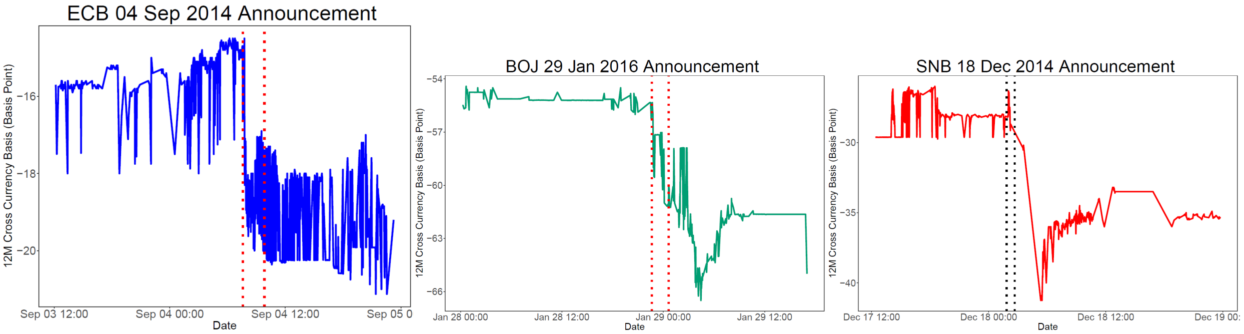
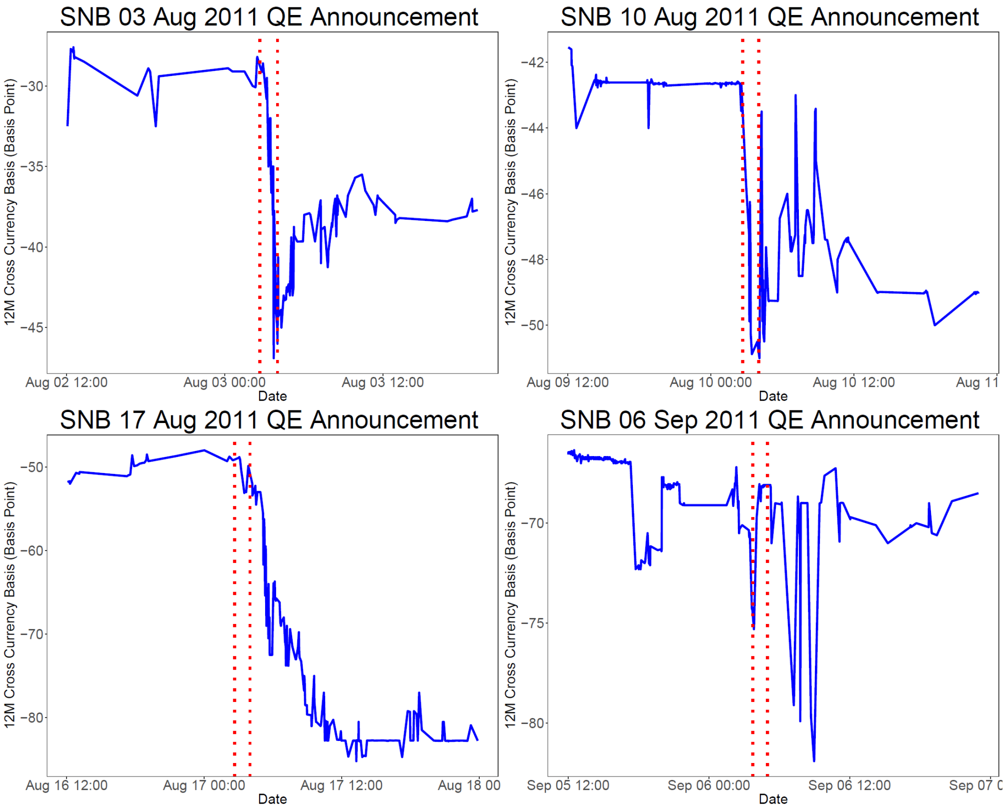


Figure 1.17: Negative interest rate announcements by the ECB, SNB and BOJ.



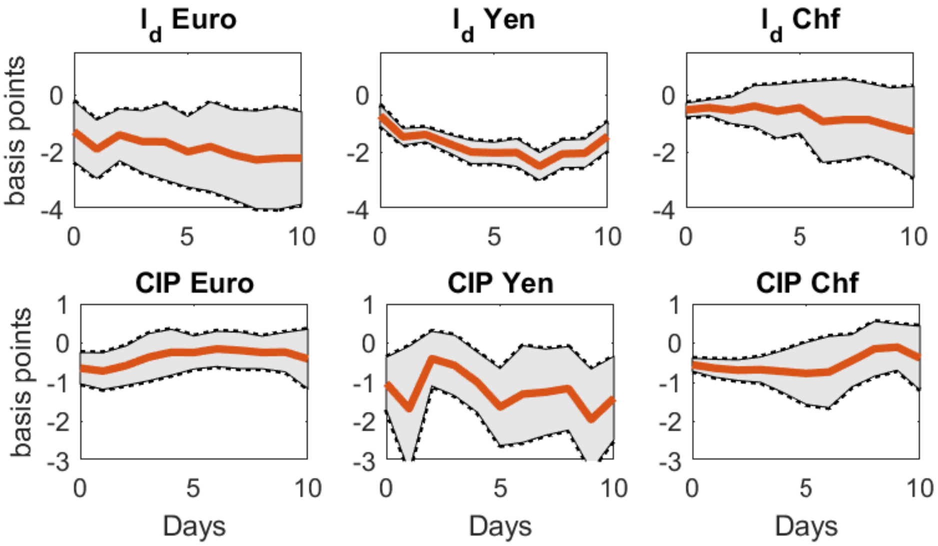
Note: Response of 12m cross-currency basis of the euro/\$, chf/\$ and yen/\$ to negative interest rate announcements by the ECB, SNB and BOJ respectively. Source: Thomson Reuters Tick History

Figure 1.18: 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 1.19: 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 1.1: **Calibration of Parameters: Initial equilibrium**

| Parameter | | |
|---|---|---|
| Dealer supply elasticity | $\Gamma$ | 0.0045 |
| Value at Risk | $\alpha$ | 4.02 |
| Convex synthetic funding cost $F(x_{\$}^{D}) = ax^2$ | $a$ | 0.085 |
| Dollar borrowing constraint | $\gamma$ | 1 |
| Credit spread elasticity to QE ($\ell_d = \bar{\ell}_d - \delta log M_t$) | $\delta$ | 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% |

Table 1.2: 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 1.3: Descriptive statistics, monetary shocks

| | Mean | SD | p-5 | p-25 | p-50 | p-75 | p-95 | Obs | Contract Period |
|---|---|---|---|---|---|---|---|---|---|
| $\mathrm{MP1}_{\mathrm{US}}$ | -0.012 | 0.076 | -0.121 | -0.010 | 0.000 | 0.040 | 0.210 | 168 | 07/95 - 09/16 |
| $\mathrm{MP}_{\mathrm{SWZ}}$ | -0.029 | 0.101 | -0.180 | -0.060 | -0.010 | 0.010 | 0.080 | 90 | 02/91 - 09/16 |
| $\mathrm{MP}_{\mathrm{UK}}$ | -0.006 | 0.063 | -0.090 | -0.020 | 0.000 | 0.010 | 0.080 | 232 | 06/97 - 09/16 |
| $\mathrm{MP}_{\mathrm{EU}}$ | 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 1.4: 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 × $\mathbb{1}[U_{\mathrm{MP}}]$ | 1.893 | 1.493 | 0.496 | 0.479 | 0.344 |
| | $(0.766)^{*}$ | $(0.590)^{*}$ | $(0.167)^{**}$ | $(0.157)^{**}$ | $(0.119)^{**}$ |
| $\delta$ | 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 1.5: 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 × $\mathbb{1}[U_{\text{MP}}]$ | 0.992 | 1.029 | 0.595 | 0.190 | 0.145 |
| | (0.668) | (0.410)$^{*}$ | (0.099)$^{***}$ | (0.043)$^{***}$ | (0.038)$^{***}$ |
| $\delta$ | 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 1.6: 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 × $\mathbb{1}[U_{\text{MP}}]$ | 10.443 | 4.810 | 1.167 | 1.134 | 0.779 |
| | (6.928) | (3.792) | (0.821) | (0.480)$^{*}$ | (0.334)$^{*}$ |
| $\delta$ | 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 1.7: Share of Interoffice Funding to Total Dollar Assets, Call Reports

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

Note: This table reports total dollar assets, $A_\$$, and the share of interoffice flows to total dollar assets, $\frac{x_\$}{A_\$}$, for U.S. branches of foreign (non U.S.) banks. Data is obtained from the FFIEEC 002 form and Call Reports of Chicago Federal Reserve. 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 1.8: Determinants of the fraction of synthetic dollar funding for U.S. subsidiaries of European, Japanese and Swiss banks

| | (1)<br>$S_{ijt}$ | (2)<br>$S_{ijt}$ | (3)<br>$S_{ijt}$ | (4)<br>$S_{ijt}$ | (5)<br>$S_{ijt}$ |
|---|---|---|---|---|---|
| $i_{d,ois} - i_{\$,ois}$ | -0.0928*** | | | -0.0474 | |
| | (0.0333) | | | (0.0316) | |
| $i_{d,ois} - i_{\$,ois} \times \mathbb{1}[U_{\text{MP}}]$ | 0.0127 | | | | |
| | (0.272) | | | | |
| $\text{cs}_d$ | | -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.

## 1.6 Appendices

### A: Model Proofs

#### Proof of Proposition 1: QE

#### Unconstrained Bank

From equation 1.16, 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.

$$F'(x^D_\$) = \ell_\$ - (\bar{\ell}_d G(M) + \Delta) \tag{1.6.25}$$

In equilibrium, dealers set a price $\Delta$ such that in equilibrium, $x^D_\$ = N\frac{\Delta}{\rho\theta^2\sigma_s^2}$. Taking the derivative of equation 1.6.25 with respect to M,

$$F''(x^D_\$) N \frac{\Delta}{\rho\theta^2\sigma_s^2}\frac{\partial\Delta}{\partial M} = -\bar{\ell}_d G'(M) - \frac{\partial\Delta}{\partial M} \tag{1.6.26}$$

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

$$\frac{\partial\Delta}{\partial M} = -\frac{\bar{\ell}_d G'(M)}{1 + \frac{NF''(x^D_\$)}{\rho\theta^2\sigma_s^2}} > 0 \tag{1.6.27}$$

#### 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, $x^D_\$ = N\frac{\Delta}{\theta\rho\sigma_s^2}$.

$$N\frac{\Delta}{\rho\theta^2\sigma_s^2} = A_\$ - \gamma K \tag{1.6.28}$$

Taking derivative with respect to M,

$$\frac{N}{\theta\rho\sigma_s^2}\frac{\partial\Delta}{\partial M} = \frac{\partial A_\$}{\partial M} + \frac{\partial A_\$}{\partial\Delta}\frac{\partial\Delta}{\partial M} \tag{1.6.29}$$

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

$$\frac{\partial\Delta}{\partial M} = \frac{\frac{\partial A_\$}{\partial M}}{\frac{N}{\rho\theta^2\sigma_s^2} - \frac{\partial A_\$}{\partial\Delta}} \tag{1.6.30}$$

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 $y_\$ - (l_d + r^f_\$ + \Delta + F'(x^D_\$))$. $\Sigma$ 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,

$$\frac{\partial A_\$}{\partial M} = -\bar{\ell}_d G'(M) A_\$ \left( \frac{1}{R_\$} + \frac{R_\$}{R^T R} \right) \tag{1.6.31}$$

$$\frac{\partial A_\$}{\partial \Delta} = -\left( 1 + \frac{N F''(x_\$^D)}{\rho \theta^2 \sigma_s^2} \right) A_\$ \left( \frac{1}{R_\$} + \frac{R_\$}{R^T R} \right) \tag{1.6.32}$$

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

$$\frac{\partial \Delta}{\partial M} = -\frac{\bar{\ell}_d G'(M)}{1 + \frac{N F''(x_\$^D)}{\rho \theta^2 \sigma_s^2} + \frac{N}{\rho \theta^2 \sigma_s^2 A_\$} \left( \frac{1}{\frac{1}{R_\$} + \frac{R_\$}{R^T R}} \right)} > 0 \tag{1.6.33}$$

### Proof of Proposition 2: Negative interest rates

### Constrained Bank

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

$$N \frac{\Delta}{\rho \theta^2 \sigma_s^2} = A_\$ - \gamma K \tag{1.6.34}$$

Taking the derivative with respect to $r_m$,

$$\frac{N}{\theta \rho \sigma_s^2} \frac{\partial \Delta}{\partial r_m} = \frac{\partial A_\$}{\partial r_m} + \frac{\partial A_\$}{\partial r_m} \frac{\partial \Delta}{\partial r_m} \tag{1.6.35}$$

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

$$\frac{\partial \Delta}{\partial r_m} = \frac{\frac{\partial A_\$}{\partial r_m}}{\frac{N}{\rho \theta^2 \sigma_s^2} - \frac{\partial A_\$}{\partial \Delta}} \tag{1.6.36}$$

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 $R = \left[ \begin{array}{cc} R_d & R_\$ \end{array} \right]^T$.$R_d$ is the domestic excess return $y_d - c_d$, and $R_\$$ is the dollar excess return $y_\$ - (l_d + r_\$^f + \Delta + F'(x_\$^D))$. $\Sigma$ 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:

$$\frac{\partial A_\$}{\partial r_m} = -\frac{R_d A_\$}{R^T R} \tag{1.6.37}$$

$$\frac{\partial A_\$}{\partial \Delta} = -\left( 1 + \frac{N F''(x_\$^D)}{\rho \theta^2 \sigma_s^2} \right) A_\$ \left( \frac{1}{R_\$} + \frac{R_\$}{R^T R} \right) \tag{1.6.38}$$

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

$$\frac{\partial \Delta}{\partial r_m} = -\frac{R_d}{\frac{NR^TR}{\rho\theta^2\sigma^2 A_\$} + \left(1 + \frac{NF''(x_\$^D)}{\rho\theta^2\sigma_s^2}\right)\left(\frac{R^TR}{R_\$} + R_\$\right)} \tag{1.6.39}$$

## 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]

$$CIP_t^T = \underset{\text{direct}}{y_{\$,t}^T} - \underbrace{\left(y_{d,t}^T + f_t - s_t\right)}_{\text{synthetic}} \tag{1.6.40}$$

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 $\Delta$, 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 LIBOR to obtain floating LIBOR. The forward premium, which is the net cost of engaging in the cross-currency swap, is expressed in equation 1.6.41, where $IRS_{\$,t}$ and $IRS_{d,t}$ are the fixed-floating interest rate swaps in USD and domestic currency respectively.

$$f_t - s_t = IRS_{\$t} - \Delta_t - IRS_{d,t} \tag{1.6.41}$$

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[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.

Finally, substituting the formula for the forward premium in equation 1.6.42, I obtain a formula for the Treasury basis.[44]

$$CIP_t^T = y_{\$,t}^T - y_{d,t}^T - (IRS_{\$,t} + \Delta_t - IRS_{d,t}) \tag{1.6.42}$$

The specification I test is in equation 1.6.43, 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 1.6.43 are provided in Tables 1.9, 1.10 and 1.11. 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.

$$CIP_t^T - CIP_{t-1}^T = \alpha + \kappa \mathbb{1}[U_{MPt}] + \beta MP_t + \gamma \mathbb{1}[U_{MPt}] \times MP_t + u_t \tag{1.6.43}$$

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 1.12, 1.13 and 1.14. 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 surprises.

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

[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.

Table 1.9: 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 × $\mathbb{1}[U_{\mathrm{MP}}]$ | 0.101 | 0.137 | 0.266 | 0.168 | 0.533 |
| | (0.252) | (0.248) | (0.256) | (0.269) | (0.352) |
| $\delta$ | -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 1.10: 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 × $\mathbb{1}[U_{\mathrm{MP}}]$ | 0.294 | 0.533 | 0.337 | 0.101 | 0.423 |
| | (0.292) | (0.124)$^{***}$ | (0.136)$^{*}$ | (0.141) | (0.127)$^{**}$ |
| $\delta$ | 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 1.11: 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 × $\mathbb{1}[U_{\text{MP}}]$ | 0.762 | 0.621 | 0.474 | -0.171 | 0.237 |
| | (0.845) | (0.392) | (0.486) | (0.593) | (0.390) |
| $\delta$ | 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 1.12: 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 × $\mathbb{1}[U_{\text{MP}}]$ | 0.792 | -0.528 | -2.121 | -4.307 | -1.796 |
| | $(0.367)^{*}$ | $(0.210)^{*}$ | $(0.304)^{***}$ | $(0.203)^{***}$ | $(0.266)^{***}$ |
| $\delta$ | 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 1.13: 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 × $\mathbb{1}[U_{\mathrm{MP}}]$ | 0.348 | 0.301 | -0.411 | -2.836 | -1.039 |
| | (0.174)$^{*}$ | (0.125)$^{*}$ | (0.096)$^{***}$ | (0.170)$^{***}$ | (0.097)$^{***}$ |
| $\delta$ | 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 1.14: 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 × $\mathbb{1}[U_{\mathrm{MP}}]$ | 0.915 | -0.162 | -0.486 | -2.870 | -0.498 |
| | (0.238)$^{***}$ | (0.146) | (0.120)$^{***}$ | (0.207)$^{***}$ | (0.106)$^{***}$ |
| $\delta$ | 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.

# Chapter 2

# Price-setting in the Forex Swap Market: Evidence from Order Flow

## 2.1 Introduction

Pricing in the forex swap market has been subject to considerable scrutiny since the global financial crisis. The pricing of forwards no longer obeys the iron law of covered interest rate parity (CIP). A theory of arbitrage, CIP states that the rate of return on equivalent domestic and foreign assets should equalize after covering exchange rate changes in the forward market[1]. Since 2008, CIP deviations have been large and persistent for the euro/\$, chf/\$ and yen/\$ pairs, and have implied a systematic premium for banks to swap euros, swiss francs and yen into dollars in the forex swap market (Figure 2.1). Much attention has been on explaining the price puzzle, and range from explanations that center on limits to the supply of dollars in the forex swap market, as well as macroeconomic factors that lead to an excess demand for swapping euros, swiss francs and yen into dollars in the forex swap market.

CIP is a constellation of four rates, the spot and forward rate, and the domestic and foreign interest rates. In normal times, a dealer sets the forward rate to mechanically equate the domestic and foreign rates of return after hedging exchange rate risk– in other words, the forward rate is set to ensure the arbitrage condition of CIP holds. However, the fact that deviations from parity exist enables us to shine a light on price determination that would not be available in a world in which the forward rate is set mechanically to make the CIP condition hold. Dealers, who set the forward rate of the swap, submit excess demands for swapping euros, swiss francs and yen to an interdealer market. Crucially, these excess demands can then be used by dealers to update the forward rate of the swap. We define these excess demands as order flow, which are net demand changes that are publicly observable and only impact price when signals of it are manifested in FX trading.

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[1] In the appendix, we briefly outline key definitions of CIP and the operation of foreign exchange and cross-currency basis swaps.

In this paper, we propose a framework to understand the relationship between order flow and price-setting in the forex swap market. The model has two key agents, customers and dealers in the forex swap market. Customers represent European, Swiss and Japanese banks who are swapping euros, swiss francs and yen into dollars to hedge their dollar asset positions. Dealers take the other end of the transaction, and supply dollars in exchange for euros, swiss francs and yen. Dealers submit excess customer orders it cannot meet to an interdealer market. Dealers typically keep their positions flat and do not want to hold inventory in non dollar currencies. This yields a price-setting condition in the interdealer market, wherein the forward rate is set so that order imbalances are expected to be zero.

Using the framework, we predict shocks to customer demand that are unanticipated by the interdealer market lead to a rise in order flow. To offset order imbalances, dealers then raise the forward premium, resulting in a widening of the cross-currency basis. In contrast, shocks to customer demands that are incorporated into public information leads to a contemporaneous price-setting without order flow actually taking place. Therefore, order flow only matters for price-setting in response to shocks that are based on private information. In Figure 2.5 we illustrate the two cases of public and private information, and show the corresponding time path for order flow and price-setting in response to a shock to customer demands.

To test the order flow hypothesis, we use two data sources for order flow. For short-term maturities, we use the Thomson Reuters D2000-2 platform available at the Norges Bank. This records interdealer transactions in the foreign exchange swap market for maturities of 1 week, 2 weeks and 3 weeks, and the key bilateral pairs of euro/\$, yen/\$ and chf/\$. At maturities of greater or equal to 1 year, we use swap repository data from Bloomberg SDR. This records trades in cross-currency swaps. We first provide evidence on whether order flow matters for price-setting by showing that an unconditional shock to order flow causes a widening of CIP deviations. Assuming a structural ordering in which dealers reset the forward rate and cross-currency basis with a lag in response to a rise in order flow, we find that across the term structure, an unconditional shock to order flow imbalances cause a widening of the cross-currency basis for all pairs.

We then provide three tests of the order flow hypothesis in which we identify sources of shocks to customer demands and dealer supply of dollars in the forex swap market. First, we test for whether there is an increase in order flow around expansionary unconventional monetary announcements of the European Central Bank, Bank of Japan and Swiss National Bank. A recent literature has argued that expansionary monetary policies have caused relative declines in domestic funding costs. All else equal, this makes it relatively cheaper to borrow euros, swiss francs and yen into dollars, and swap into dollars via the forex swap market. This results in a rise in order flow. As dealers need to offset the order flow on their balance sheets, they reset the forward rate to increase the premium at which domestic currency is swapped into dollars, resulting in a widening of the cross-currency basis.

To test this hypothesis, we use interest rate futures around scheduled monetary announcements as a measure of the surprise component of monetary policy. We find evidence of significant price effects, a widening of the cross-currency basis, a decline in domestic credit spreads, but limited effect on order flow. This limited impact on order flow is surprising, given that the model predicts that dealers should adjust the cross-currency basis in response to a rise in order flow. A possible explanation is that dealers use monetary announcements to update their information sets. If so, then dealers may adjust the cross-currency basis in anticipation of rising demand for dollars via forex swaps from banks, in response to the announcement and in advance of the order flow. In this case, dealers adjust prices without order flow actually taking place.

Using interest rate futures may be problematic if the channel through which credit spreads actually decline is due to a significant rise in central bank asset purchases. For example, Bank of Japan meetings are typically focused on setting monetary aggregates, with little reference made to the path of interest rates. As an alternative identification procedure for monetary surprises, we use the relative balance sheet growth of the central bank balance sheet. We then conduct local projections of the cross-currency basis and order flow with respect to the measure of balance sheet growth to identify the effect of central bank asset purchases. We find domestic funding costs decline, and a rise in order flow that is strongest for the yen/$ pair and a widening of the cross-currency basis. This is consistent with the view that price-setting follows order flow.

Second, we test the effect of Federal Reserve Swap line allotments during 2008-2010. Swap lines provide dollar funding to counterparty central banks, who allocate dollar funding to non-US banks that are suffering from a dollar shortage. By providing an alternative source of dollar liquidity to non-US banks, these banks will no longer requires dollars via the swap market. This will lead to a decline in order flow, resulting in a narrowing of the cross-currency basis.. Identifying the impact of swap lines is difficult, because swap lines are a non-randomized treatment used precisely at times of scarce funding. We use a structural VAR methodology in which the direction of causation is assumed to run from swap allotments to order flow and from there to the cross-currency basis. We show that a shock to the volume of Federal Reserve allotments in 2008-2010 caused a decline in the USD libor-ois spread, a decline in order flow and a narrowing of the cross-currency basis. This is consistent with the hypothesis that the Fed's dollar swaps had a noticeable impact in reducing CIP deviations. Consistent with this theory, we find a significant decline in order flow for the euro/$ and yen/$ pairs, and a narrowing of CIP deviations.

Third, we provide evidence of idiosyncratic shocks to dealer balance sheets, we utilize variation in order flow of short-term maturities relative to a set of longer-term forex swaps around quarter-ends. As a subset of dealers face leverage constraints at quarter-ends, we expect a relative decline in the supply of dollars in short-term (less than 1 month) forex swaps, as dealers offload their balance sheets to meet regulatory capital requirements. In theory, this should result in an increase in order flow, and a widening of CIP deviations of short-term maturities. We find dealer leverage constraints at quarter-ends increase order flow of short-term maturities, supporting the hypothesis that price-setting is occurring in response to order imbalances in the interdealer market.

## Related Literature

The literature has explained the CIP puzzle through constraints on the supply of dollars in the forex swap market. Theories include rising balance sheet costs and regulatory requirements (Du et al., 2018a; Liao, 2018; Bräuning and Puria, 2017), the role of the dollar in constraining dealer leverage (Avdjiev et al., 2016), rising bid-ask spreads due to limited dealer capacity (Pinnington and Shamloo, 2016), and rising counterparty risk (Baba and Packer, 2009). Other factors affecting agents demands for dollars in the forex swap market include unconventional monetary policies, and central bank swap lines. This paper contributes to understanding CIP violations by understanding how constraints on dealer supply and factors that affect customer demands cause systematic changes in order flow. Through identifying these factors, we can see if observed price-effects are occurring via order imbalances.

The paper contributes to a literature in understanding the role of order flow in price-discovery in forex swaps. The seminal work on market microstructure in forex has typically examined the price impact of order flow on spot foreign exchange markets (Evans and Lyons, 2002, 2005, 2006). The authors find order flow is a good predictor of exchange rate movements, and can perform well as a predictor in out-of-sample forecasting. Order flow has also been studied in the equity market (Hasbrouck, 1991). This literature emphasizes that order flow has an effect on price discovery insofar in that it reflects private information of customers, that are not part of the dealer information set. Microstructure models (Evans and Lyons, 2002) have typically used simultaneous trade models in which dealers set prices, and use interdealer order flow following a trading round as information to reset prices. Extensions of these models also examine the impact of order flow in the forex spot market is largely dependent on macroeconomic information. This is important as order flow conveys private information of customers that are not known by dealers when they set prices. If so, order flow conveys useful information on macroeconomic fundamentals that dealers use to update prices.

While order flow has been studied exhaustively in these markets, there has only been recent interest in understanding the impact of order flow in forex swaps. This has been a post-crisis phenomenon, as prior to 2008 covered interest rate parity violations were small and within bid-ask spreads. Therefore forward rates were typically set based on the covered interest rate parity condition. However, since 2008, there is increasing evidence on the role of dealer leverage playing a role in the ability to absorb order imbalances. Evidence in the following papers (Cenedese et al., 2017; Rime et al., 2017) make the argument that order flow, measured as the net of trades swapping domestic currency (euros, yen and swiss francs) to dollars, is positively associated with a widening of cross-currency basis for these currency pairs.

The paper is outlined as follows. In section 2.2, we outline the framework of dealers, customers and the interdealer market. We impose a price-setting condition in the interdealer market and show order imbalances arise as the component of customer demands and dealer supply that are unanticipated by the interdealer market. In section 2.3, we outline our two data sources on order flow, Norges Bank TR D2000-2 platform for swaps with maturities <1m, and Bloomberg SDR which contain data on cross-currency swaps at longer (>3m) maturities. In section 2.4, we provide empirical evidence to test the hypothesis that price-setting occurs in response to order imbalances in the interdealer market. In section 2.4, we use our structural VAR methodology to obtain the unconditional response of cross-currency basis to a shock in order flow. In section 2.4, we examine the impact of expansionary monetary announcements of ECB, BOJ and SNB through order flow. In section 2.4, we examine the effect of swap line and TAF allotments. In section 2.4, we examine quarter-end effects on short-term (1m) cross-currency basis and order flow relative to a set of longer maturities. In section 2.5 we conclude.

## 2.2 Model

FX swap markets are structured to have a dealer-customer market, and an interdealer market (Figure 2.2). Customers include banks and other financial institutions that swap euros, swiss francs and yen into dollars to hedge their dollar asset positions. They submit their orders to dealers, who take the other side of the trade. Dealers supply these dollars in exchange for euros, swiss francs and yen, and make a forward premium on the swap trade. Dealers operate in dollars, and customer demands beyond the amount they are willing to supply are submitted to the interdealer market, we denote this as order flow $OF$. Interdealer order flow is then defined as the sum of each dealer's excess customer demands. The interdealer market aims to set a forward rate such that order imbalances are zero.

### Dealers

Following Sushko et al. (2017), we model a dealer that has expected exponential utility over next period wealth $W_{t+1}$. Formally, we define $U_t = E_t\left[-e^{-\rho W_{t+}}\right]$, where $\rho$ is a measure of risk aversion.

The dealer decides to lend $x_{j,t}$ dollars in the forex swap market. To do so, they first borrow at the dollar risk-free rate $r^f_\$$. 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 $f_t$. During the contract, they invest the domestic currency at a risk-free rate $r^f_d$. The net profit they make per unit of arbitrage is defined as the cross-currency basis, $\Delta_t$,which is the excess of the forward premium over the interest rate differential, $\Delta_t = f_t - s_t - (r^f_\$ - r^f_d)$.

The dealer bears exchange rate risk. In the event of a default with a given probability $\theta$, 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 $s_{t+1}$. We can write the evolution of wealth in the next period 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. We capture costs to dealer leverage, $\phi_{j,t}\left(\frac{x}{W}\right)$, with $\phi_{j,t}(.) > 0$. This is a stylized way of capturing regulatory factors such as requirements on a minimum level of risk-weighted capital to assets, and other costs of scaling the balance sheet to conduct CIP arbitrage.

$$W_{j,t+1} = \underbrace{W_{j,t}(1+r^f_\$)}_{\text{return on wealth}} + \underbrace{x^j_{\$,t}\Delta_t}_{\text{cip arbitrage}} + \underbrace{\theta x_{j,t}(s_{t+1}-f_t)}_{\text{counterparty risk}} - \underbrace{W_{j,t}\phi_{j,t}\left(\frac{x_{j,t}}{W_{j,t}}\right)}_{\text{leverage constraint}} \tag{2.2.1}$$

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

$$\max_{x^*_{j,t}} \rho \left( W_t(1+r^f_\$) + x_{\$,t}\Delta_t - \frac{1}{2}\rho\theta^2 x^2_{\$,t}\sigma^2 - W_t\phi_{j,t}\left(\frac{x_{j,t}}{W_{j,t}}\right)\right) \tag{2.2.2}$$

Assuming a linear cost function $\phi_{j,t}\left(\frac{x}{W}\right)$, the optimal supply of dollars by a dealer is given by $x^*_{j,t}$. Dealer supply of dollars is positively associated with the forward premium (and hence cross-currency basis), marginal costs of leverage.

$$x^*_{j,t} = \frac{\Delta_t - \phi'_j\left(\frac{x_{j,t}}{W_{j,t}}\right)}{\rho\theta^2\sigma^2} \tag{2.2.3}$$

## Customers

Conceptually, customers, typically banks, use the forex swap market to swap domestic currency (for example euros, swiss francs and yen) into dollars to hedge their dollar asset positions. We capture bank demand by the following stylized function, where banks are in a continuum [0,1] indexed by bank quality $\theta_b$. Other determinants include domestic and dollar funding costs, $c_d$ and $c_\$$, and the cross-currency basis $\Delta$.

$$x^D_{\$,t} = \int_0^1 f(\theta_b, c_d, c_\$, \Delta)db \tag{2.2.4}$$

Below we describe in more detail the potential determinants of customer demand for forex swaps.

**Bank quality:** All else equal, banks with higher quality are more likely to obtain dollars directly, as they have easier access to commercial paper markets and direct dollar deposits. Therefore demands for dollar funding via forex swaps is inversely related to bank quality. Examples where bank quality are key determinants are the decline in credit ratings of banks during the Euro crisis causing a rise in dollar funding via forex swap markets as banks lost access to dollar commercial paper markets.

**Funding costs:** Relative funding costs across currencies matter for customer demands in the forex swap market. All else equal, a decline in domestic funding costs makes it cheaper to issue a bond, say in euros, and swap euros into dollars to obtain dollar funding.

**Forward premium:** Based on the discussion of the forex swap in the section on dealer, the customer pays the cross-currency basis, a premium of $\Delta = f - s + r^f_d - r^f_\$$, for every

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[2] To derive this formula, note that $U_t = -e^{-\rho\left(W_t(1+r^f_\$)+x_{\$,t}\Delta_t-\theta x_{\$,t}f_t\right)}E_t e^{-\rho\theta x_{\$,t}s_{t+1}}$. Using the properties of the exponential distribution, $E_t e^{-\rho\theta x_{\$,t}s_{t+1}} = e^{-\rho\theta x_{\$,t}f_t-\frac{1}{2}\rho^2\theta^2 x^2_{\$,t}\sigma^2}$. Taking logs and simplifying yields the expression in equation 2.2.2.

dollar they obtain via a forex swap contract. This means, all else equal, a higher forward premium of the swap leads to a decline in customer demand.

## Interdealer market

Each dealer supplies an optimal level of dollars $x_j^*$ determined in equation 2.2.3. Orders they cannot meet are submitted to the interdealer market. Order flow, $OF_t$ is then defined as customer demands for swapping domestic currency into dollars in excess of the optimal supply of dollars by dealers.

$$OF_t = x_{\$,t}^D - \sum_{j=1}^{N} x_j^* \tag{2.2.5}$$

To illustrate the timing of customer-dealer trades and price-setting, Figure 2.3 depicts a two period model, in which customers and dealers trade at the beginning of each period. Immediately after each period of trading, the interdealer market observes order flow. Dealers then set the forward rate of the forex swap, and hence the cross-currency basis $\Delta$, to set expected order imbalances to zero for the next period of trading.

**Definition [Price setting]:** *Assume the interdealer market sets a forward price for the entire market, based on an information set that includes bank funding costs, returns. The cross-currency basis $\Delta_t$ is set to generate zero order flow in expectation.*

$$E_t\left[OF_t(\Delta_t)|\mathcal{I}_t\right] = 0 \tag{2.2.6}$$

The price-setting condition is common to the interdealer market, in which all dealers quote a common price. If dealers set different prices, this would not be a feasible equilibrium as customers will only execute swap trades with the dealer that sets the lowest ask price. Combining equations 2.2.5 and 2.2.6, we can rewrite the order flow in period $t$ as the unanticipated components of customer demand and dealer supply of dollars in the forex swap market.

$$OF_t = x_{\$,t}^D - E\left[x_{\$,t}^D|\mathcal{I}_t\right] - \sum_{j=1}^{N}\left(x_{j,t}^* - E\left[x_{j,t}^*|\mathcal{I}_t\right]\right) \tag{2.2.7}$$

In the model, order flow responds to changes to demand fundamentals that are not forecast by dealers. This provides a simple decomposition of order imbalances into unexpected idiosyncratic shocks to customers and dealers, shown in equation 2.2.8. The first term reflects unanticipated shocks to customer type and funding costs. For example, the interdealer market may not directly observe customer types, such as credit ratings and their ability to borrow dollars in alternative markets. The second term reflects unanticipated rises in the cost of leverage.

$$OF_t = \underbrace{\int_0^1 f(\theta_b, .) - E\left[f(\theta_b, .)|\mathcal{I}_t\right] db}_{\text{customer type and funding costs}} + \frac{1}{\rho\theta^2\sigma^2} \underbrace{\sum_{j=1}^{N} \phi'_{j,t}\left(\frac{x}{W}\right) - E\left[\phi'_{j,t}\left(\frac{x}{W}\right)|\mathcal{I}_t\right]}_{\text{dealer leverage constraints}} \tag{2.2.8}$$

Finally, we can solve for the equilibrium cross-currency basis $\Delta$, can be derived from setting expected order flow to zero, in equation 2.2.9. Intuitively, an increase in customer demands, or a tightening of leverage constraints on dealers, leads to a widening of the basis.

$$\Delta_t = E\left[\phi'_{j,t}\left(\frac{x}{W}\right)|\mathcal{I}_t\right] + \frac{\rho\theta^2\sigma^2}{N}\int_0^1 E\left[f(\theta_b, .)|\mathcal{I}_t\right] \tag{2.2.9}$$

We present a stylized illustration of price-setting in Figure 2.4. In period 0, an unanticipated shock to customer orders increases order flow to $OF_{0^+}$. The interdealer market uses this information to reset the forward rate to offset the rise in order flow. The cross-currency basis transitions to $\Delta_1$ such that $E_1\left[OF_1(\Delta_1)|\mathcal{I}_1\right] = 0$.

We can use the framework to study different sources of shocks to customers and dealers. Shocks to customers include monetary announcements, which affect the relative cost of synthetic and direct dollar funding, and central bank swap lines, which provides an alternative source of dollar funding for banks facing a dollar shortage. Shocks to dealers could be in the form of regulations on maintaining a minimum level of regulatory capital at quarter-ends.

**Monetary announcements and funding costs**

Expansionary announcements by the ECB, BOJ and SNB have led to a decline in domestic funding costs. All else equal, this causes customers to borrow domestic currency and swap into dollars. If monetary announcements are unanticipated by the interdealer market, this translates to a rise in order flow. To restore order flow, the dealers raise the forward premium of the swap trade.

**Central bank swap lines**

Central bank swap lines by the Federal Reserve provide incremental dollar liquidity to sufficiently dollar constrained banks. As banks of low quality are more likely to use central bank swap lines as a way to meet dollar funding, we can interpret this as reducing customer demand for dollars via forex swaps. If the swap line auctions to dollar constrained banks are private information, it is likely the reduced customer demands are unanticipated by the interdealer market. This results in a decline in order flow, causing a decline in the forward premium of the swap trade.

**Order Flow around quarter-ends**

Recent empirical evidence points to balance sheet reporting requirements at quarter-ends that limit the amount of leverage dealers can take. Therefore, at quarter-ends, a constrained dealer may have to deleverage significantly to meet regulations. Formally, an unanticipated rise in leverage costs for dealer $j$, $\phi'_{j,t}\left(\frac{x}{W}\right) \uparrow$ leads to a rise in order flow. The interdealer market then absorbs the order flow by adjusting the forward premium, widening the cross-currency basis.[3]

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[3] For more micro-level evidence that leverage matters, we refer the reader to Cenedse et al (2018) that

To conclude, the model has provided a framework to show how unanticipated shocks to customer demand and dealer supply can translate to order flow in the interdealer market. In turn, the interdealer market aims to set expected order imbalances to zero in an effort to continuously hedge their positions. In response to an increase in order flow, dealers need to reset the forward premium of the forex swap to offset order flow, resulting in a widening of the cross-currency basis. In the empirical section, we will first test whether an unconditional shock to order flow results in price-setting. We then identify the factors of monetary policy, central bank swap lines, and quarter-end regulations and examine if they lead to a significant change in order flow and price-setting.

## 2.3 Order Flow Data

Order flow is defined as the net of buyer initiated transactions. We define a transaction as buyer initiated if it is initiated by a counterparty swapping euros, Swiss francs and yen into dollars. Conversely, a transaction is seller initiated if the transaction is swapping dollars into euros, swiss francs and yen. We sign trades using the Lee-Ready algorithm. Formally, let us define $p_T$ is the transaction price, $p_a$ is the ask price and $p_b$ is the bid price.

1. If $p_{T,t} < \frac{p_{a,t}+p_{b,t}}{2}$, transaction is seller initiated
2. If $p_{T,t} > \frac{p_{a,t}+p_{b,t}}{2}$, transaction is buyer initiated
3. If $p_{T,t} = \frac{p_{a,t}+p_{b,t}}{2}$, transaction price is buyer initiated if $p_{T,t} > p_{T,t-1}$ and transaction price is seller initiated if $p_{T,t} < p_{T,t-1}$.[4]

We can construct a measure of volume order flow can then be expressed as the difference between buyer and seller initiated transactions, where $T_k$ is the transaction, $B$ indicates it is buyer initiated and $S$ indicates it is seller initiated, and $V_{T_k}$ is the volume of the transaction.

$$OF_t^{vol} = \sum_{k=t_0}^{k=t} V_{T_k} \left(\mathbb{1}[T_k = B] - \mathbb{1}[T_k = S]\right)$$

To measure order flow, we use two data sources. For short-term maturities, we use the Reuters D2000-2 trading platform available at Norges bank, which contains interdealer trades from 2005 for forex swaps for the euro/\$, chf/\$ and yen/\$ pairs for maturities of 1 week, 2 weeks and 3 weeks.[5] As we do not have the volume of transactions, we construct a count measure of order flow.[6] Summary statistics of order flow are provided in Table 2.3.

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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.

[4] If the history of bid and ask prices is not known, then trade cannot be signed and is omitted from the measure of order flow. This introduces some amount of measurement error, however a high success rate of matched trades (~90%) would suggest that this measurement error is minimal.

[5] We use the same trading platform to construct order flow in the forex swap market as in Rime et al. (2017).

[6] Count order flow is given as the net of buyer initiated transactions, where buyer initiated transactions are signed +1 and seller initiated transactions are signed -1. $OF_t^{count} = \sum_{k=t_0}^{k=t} \mathbb{1}[T_k = B] - \mathbb{1}[T_k = S]$

The second source we use is the swap repository facility available at Bloomberg (SDR), which records real-time transactions of cross-currency swap transactions with maturities of greater than 3 months. This captures a subset of the market insofar as they are institutions that report to the Bloomberg SDR facility, and is available since 2013. The per cent of buyer initiated transactions and matching rates are provided in Table 2.4, and summary statistics on both count and volume order flow for 1Y, 2Y, 5Y and 10Y swaps in Table 2.5.[7] Plots of daily order flow, cumulative order flow and the cross-currency basis for the maturities of 1 month, 1 year and 5 years are provided in the Appendix.

We raise two potential concerns with the data. First, both data sets are limited as they only capture a subset of interdealer transactions, and we only have information on executed market trades. Because of the lack of trades, we aggregate the order flow measure to a daily frequency. If dealers are resetting the forward rate at an intra-day frequency, this may reduce the explanatory power of a daily order flow shock. The second issue is that we only have executed trades, and do not have access to the limit order book. While market orders have typically been used in order flow studies, there may be additional information from limit orders that is used for price-setting that is not captured by our measure of order flow.

## 2.4 Empirical Evidence

### Unconditional shock to order flow

To test the validity of the order flow data, we estimate the effect of an unconditional shock to order flow on the cross-currency basis, for both short and long maturities, and the euro/$, chf/$ and yen/$ bilateral pairs. The model predicts that an exogenous shock to order flow cause dealers to increase the premium at which domestic currency is swapped into dollars. This causes a widening of the cross-currency basis. To test this, we use a structural vector autoregression (VAR).

Defining the reduced form $Y_t = \Phi Y_{t-1} + e_t$, we transform the reduced form with a lower triangular matrix $Q = \begin{bmatrix} 1 & 0 & 0 \\ b_{21} & 1 & 0 \\ b_{31} & b_{32} & 1 \end{bmatrix}$, where $QQ^T = \Omega = var(e_t)$, and the structural errors are $\epsilon_t = Q^{-1}e_t$. We implement an ordering $Y_t = \begin{bmatrix} cip_t & of_t \end{bmatrix}^T$. This ordering is based on the identifying assumption that causality runs from order flow imbalances to the cross-currency basis. We now test the effects of an unconditional shock to order flow on the CIP deviation, using the Thomson Reuters D2000-2 dataset, which contains order flow for maturities up to 1 month, and the swap repository available via Bloomberg, which contains maturities typically greater than 1 year. [8]

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[7] Not all trades are successfully matched, as in some cases the transaction price is at the midpoint of the bid-ask. We omit these trades in classifying buyer and seller initiated trades. Although this amounts to a measurement error, the number of matched trades is at least 80% of total trades for all currency-tenor pairs.

[8] A relevant concern is that the results of a structural VAR are dependent on the assumption, in particular that the cross-currency basis responds to order flow with a delay. As an alternative method, we present results using Jorda local projections in the Appendix.

### Thomson Reuters D2000-2

We shock order flow imbalances and plot the impulse response of the 1 month cross-currency basis in Figure 2.6. We stratify the full sample (2005-2017) into two periods, pre 2008 and post 2008. In the pre-2008 period, there is no systematic effect of order flow imbalance on the cross-currency basis for all 3 pairs. However, in the post 2008 period, we find the cross-currency basis widens by approximately 3 basis points 2 to 4 days after an order flow shock for both the euro/$ and yen/$ pairs. This is consistent with the hypothesis that the information content of order flow is only important in the post-crisis period. Prior to 2008, covered interest rate parity held reasonably well, and so the forward rate was set to meet the parity condition. In contrast, order imbalances in the post-crisis period conveys information to dealers of underlying demand imbalances for dollars in the forex swap market.

### Bloomberg Swap Repository Facility (SDR)

Figure 2.7 plots the impulse response of the cross-currency basis to a $1B shock in volume order flow for cross-currency swaps at the horizons of 1 year, 2 years, 5 years and 10 years. The results are strongest for the Yen/$ basis, with a widening of the basis for all 4 tenors and a peak widening of the basis by 0.2 basis points for a $1B USD shock in order imbalances, peaking at approximately 4 days after the shock. However, for both the short and long-term maturities, we find a weak systematic effect on the chf/$ cross-currency basis. The results are consistent with the hypothesis that an unexpected rise in order flow imbalances cause dealers to raise the premium at which domestic currency is swapped into dollars, widening the cross-currency basis.

## Monetary Announcements

### Interest rate announcements

We predict expansionary monetary announcements by the ECB, BOJ and SNB reduce domestic funding costs. All else equal, this makes it cheaper for customers to borrow euros, swiss francs and yen into dollars using forex swaps. If the decline in funding costs is unanticipated by the interdealer market, the customer demands translates to an increase in order flow. The model predicts that dealers offset order flow, causing price adjustment via a widening of the cross-currency basis. To test this hypothesis, we use shocks to interest rate futures around scheduled monetary announcements of the ECB, BOJ and SNB. The identifying assumption is that surprises to the interest rate reflects monetary news, which is plausible given the window is at a high frequency. We compute the change in the interest rate futures of the central bank 90 day rate for ECB, BOJ and SNB around scheduled monetary announcements.[9]

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

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[9] we use 90 day contracts as the equivalent to 1 month contracts of the Federal Reserve policy rate are not available.

Intraday changes are typically based on a wide window, defined as the change in futures rate 15 minutes prior to the announcement and 45 minutes after the announcement. The exception is for the ECB, the wide window is calculated for 15 minutes prior to and 105 minutes after the announcement. A summary of interest rate futures for the central bank policy rate is provided in Table 2.6. Descriptive statistics including contract length is provided in Table 2.7. We conduct local projections of the outcome $Y_t$, which includes cross-currency basis, order flow and credit spreads, on the monetary shock $MP_t$ relevant to the currency pair, lags of the outcome variable, as well as controls $X_t$ that include the trade weighted dollar exchange rate, VIX volatility index and the USD libor-ois spread.

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_i + \beta_h MP_t + \sum_{l=1}^{L} \delta_l \Delta Y_{i,t-l} + X_t + \epsilon_t,\ \ h = 0, 1, 2, ....10$$

We present results for a 1 basis point expansionary shock for Euro, Yen and Swiss Franc using our constructed measure of order flow for long maturities (1Y+) in Figure 2.8. We find evidence of a widening of cross-currency basis, a decline in domestic credit spreads. However, for all three currency pairs, there is a weak positive contemporaneous effect on order flow, and these effects die out at horizons longer than one day. The limited impact on order flow is surprising, given the model predicts that dealers should adjust the cross-currency basis in response to a rise in order flow. To reconcile this finding, we propose that monetary announcements are a source of public information, and released to financial markets in a transparent way, with meeting times known well in advance. Dealers can accordingly update their information sets contemporaneously. If they anticipate the monetary announcement will increase bank demands for dollar funding, they raise the premium to swap euros, Swiss francs and yen into dollars. In doing so, they adjust prices without order imbalances taking place. Second, data limitations require aggregation of data to a daily frequency. In reality, trading rounds between dealers and banks occur at an intra-day frequency.

### QE announcements

As an alternative test of the effects of unconventional monetary policy, we use balance sheet growth of the central bank as a measure of the extent of quantitative easing. The merits of this is that in many cases, meetings by the central bank, such as the BOJ, typically focus on setting targets for the money supply, in contrast to setting the interest rate. Large asset purchases may happen without the base interest rate changing, and there is insufficient variation in interest rate futures during the relevant period of zero and negative interest rate regimes.

We use the total assets of central banks to construct $\Delta BS_{t+m}$, which is defined as the per cent growth differential between the domestic balance sheet growth and Federal Reserve asset growth, at a horizon $m$. Monthly data on central bank balance sheets are obtained from the FRED database. Following the methodology in Dedola et al. (2017a), we identify the effects of balance sheet growth at a horizon $m = 3$ months for our baseline results. We conduct local projections of the outcome $Y_t$, which includes the cross-currency basis, order flow and credit spreads, on the balance sheet growth $\Delta BS_{t+m}$ , lags of the outcome variable, as well as controls $X_t$ that include the trade weighted dollar exchange rate, VIX volatility index and the USD libor-ois spread. We take averages of the cross-currency basis, domestic credit spreads at a monthly frequency. For order flow, we construct a measure of cumulative order flow, with the outcome variable $Y_{i,t+h} - Y_{i,t-1}$ measuring the cumulative order flow response at horizon h following the expansionary QE shock.

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_i + \beta_h \Delta BS_{t+m} + \sum_{l=1}^{L} \delta_l \Delta Y_{t-l} + X_t + \epsilon_t,\ h = 0, 1, 2, ....10$$

The results are presented in Figure 2.9. A relative increase in domestic central bank balance sheet growth has a significant impact on widening CIP deviations. A 1 per cent rise in the BOJ assets relative to the Federal Reserve leads to an approximate 4 basis points widening of the yen/\$ cross-currency basis, an increase in cumulative order flow by up to \$1B USD for the Yen 10 months after announcement, and a decline of 10 basis points in Yen funding costs relative to USD funding costs. In contrast, the euro/\$ cross-currency basis widens by up to 2 basis points, with no significant effect on cumulative order flow, and a 2-3 decline in domestic funding costs.

## Swap lines and Term Auction Facility

Central bank swap lines provide incremental dollar liquidity to sufficiently dollar constrained banks. Banks who resorted to the forex swap market for dollars in the crisis period now obtained their dollars via a central bank swap line or TAF loan. As banks no longer need dollars via the swap market, we expect a decline in buyer initiated transactions. Alternatively, if loans are instead made to dealers or banks supplying dollars in the swap market, they increase seller initiated transactions. In both cases, we predict an increase in allotments to reduce order flow, cause a narrowing of the cross-currency basis and declining USD libor-ois spreads. As motivation, we first examine cumulative order flow for both the euro/\$ and yen/\$ pairs in Figure 2.15. In both pairs, we see a systematic decline in cumulative order flow over this period. This is in line with our prediction, as the Federal Reserve supplements dollar liquidity, the net demand for dollar liquidity via the swap market should fall. To test this, we use data on Federal Reserve swap line allotments to counterparty banks. This consists of auctions of dollar funds between the Federal Reserve and a counterparty central bank. The funds are then allocated to banks in its jurisdiction. The data contains a record of every transaction made, with both amounts and maturity listed. The maturity of a swap line can range from one week to 1 month. A supplementary source of dollar liquidity is the Term Auction Facility, in which the Federal Reserve provides 28 day loans through an auction to U.S. banks and foreign (non U.S.) banks with subsidiaries in the U.S.. This provides an alternative channel through which a European, Japanese or Swiss bank can obtain dollar funding.[10]

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[10] There are a number of reasons why the Term Auction Facility may be used instead of obtaining funds via the Federal Reserve discount window, or alternatively via a central bank swap line. TAF auctions are not disclosed to the public. There is a stigma associated with using the discount window as it may signal to the market that the bank is a rollover risk. A foreign (non U.S.) bank may prefer to raise its dollar funding via

Using this data, we construct a measure of total allotments outstanding. A formal definition is provided in equation 2.4.1, in which $L_i(t_i \leq t \leq t_i + M)$ is a loan to counterparty central bank $i$ that is still outstanding at time $t$, where $t_i$ is the time at which loan is first made, and $t_i + M$ is the time of maturity of the loan. The total allotments outstanding are then summed twice, once over all counterparty central banks, and for all loans outstanding since the inception of the program. This is the most direct measure of incremental liquidity provided by the Federal Reserve to foreign (non U.S.) banks. We construct a measure f total allotments for both the central bank swap line and the TAF.

$$Allott_t = \sum_{t_0}^{t} \sum_{i} L_i(t_i \leq t \leq t_i + M) \tag{2.4.1}$$

Figure 2.10 plots the total allotments outstanding to the ECB, BOJ and SNB, as well as loans made to banks in the Eurozone, Japan and Switzerland through the TAF program. At the height of the crisis, in October of 2008, allotments peaked at approximately \$250B to the ECB, and approximately \$100B to the BOJ. The sharp rise in allotments was due to a move by the Federal Reserve to raise the ceiling on allotment amounts. The TAF program, in contrast, were loans mainly to banks headquartered in the U.S. Loans to Eurozone banks peaked at approximately \$50B, which is much smaller than the funds extended to Eurozone banks via the swap line to the ECB. To construct a global measure of total loans to banks in the Eurozone, Japan and Switzerland. We add the total amounts outstanding for lines extended to the ECB, BOJ and SNB, and TAF loans extended to the Eurozone, Japan and Switzerland.

We implement a structural VAR methodology with 4 variables, the constructed measure of swap line allotments outstanding, and a measure of CIP deviations, order flow and the USD LIBOR-OIS spread, all at a one month maturity. The LIBOR-OIS spread is conventionally used to measure default risk in interbank markets. For the measure of order flow, we use data available at the Norges Bank, which provides daily count order flow data for a set of maturities of less than one months.[11] This is a suitable measure of order flow given that the disruption to funding in interbank markets in 2008 were at shorter maturities. In addition, central bank swap line auctions were auctioning funds at maturities ranging from one week to one month.

The identifying assumption of the structural VAR assumes a direction of causation from swap line allotments, to a predicted decline in order flow, as banks substitute away from the forex swap market toward the swap line for additional dollar funding. The decline in order flow cause dealers to reduce the dollar borrowing premium, resulting in a narrowing of the CIP deviation. The vector therefore has the ordering $Y_t = \begin{bmatrix} cip_t & of_t & libor - ois_t & Allott_t \end{bmatrix}^T$. As the measure of allotments outstanding is ordered last, shocks to allotments affect the LIBOR-OIS, order flow and CIP deviations with a lag.[12]

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the subsidiary located in the U.S. Central bank swap lines are more likely auctioned off to the headquarters bank.

[11] For more details on construction, please refer to data section.

[12] For details on implementation of the structural VAR, please see appendix A.

The impulse response to a \$1B shock in $A_t$ is shown in Figure 2.11. Consistent with model predictions, there is an immediate decline in order flow in the days following the shock for the euro/\$ and yen/\$ pairs, and a narrowing of CIP deviations. The effect on order flow is strongest for the euro/\$. This is intuitive, given the majority of swap line allotments were extended to the ECB, who then auctioned off funds to banks in the Euro area.

Instead of constructing a global shock to allotments, an alternative is to construct a region specific shock. Assuming that Eurozone banks only swap euros into dollars in the forex swap market, the swap lines extended to the ECB are a more representative measure for affecting the relative demand for dollar funding in the euro/\$ swap market. Under the identifying assumption that swap lines extended to the ECB, BOJ and SNB are increasing dollar liquidity to banks predominantly operating in the euro/\$, yen/\$ and chf/\$ swap markets, we consider a \$1B shock to allotments to each central bank in Figure 2.12. The results are qualitatively similar for the euro/\$ pair, however order flow for the yen/\$ still decreases but is attenuated relative to the aggregate shock. The finding that euro/\$ order flow is most responsive is consistent with the fact that the majority of swap line allotments were extended to the ECB.

The significant effect of central bank swap lines in reducing order flow contrasts with the limited evidence in response to monetary policy announcements. To reconcile this finding, we argue that in the instance of swap lines, the information is private and not known to dealers in advance. For example, suppose the Federal Reserve extends a swap line to the ECB. They then auction those funds to Eurozone banks, the details of which are unknown to the dealers. In particular, dealers do not know whether the banks, upon receiving funds from the ECB, will reduce their demands for dollar funding in the forex swap market.[13] Dealers can only reset prices once they observe bank demands for dollar funding decline, and order imbalances decline. Scheduled monetary announcements, on the other hand, is public information. Dealers anticipate higher demand for dollar funding, and incorporate this into price-setting instantaneously.

## Quarter-end effects

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). These findings suggest that balance sheet constraints play a role, and the supply of dollars in the forex swap market by dealers is constrained.

When examining deviations in CIP across the term-structure, it is evident there is a

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[13] For example, the ECB auctions dollar funding to a set of banks, some of whom do not require dollar funding via the forex swap market. In this case, these banks substitute away from direct dollar funding to obtaining funds via a swap line.

relative increase in the 1 month cross-currency basis relative to a longer maturity around quarter-ends. This can be seen by taking the absolute difference of 1 month and 12 month deviations for the euro/usd, yen/usd and chf/usd currency pairs. Within 1 month of each quarter-end, banks have an incentive to offload their holdings of 1 month contracts as a way to deleverage sufficiently to meet the leverage requirement. First, we test for the sensitivity of 1 month cross-currency basis in response to the quarter-end adjustment. The outcome variable $Y_{1m,t}$ includes both 1 month cross-currency basis and the corresponding order flow count. $Qend_t$ is an indicator for quarter ends, and is equal to 1 in the months of March, June, September and December. Controls $X_t$ include the trade weighted dollar exchange rate, VIX volatility index and the USD libor-ois spread.

$$Y_{1m,t} = \alpha + \gamma_1 Post2008_t + \gamma_2 Post2015_t + \theta_1 \left[Qend \times Post2008\right]_t + \theta_2 \left[Qend \times Post2015\right]_t + X_t + u_t$$

Results for both 1 month CIP and 1 month OF count are in Table 2.8. 1 month CIP rises by approximately 18 basis points during the months preceding quarter-ends in the post 2015 period, and this result is robust to adding controls. The increased sensitivity of deviations in the post 2015 period corresponds to requirements on balance sheet reporting. When examining the same specification but with count order flow as the outcome, the effect on order imbalances is statistically significant and rises by 0.2 counts. This is the expected sign, as arbitrageurs are constrained at quarter-ends there are less seller-initiated transactions. However, quantitatively the effects are small to fully explain adjustment of the cross-currency basis, as 0.2 daily counts leads to an approximate 6 order flow count over a month. Although we find the quarter-end effects for 1 month cross-currency basis, the same should not hold for cross-currency basis at longer maturities, as these contracts will be on the balance sheet for consecutive quarters. To test this formally, we run a panel differences-in-differences specification including maturities at 1m and a set of control maturities.[14]

$$\begin{aligned} Y_{it} = \alpha_i + \gamma_1 Post2008_t + \gamma_2 Post2015_t + \theta_1 \left[Qend \times Post2008\right]_t + \theta_2 \left[Qend \times Post2015\right]_t + \\ + \delta_1 \left[Qend \times Post2008 \times \mathbb{1}[1m]\right]_{it} + \delta_2 \left[Qend \times Post2015 \times \mathbb{1}[1m]\right]_{it} + X_t + u_{it} \end{aligned}$$

We test for whether there is a differential effect of quarter-ends for the 1 month relative to a set of control maturities that should not be affected by the quarter-end balance sheet reporting constraint of banks. We interact our quarter-end dummy for both the post 2008 and post 2015 periods with a variable $\mathbb{1}[1m]$ is an indicator for the maturity of 1 month. Using this approach, results in Table 2.9 confirm the hypothesis that both CIP and order flow are affected differently at the 1 month maturity around quarter-ends. cross-currency basis for longer maturities are higher by 0.5 to 1 basis points around quarter-ends, which is relatively small compared to the ~18 basis point increase in 1 month deviations during months preceding quarter-ends in the post 2015 period. The order flow effects are positive and significant for one month CIP, with a similar effect of ~0.2 in the post 2008 period.

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[14] Control maturities selected are 1y, 2y, 3y, 4y, 5y, 7y and 10y. These account for ~60% of trades in Bloomberg SDR Cross-Currency Swaps.

## 2.5 Conclusion

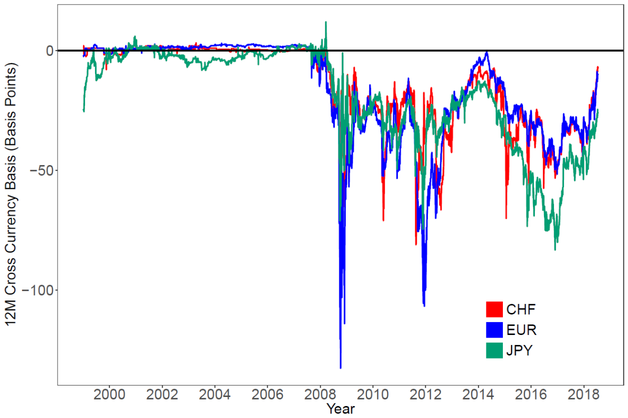
We provide a framework to understand how price-setting is determined in the forex swap market. Our framework centers on dealers learning about underlying customer demand for forex swaps through order flow. We show that order flow reflects unanticipated shocks to customer demand and dealer supply of dollars in the forex swap market. Through this framework, we can test for the information content of order flow. We measure excess demand in the forex swap market by using order flow imbalances, defined as the net of buyer initiated transactions for swapping domestic currency into US dollars. We construct a measure using the Thomson Reuters D2000-2 platform for maturities less than 1m, and for longer-term maturities ( greater or equal to 1 year) we use cross-currency swap data from a swap repository available on Bloomberg.

First, we find an unconditional shock to order imbalances, defined as the net demand for swapping domestic currency into dollars, cause a widening of cross-currency basis across the term structure. We then argue that unconventional monetary policies cause an excess demand for dollars in the swap market, increasing order flow and causing dealers to reset prices to offset order flow; this results in a widening of the cross-currency basis. We find limited evidence that price-setting is occurring in response to order flow, and reconcile this result by suggesting that monetary announcements are publicly announced and are likely to be incorporated into dealer information sets contemporaneously. We also study the provision of central bank swap lines and the term auction facility (TAF) by the Federal Reserve in 2008-2010. We find a shock to total swap line allotments leads to a significant decline in order flow for the Euro/$ and Yen/$ pairs. The rise in allotments to the ECB had the most significant impact on narrowing euro/$ cross-currency basis and libor-ois spreads. Lastly, we find some evidence that order flow at the 1m maturity rises relative to a set of control tenors at quarter-ends, suggesting that limits to the supply of dollars in the forex swap market has the potential to reduce cross-currency basis via order flow.

More work can be done to support the empirical evidence we present in this paper. The main limitations we face in our measures of order flow are, firstly, that our measures capture only a subset of both forex swap and cross currency swap transactions, and secondly, we do not know details of counterparties. This would be particularly useful as it would allow us to see in finer detail whether dealer leverage matters for the sensitivity of order flow to quarter-ends, and to derive the order flow history for individual customers and examine how their orders responded to monetary policy and swap line programs.

# Figures

Figure 2.1: Covered Interest Rate Parity Deviations for euro/\$, yen/\$ and chf/\$ pairs



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 $\Delta$ 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 2.2: Schematic of the interactions between customers, dealers and the interdealer market

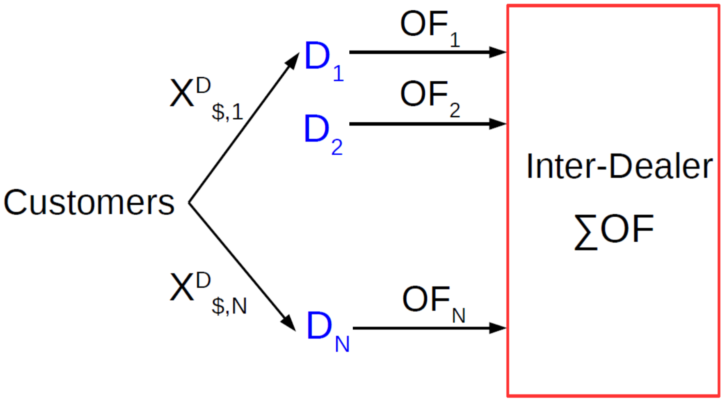


Figure 2.3: Timing

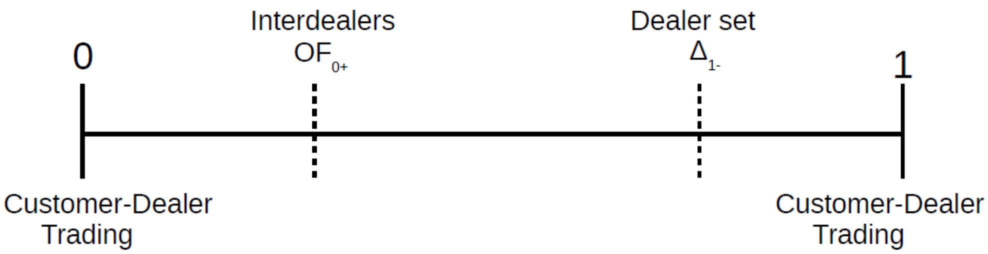


Figure 2.4: Transition dynamics of the cross-currency basis and order flow: Response to a shock to customer demands

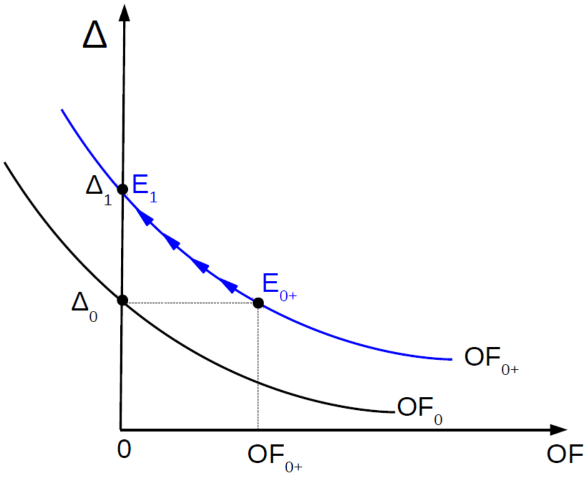
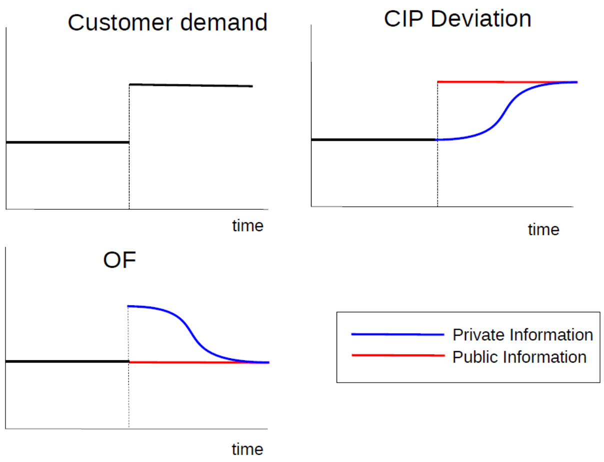
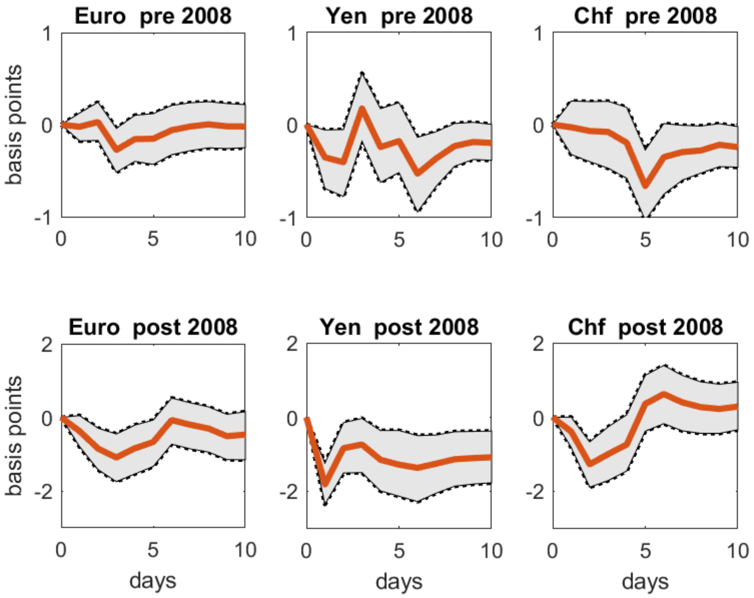


Figure 2.5: Response of order flow and CIP deviations to a shock to customer demands in forex swap market



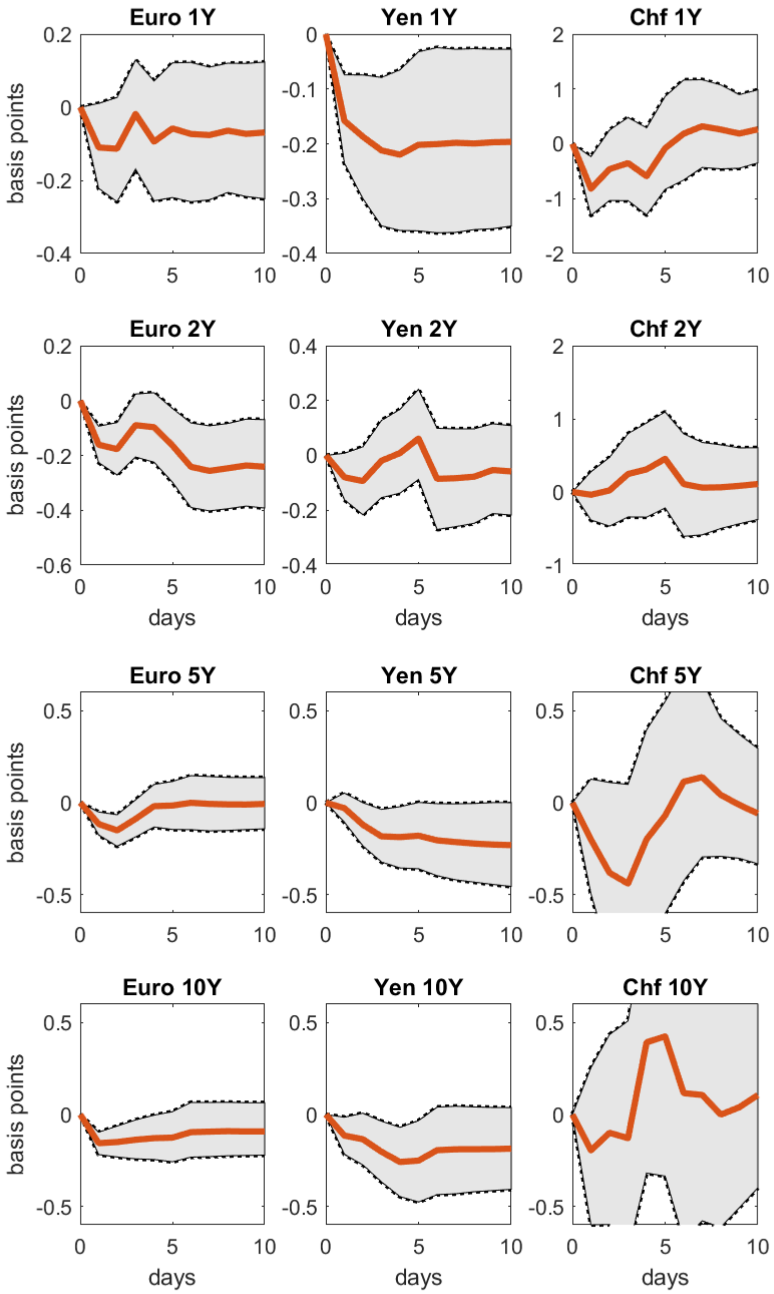
Note: Time series response of order flow and CIP deviations in response to a demand for dollar funding by customers. If the shock is based on private information outside the dealer set, order imbalances rise, and there is a delay in price-setting where dealers raise the forward premium (and hence the cross-currency basis). In contrast, if the shock is public information, then prices adjust contemporaneously and order imbalances remain unchanged.

Figure 2.6: Response of Euro/\$, Yen/\$ and Chf/\$ 1m cross-currency basis to unit shock in count order flow in pre 2008 (left) and post 2008 (right)



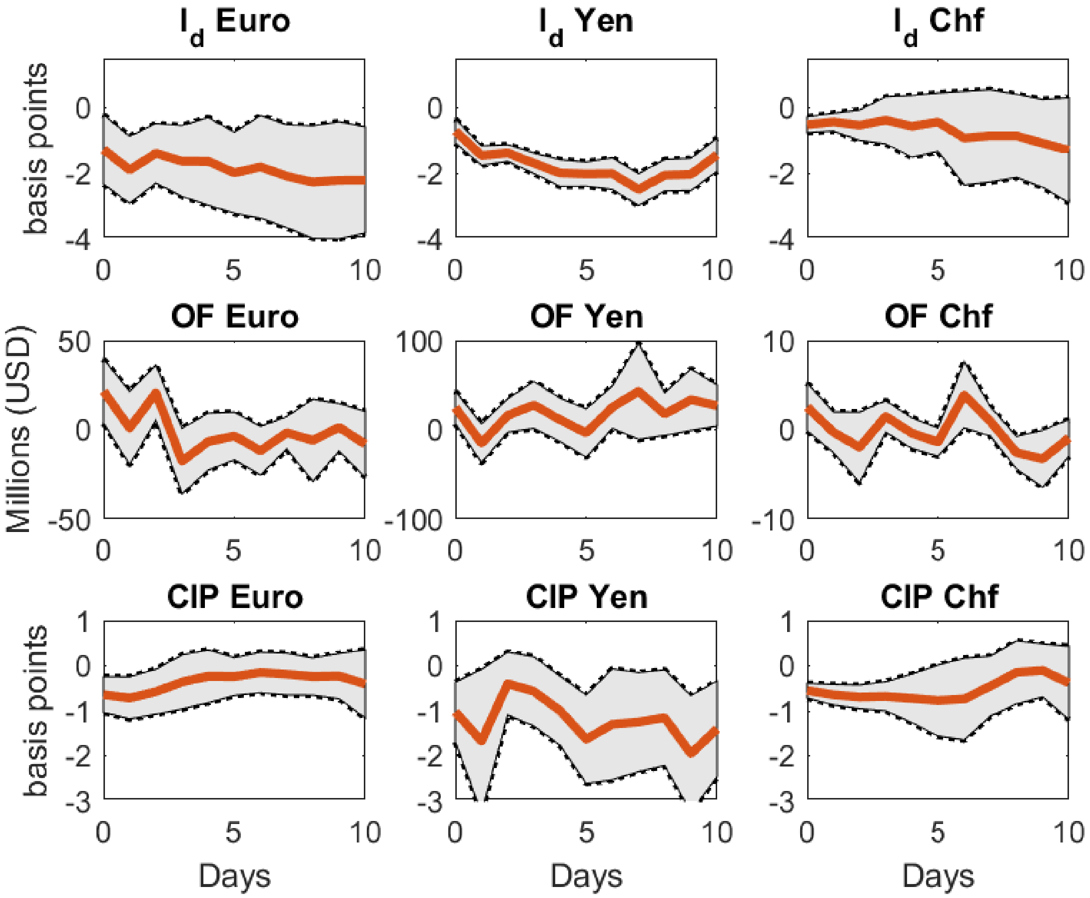
Note: This plot uses Order flow from Reuters D2000-2 platform contains swap maturities <1m, from 2005-present. We implement a +1 count order flow shock for periods pre and post 2008. We use 1 month cross-currency basis as a benchmark maturity corresponding to the order flow measure. Baseline SVAR specification is with 4 lags, with ordering $Y_t = \left[\begin{array}{cc} cip_t & ob_t \end{array}\right]^T$.

Figure 2.7: Response of Euro/$, Yen/$ and Chf/$ Cross-Currency Basis to a $1B USD shock in volume order flow, for tenors 1Y, 2Y, 5Y and 10Y



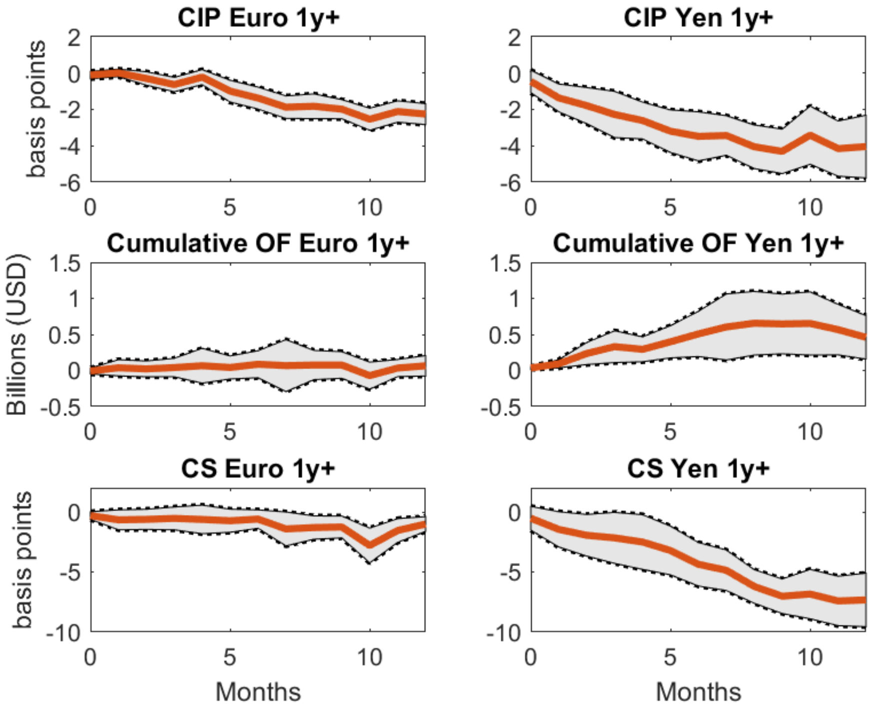
Note: This plot uses Order flow from Bloomberg Swap repository (SDR), which contains transactions in cross-currency swaps for maturities >=3m, from 2013-present. We implement a +1 USD Billion Volume order flow shock for tenors 1Y,2Y,5Y and 10Y, and plots examine response of corresponding cross-currency basis (CIP deviation) deviations at the same maturity. Baseline SVAR specification is with 4 lags, with ordering $Y_t = \left[ \begin{array}{cc} cip_t & ob_t \end{array} \right]^T$.

Figure 2.8: Response of 1y+ cross-currency basis, order imbalances and credit spreads in response to an expansionary monetary announcement



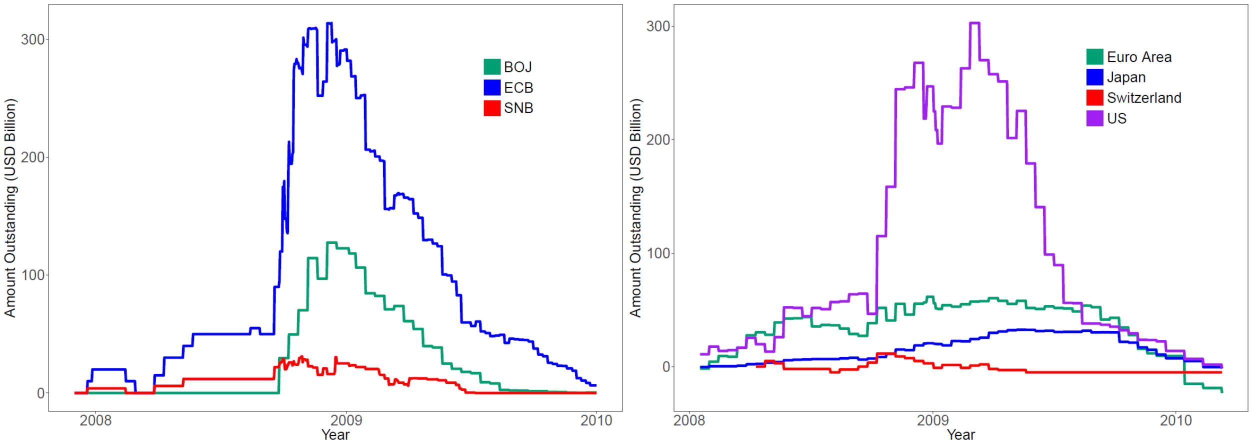
Note: This plot uses Order flow from Bloomberg Swap repository (SDR), which contains transactions in cross-currency swaps for maturities >=3m, from 2013-present. We conduct local projections of 1m cross-currency basis, Order Flow and 5 year credit spreads in response to a -1 basis point shock to the interest rate futures for the 90 day interbank rate.

Figure 2.9: Response of 1y+ cross-currency basis, order imbalances and credit spreads in response to shock to the relative balance sheet size of domestic central bank



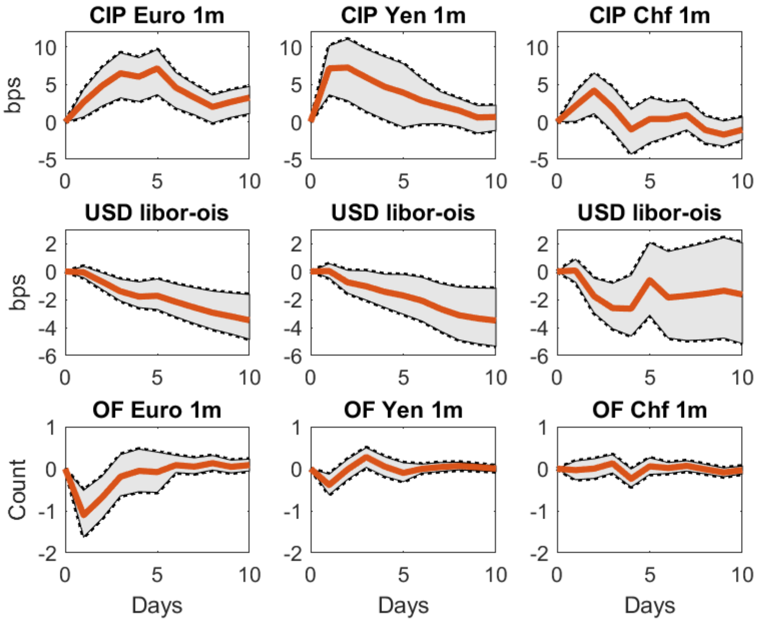
Note: This plot uses Order flow from Bloomberg Swap repository (SDR), which contains transactions in cross-currency swaps for maturities >=3m, from 2013-present. We conduct local projections of 1m cross-currency basis, Order Flow and 5 year credit spreads in response to a 1 per cent positive shock to the domestic central bank balance sheet relative to the US Federal Reserve balance sheet. As our measure of QE shocks is monthly, we take averages of the cross-currency basis, domestic credit spreads at a monthly frequency. For order flow, we construct a measure of cumulative order flow, with the outcome variable $Y_{t+h} - Y_{t-1}$ measuring the cumulative order flow response at horizon h following the expansionary QE shock.

Figure 2.10: Loans outstanding: Swap line allotments (left) and Term Auction Facility allotments (right), to banks in Euro area, Japan and Switzerland



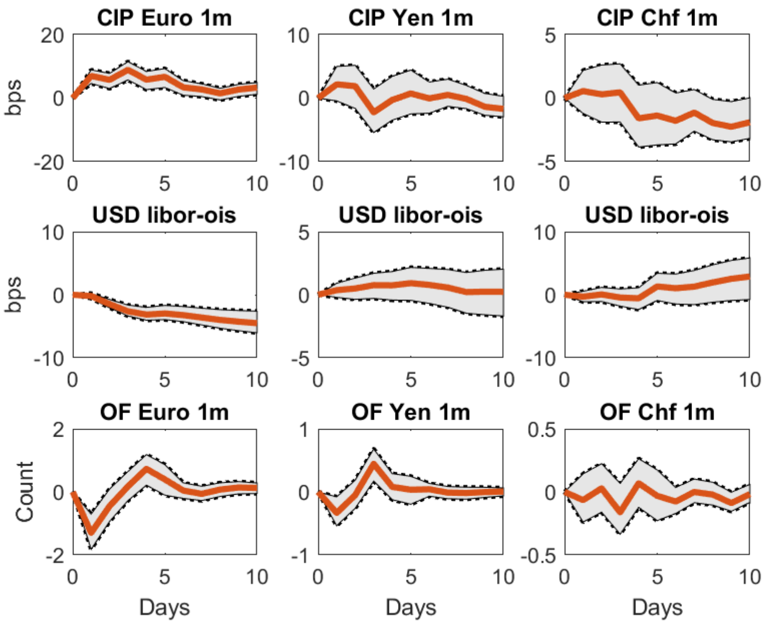
Note: This plots total allotments by the Federal Reserve to central banks (left) via swap line arrangements, and the TAF program to US banks and US subsidiaries of foreign banks (right).

Figure 2.11: CIP, libor-ois and OF Response to $1B Swap line+TAF



Note: This plot uses Order flow from Reuters D2000-2 platform contains swap maturities <1m, and covers the period 2007-2010 when Swap lines were drawn. We implement a $1B USD shock to swap line+TAF allotments, examining the response of 1m cross-currency basis, order flow and USD libor-ois spreads. Baseline SVAR specification is with 4 lags, with ordering $Y_t = \left[\begin{array}{cccc} cip_t & of_t & libor - ois_t & L_t \end{array}\right]^T$.

Figure 2.12: CIP, USD libor-ois and OF Response to $1B Swap line



Note: This plot uses Order flow from Reuters D2000-2 platform contains swap maturities <1m, and covers the period 2007-2010 when Swap lines were drawn. We implement a $1B USD shock to swap line allotments, where for each pair we only consider allotments to that counterparty central bank. For example, the euro/$ pair only considers allotments to the ECB. We examine the response of 1m cross-currency basis, order flow and USD libor-ois spreads. Baseline SVAR specification is with 4 lags, with ordering $Y_t = \begin{bmatrix} cip_t & of_t & libor - ois_t & L_t \end{bmatrix}^T$.

# Tables

Table 2.1: Underlying interest rate futures to measure monetary shocks

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

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

Table 2.2: Descriptive statistics, monetary shocks

| | Mean | SD | p-5 | p-25 | p-50 | p-75 | p-95 | Obs | Contract Period |
|---|---|---|---|---|---|---|---|---|---|
| $MP1_{US}$ | -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 2.3: Summary Statistics count Order Flow.

| | Full Sample | | | | Post 2014 | | | |
|---|---|---|---|---|---|---|---|---|
| | mean | sd | min | max | mean | sd | min | max |
| Euro/$ | 0.00 | 4.54 | -29 | 30 | 0.1 | 2.88 | -12 | 13 |
| Yen/$ | -0.09 | 2.29 | -10 | 10 | 0.12 | 2.01 | -9 | 8 |
| Chf/$ | 0.27 | 1.96 | -10 | 8 | 0.48 | 1.69 | -10 | 8 |

Note: This measure of order flow is based on trades in foreign exchange swaps of maturities 1 week-3 weeks using trades in Thomson Reuters D2000-2 Platform. Data begins in 2005, and buyer and seller initiated trades were constructed by matching trades to bid-ask transaction prices.

Table 2.4: Trade counts and % buyer initiated for Cross-Currency Swaps,

| | 1Y | | | 2Y | | | 5Y | | | 10Y | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pair | N | $N_m$ | %BI | N | $N_m$ | %BI | N | $N_m$ | %BI | N | $N_m$ | %BI |
| Chf/$ | 264 | 256 | 63% | 269 | 246 | 54% | 338 | 310 | 47% | 260 | 238 | 48% |
| Euro/$ | 2187 | 1932 | 64% | 2828 | 2310 | 47% | 3352 | 2623 | 45% | 3480 | 2761 | 48% |
| Yen/$ | 4429 | 3734 | 61% | 4423 | 3532 | 53% | 2815 | 2310 | 48% | 2179 | 1777 | 47% |

Note: using Lee-Ready algorithm for matching. Trade count (N) is total number of trades recorded for each currency pair and tenor from beginning of sample in 2013. $N_m$ is the number of trades matched using Lee-Ready algorithm. %BI is the per cent of matched trades that are buyer initiated.

Table 2.5: Summary Statistics of daily Count and Volume Order Flow, using SDR data on cross-currency swaps for tenors 1Y, 2Y, 5Y and 10Y

1 Year

| | Count | | | | Volume (Billions USD) | | | |
|---|---|---|---|---|---|---|---|---|
| Pair | mean | sd | min | max | mean | sd | min | max |
| Chf/$ | 0.34 | 1.51 | -3 | 6 | 0.05 | 0.22 | -0.46 | 0.69 |
| Euro/$ | 0.67 | 2.21 | -7 | 9 | 0.15 | 0.61 | -2.85 | 2.17 |
| Yen/$ | 0.77 | 2.74 | -10 | 17 | 0.16 | 0.61 | -2.02 | 4.33 |

2 Year

| | Count | | | | Volume (Billions USD) | | | |
|---|---|---|---|---|---|---|---|---|
| Pair | mean | sd | min | max | mean | sd | min | max |
| Chf/$ | 0.12 | 1.43 | -4 | 4 | 0.02 | 0.16 | -0.36 | 0.51 |
| Euro/$ | -0.17 | 2.11 | -15 | 7 | -0.01 | 0.38 | -2.08 | 1.48 |
| Yen/$ | 0.17 | 2.51 | -16 | 12 | 0.04 | 0.33 | -1.18 | 2.02 |

5 Year

| | Count | | | | Volume (Billions USD) | | | |
|---|---|---|---|---|---|---|---|---|
| Pair | mean | sd | min | max | mean | sd | min | max |
| Chf/$ | -0.09 | 1.52 | -3 | 5 | 0.00 | 0.10 | -0.25 | 0.25 |
| Euro/$ | -0.25 | 2.07 | -12 | 8 | 0.03 | 0.23 | -1.39 | 0.98 |
| Yen/$ | -0.13 | 2.05 | -14 | 9 | 0.00 | 0.16 | -0.70 | 0.98 |

10 Year

| | Count | | | | Volume (Billions USD) | | | |
|---|---|---|---|---|---|---|---|---|
| Pair | mean | sd | min | max | mean | sd | min | max |
| Chf/$ | -0.08 | 1.34 | -5 | 3 | 0.00 | 0.06 | -0.34 | 0.11 |
| Euro/$ | -0.12 | 2.13 | -8 | 17 | 0.00 | 0.15 | -0.63 | 1.52 |
| Yen/$ | -0.13 | 1.96 | -11 | 17 | 0.01 | 0.07 | -0.41 | 0.41 |

Table 2.6: Interest Rate Futures

| Country | Underlying policy rate | Monetary shock | $\delta^-$ | $\delta^+$ |
|---|---|---|---|---|
| EU | EUREX 3-Month Euribor | $MP_{EU,t} = \Delta f_{EU,t}$ | 15 | 105 |
| JPY | TFX (TIFFE) 3-Month Euroyen Tibor | $MP_{JPY,t} = \Delta f_{JPY,t}$ | 15 | 45 |
| SWZ | LIFFE 3-Month Euroswiss Franc | $MP_{SWZ,t} = \Delta f_{SWZ,t}$ | 15 | 45 |

Table 2.7: Summary Statistics for MP shocks, Post 2008

| | Mean | SD | p-5 | p-25 | p-50 | p-75 | p-95 | Obs | Contract Period |
|---|---|---|---|---|---|---|---|---|---|
| $\mathrm{MP}_{\mathrm{EU}}$ | 0.1 | 4.20 | -6.00 | -1.50 | 0.000 | 2.00 | 6.80 | 240 | 01/99 - 09/16 |
| $\mathrm{MP}_{\mathrm{JPY}}$ | 0.000 | 1.00 | -5.50 | -3.50 | 0.000 | 2.50 | 3.00 | 287 | 01/98 - 12/16 |
| $\mathrm{MP}_{\mathrm{SWZ}}$ | -2.90 | 10.1 | -18.0 | -6.00 | 0.00 | 1.00 | 8.00 | 90 | 02/91 - 09/16 |

All values in basis points

Table 2.8: CIP and Order Flow, response of 1 month Deviations to quarter-ends

| | (1)<br>CIP | (2)<br>CIP | (3)<br>OF | (4)<br>OF |
|---|---|---|---|---|
| post2008 | 23.98*** | 12.12*** | -0.189* | 0.0145 |
| | (1.391) | (2.607) | (0.112) | (0.161) |
| post2015 | 9.861* | 23.88** | 0.221*** | -0.218 |
| | (5.445) | (9.827) | (0.0629) | (0.377) |
| Qend×$Post2008$ | 8.903*** | 9.549*** | 0.192*** | 0.167*** |
| | (1.608) | (1.346) | (0.0711) | (0.0555) |
| Qend×$Post2015$ | 18.13** | 17.40** | 0.127 | 0.156 |
| | (7.474) | (8.048) | (0.135) | (0.159) |
| Observations | 6,263 | 6,155 | 6,263 | 6,155 |
| Number of pair_tenor | 3 | 3 | 3 | 3 |
| Pair FE | Yes | Yes | Yes | Yes |
| Controls | No | Yes | No | Yes |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note:This table examines the effect of quarter-ends on 1M CIP deviations and Order Flow. Specification is

$$Y_{1m,t} = \alpha + \gamma_1 Post2008_t + \gamma_2 Post2015_t + \theta_1 \left[Qend \times Post2008\right]_t + \theta_2 \left[Qend \times Post2015\right]_t + X_t + u_t$$

Table 2.9: CIP and Order Flow, response of 1 month Deviations to quarter-ends, relative to control group of maturities >=1y

|  | (1)<br>CIP | (2)<br>CIP | (3)<br>OF | (4)<br>OF |
|---|---|---|---|---|
| post2008 | 32.10*** | 34.86*** | -0.144*** | -0.146*** |
|  | (11.95) | (12.95) | (0.0260) | (0.0151) |
| post2015 | 20.64*** | 18.68*** | 0.00125 | -0.105** |
|  | (2.107) | (3.640) | (0.0156) | (0.0442) |
| Qend $\times Post2008$ | 0.885*** | 0.582*** | 0.00986 | 0.00773 |
|  | (0.165) | (0.174) | (0.0291) | (0.0519) |
| Qend $\times Post2015$ | 0.187 | 0.708*** | -0.0261 | -0.00150 |
|  | (0.230) | (0.254) | (0.0540) | (0.0405) |
| Qend$\times Post2008 \times \mathbb{1}[1m]$ | 8.019*** | 9.239*** | 0.183** | 0.172* |
|  | (1.690) | (1.426) | (0.0864) | (0.101) |
| Qend$\times Post2015 \times \mathbb{1}[1m]$ | 17.94** | 16.61** | 0.152 | 0.156 |
|  | (7.692) | (7.787) | (0.115) | (0.139) |
| Observations | 44,230 | 28,471 | 44,230 | 28,471 |
| Number of pair_tenor | 24 | 24 | 24 | 24 |
| Pair FE | Yes | Yes | Yes | Yes |
| Controls | No | Yes | No | Yes |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note:This table examines the effect of quarter-ends on 1M CIP deviations and Order Flow, relative to a control set of longer maturities (1Y+). Specification is

$$\begin{aligned} Y_{it} = \alpha_i + \gamma_1 Post2008_t + \gamma_2 Post2015_t + \theta_1 \left[Qend \times Post2008\right]_t + \theta_2 \left[Qend \times Post2015\right]_t + \\ + \delta_1 \left[Qend \times Post2008 \times \mathbb{1}[1m]\right]_{it} + \delta_2 \left[Qend \times Post2015 \times \mathbb{1}[1m]\right]_{it} + X_t + u_{it} \end{aligned}$$

# Appendices

## A: Definitions

### Covered Interest Rate Parity

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 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 we refer to as the synthetic dollar borrowing cost, is then equal to $\frac{F}{S}(1+r_d^f)$. We then define the cross-currency basis as the difference between the direct and synthetic dollar borrowing cost.

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

To compute deviations, we use Bloomberg spot and forward swap points, and most currency pairs are expressed with the US dollar as a base currency, with the exception of some commonwealth countries (Australia, Canada, UK) in which the US dollar is a quoting currency[15]. Swap points, also referred to as pips, are used to get the forward exchange rate, $F = S + \frac{sp}{10^4}$. In our calculations, we use a tenor of 1 month for interest rates overnight index swap (OIS) and libor. When the US dollar is expressed as a quoting currency[16], the CIP deviation we calculate is expressed as the difference between the local dollar borrowing rate less the synthetic dollar borrowing rate, where $i_q$ is the US interest rate, $i_b$ is the base interest rate (domestic currency), $S_a$ is the spot rate at ask and $F_b$ is the bid forward rate. A negative $\Delta$ indicates that synthetic dollar borrowing costs exceed local borrowing costs, and this is indeed the case for the euro/\$, yen/\$ and chf/\$ pairs when using both ois rates and libor rates at lower maturities.

$$\Delta = 1 + i_q \frac{tenor}{360} - \frac{F_b}{S_a}(1 + i_b \frac{tenor}{360}) \tag{2.5.2}$$

### Foreign exchange swaps

There are two types of foreign exchange swaps (Figure 2.13). Foreign exchange swaps involve principals being exchanged at a current spot rate, and re-exchanged at an agreed upon forward rate at maturity. These are typically used at shorter maturities. Cross-currency swaps are used at longer maturities (> 3 months) is a combination of a spot, interest rate swap and a forward.

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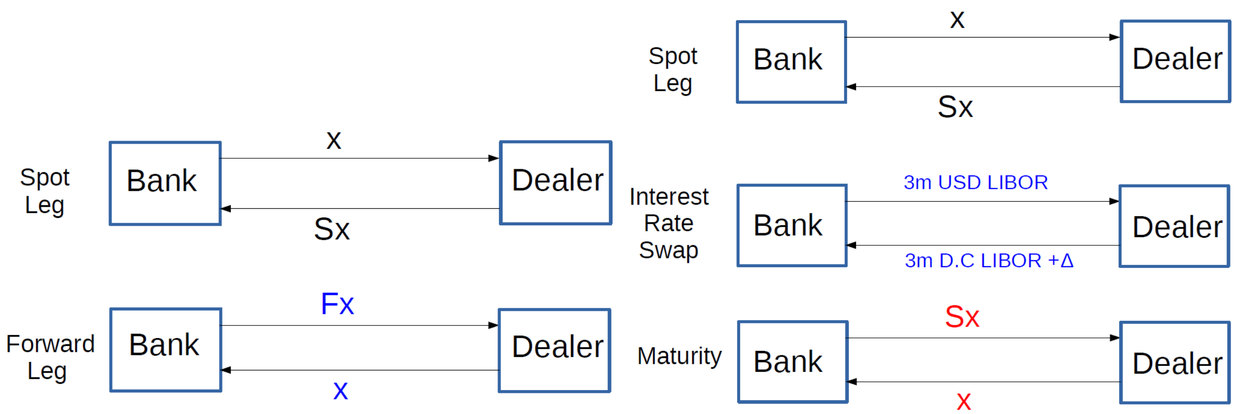
[15] An exchange rate quote of \$1.20 per Euro has Euro as the base currency, and the US dollar as the quoting currency, i.e. the currency in which all quotes are expressed. Alternatively, an exchange rate of 150 Yen/\$ has the US dollar as a base currency.

[16] 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.

$$\Delta = 1 + i_b \frac{tenor}{360} - \frac{S_b}{F_a}(1 + i_q \frac{tenor}{360}) \tag{2.5.1}$$

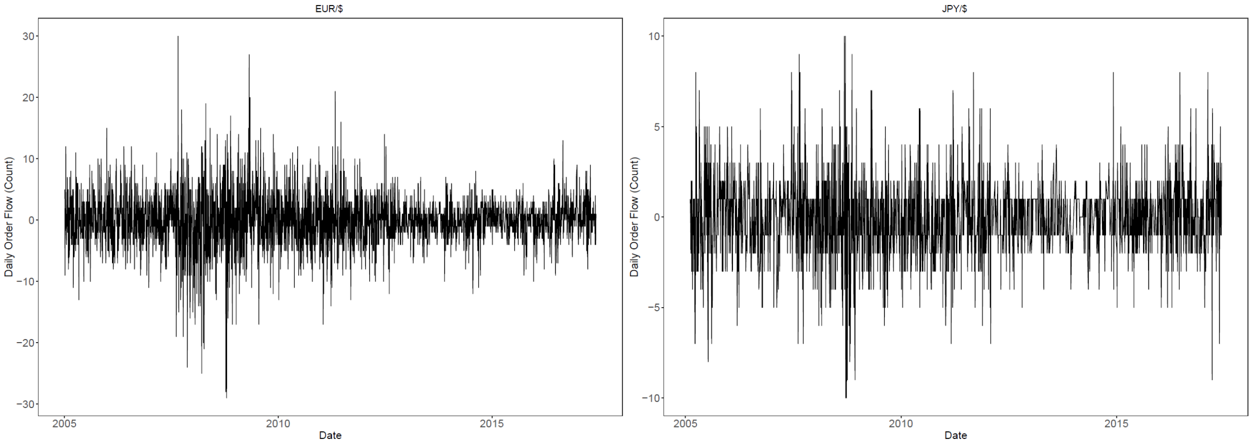
Figure 2.13: Foreign exchange swap (left) and Cross-Currency Basis Swap (right)



Note: Forex swap is typically for maturities at less than 3m. In the example, at the spot leg, Euros and Dollars are swapped at the prevailing spot rate. At maturity, the principals are re-exchanged at the forward rate. The Cross-Currency Swap is typically for maturities >3m. In the spot leg, Euros and dollars are exchanged at spot. Interest repayments on the swap are exchanged at 3 month intervals until maturity, with the European bank paying 3m USD libor, and the US bank paying 3m Euribor + Delta, which is the price of the cross-currency swap. Upon maturity the principals are re-exchanged

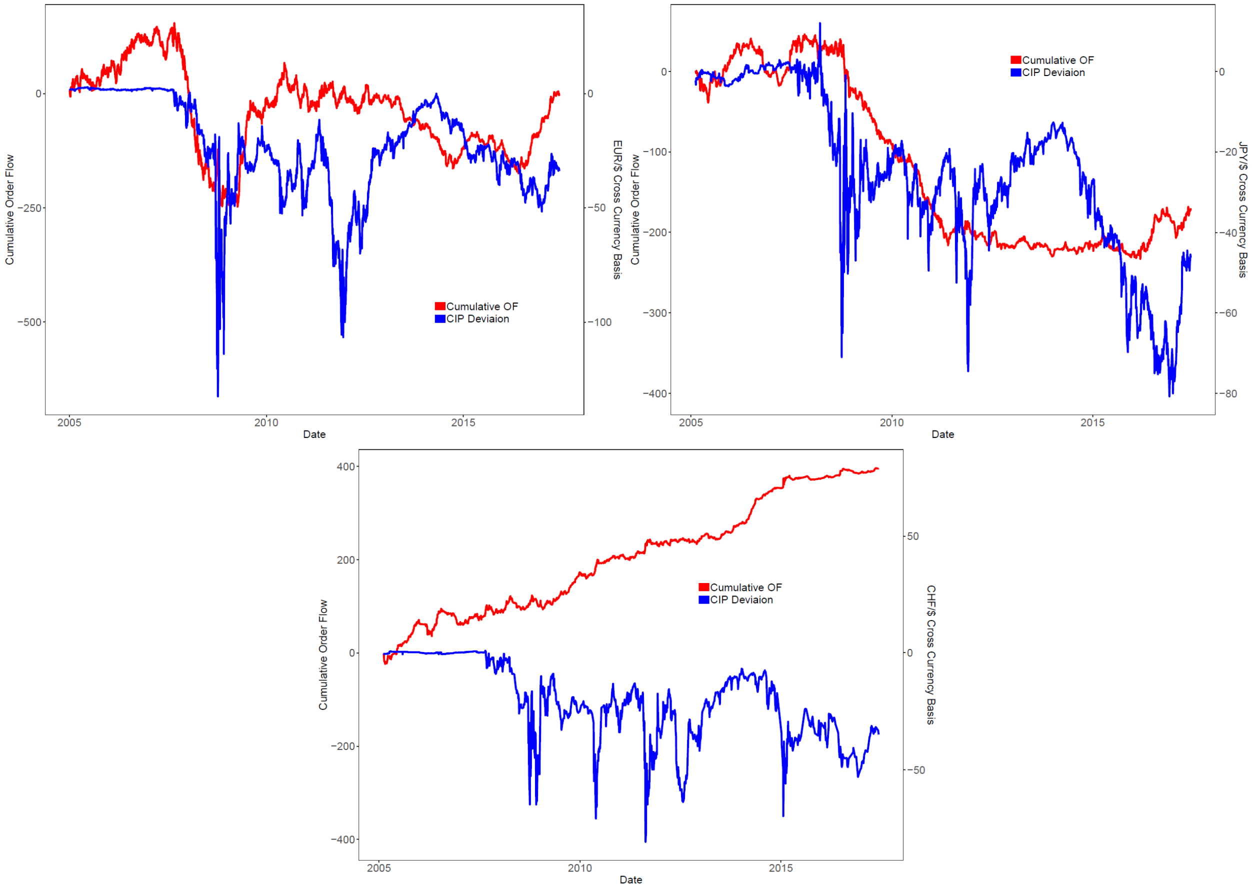
## A: Order Flow data

Figure 2.14: Daily Order Flow 1M count measure- euro/\$, chf/\$ and yen/\$



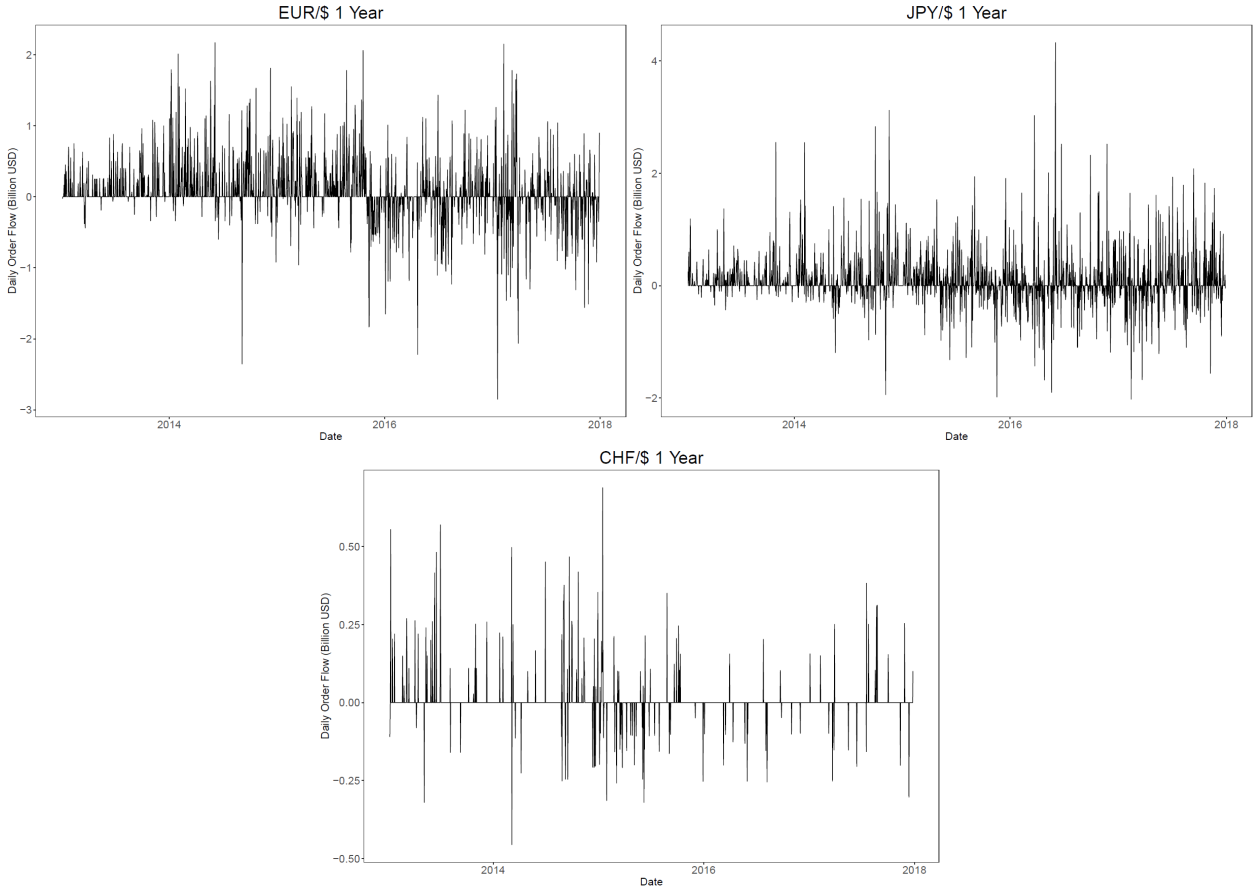
Note: Daily count order flow for euro/\$, yen/\$ and chf/\$ pairs using the TR D2000-2, for forex swap maturities at 1,2 and 3 weeks (<1 month). Count order flow is given as the net of buyer initiated transactions, where buyer initiated transactions are signed +1 and seller initiated transactions are signed -1. $OF_t^{count} = \sum_{k=t_0}^{k=t} \mathbb{1}[T_k = B] - \mathbb{1}[T_k = S]$

Figure 2.15: Cumulative Order Flow and cross-currency basis: 1M euro/$, chf/$ and yen/$



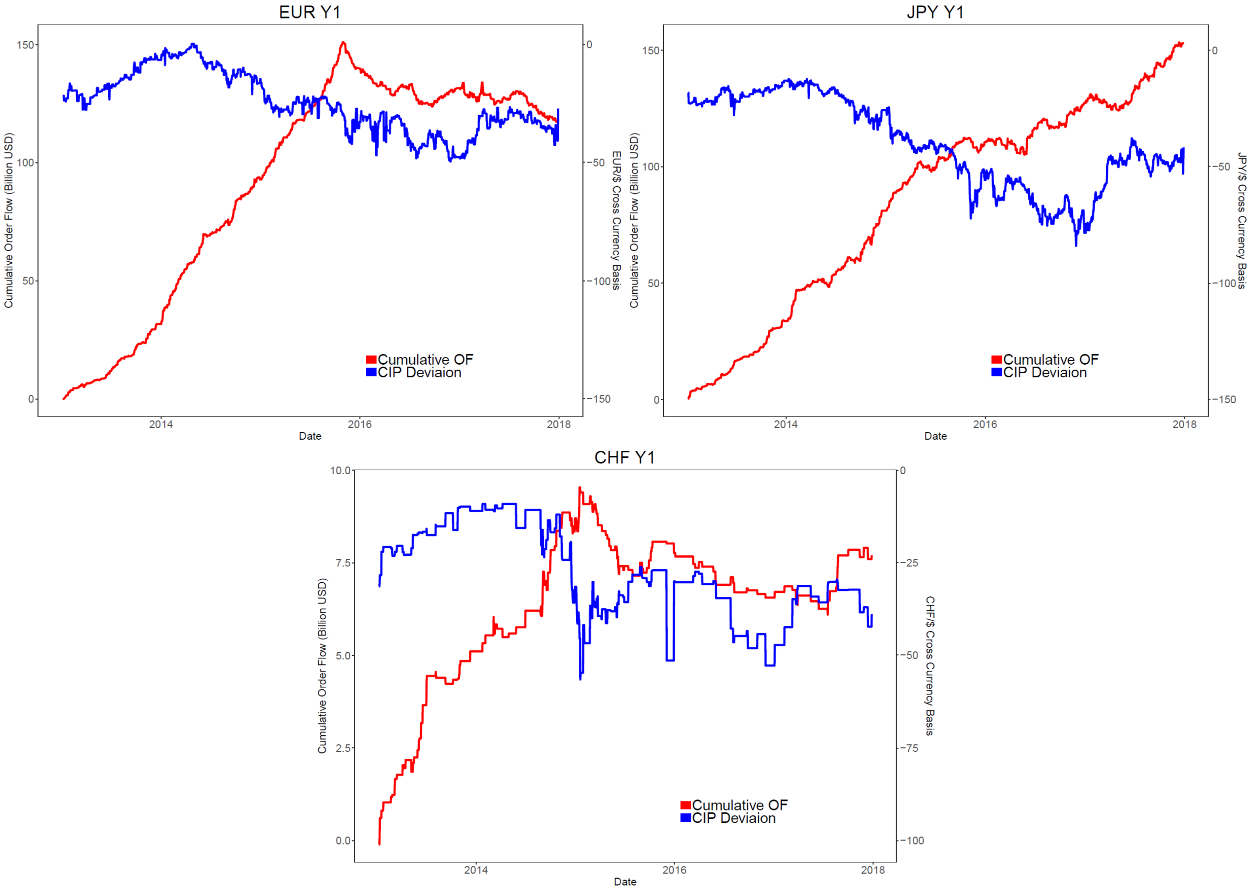
Note: Left axis, cumulative order flow for 1 month euro/$ and yen/$ pairs. Right axis, 1 month CIP deviations

Figure 2.16: Daily Order Flow 1Y Volume measure- euro/\$, chf/\$ and yen/\$



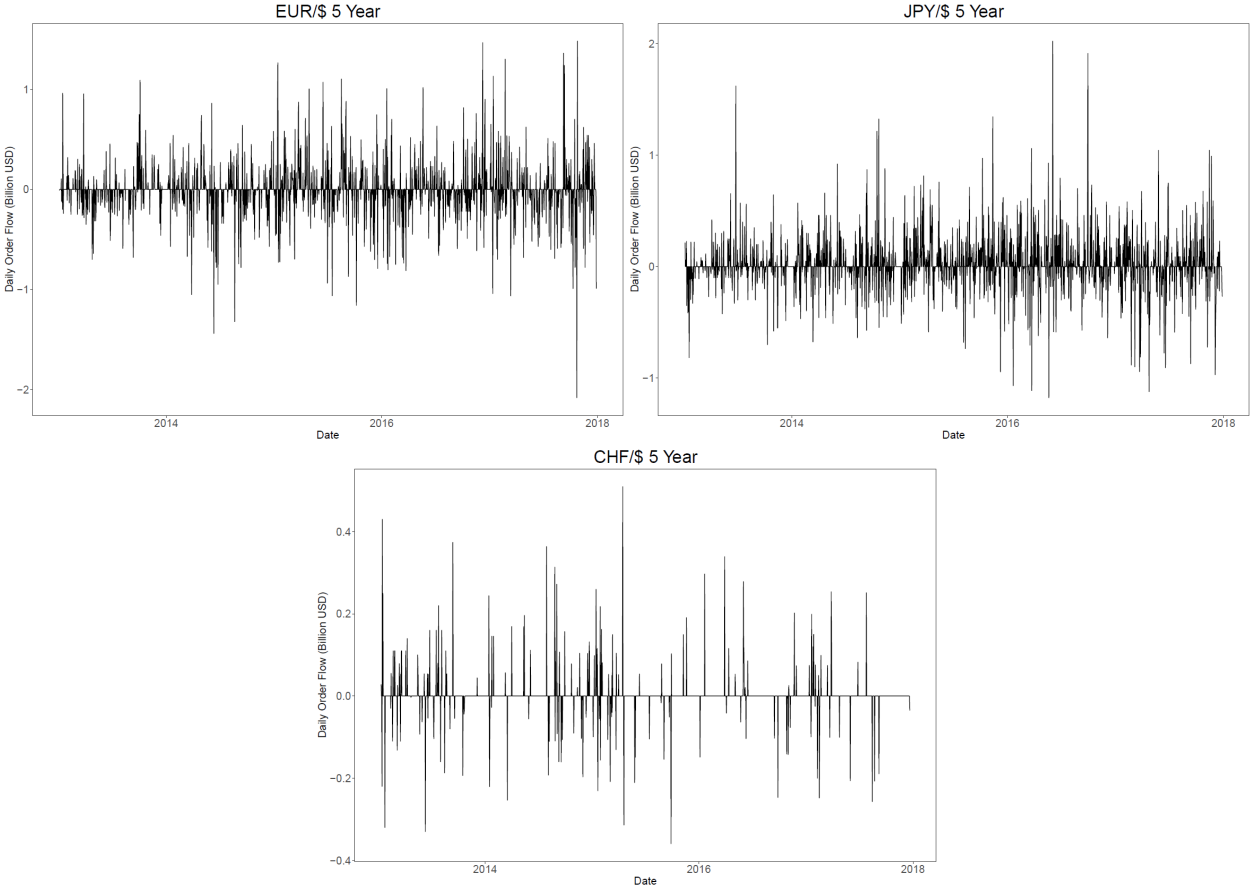
Note: Daily count order flow for euro/\$, yen/\$ and chf/\$ pairs using Bloomberg SDR, for forex swap maturity of 1 year. Volume order flow is given as the net of buyer initiated transactions, where buyer initiated transactions are signed +1 and seller initiated transactions are signed -1, and $V_{T_k}$ is the volume of transactions. $OF_t^{count} = \sum_{k=t_0}^{k=t} V_{T_k} \times (\mathbb{1}[T_k = B] - \mathbb{1}[T_k = S])$

Figure 2.17: Cumulative Order Flow and 1 year cross-currency basis: Euro/\$, Chf/\$ and Yen/\$



Note: Left axis, cumulative order flow for euro/\$ yen/\$ and chf/\$ pairs for cross-currency swaps at 1 year maturity. Right axis, 1 year cross-currency basis

Figure 2.18: Daily Order Flow 5Y Volume measure- euro/\$, chf/\$ and yen/\$

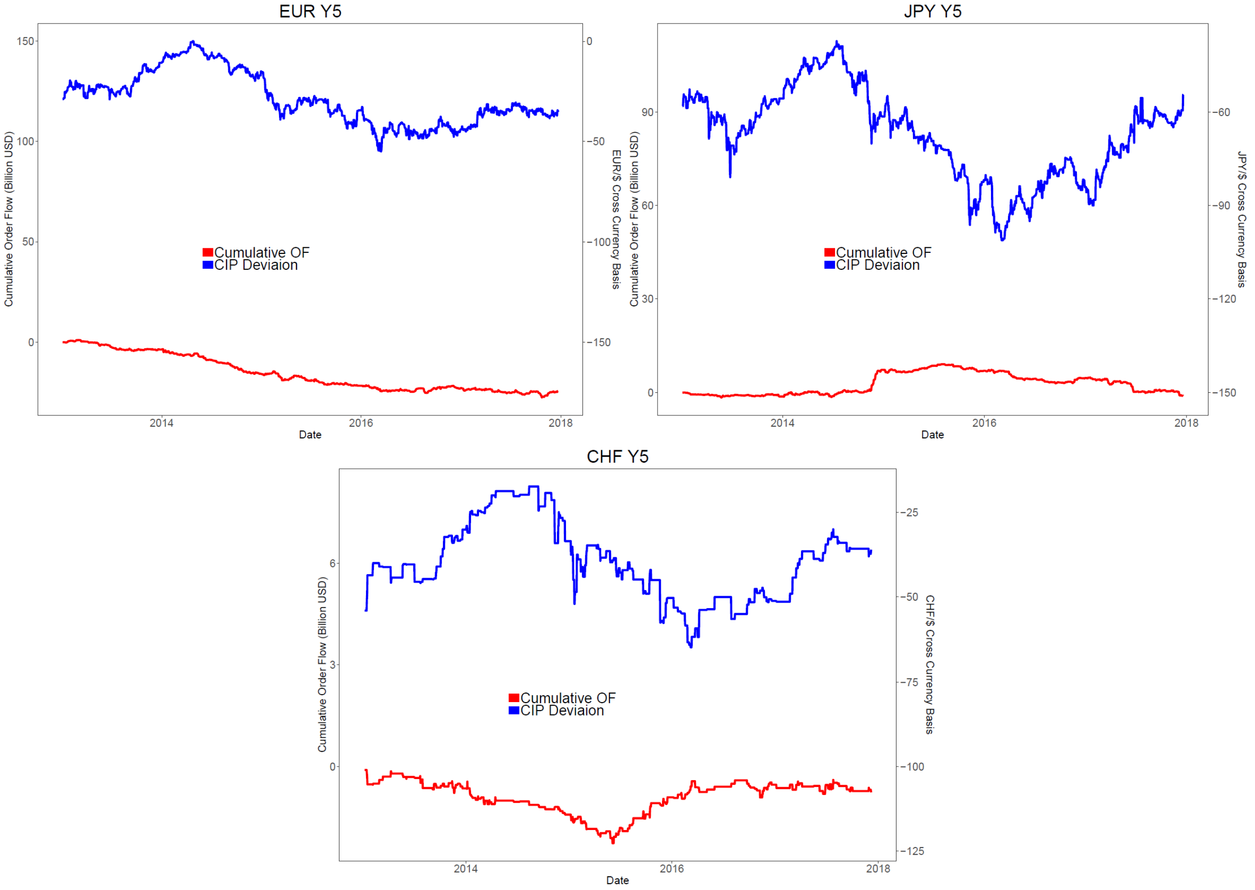

EUR/\$ 5 Year

JPY/\$ 5 Year

CHF/\$ 5 Year

Note: Daily count order flow for euro/\$, yen/\$ and chf/\$ pairs using Bloomberg SDR, for forex swap maturity of 5 years. Volume order flow is given as the net of buyer initiated transactions, where buyer initiated transactions are signed +1 and seller initiated transactions are signed -1, and $V_{T_k}$ is the volume of transactions. $OF_t^{count} = \sum_{k=t_0}^{k=t} V_{T_k} \times (\mathbb{1}[T_k = B] - \mathbb{1}[T_k = S])$

Figure 2.19: Cumulative Order Flow and 1 year cross-currency basis: Euro/$, Chf/$ and Yen/$

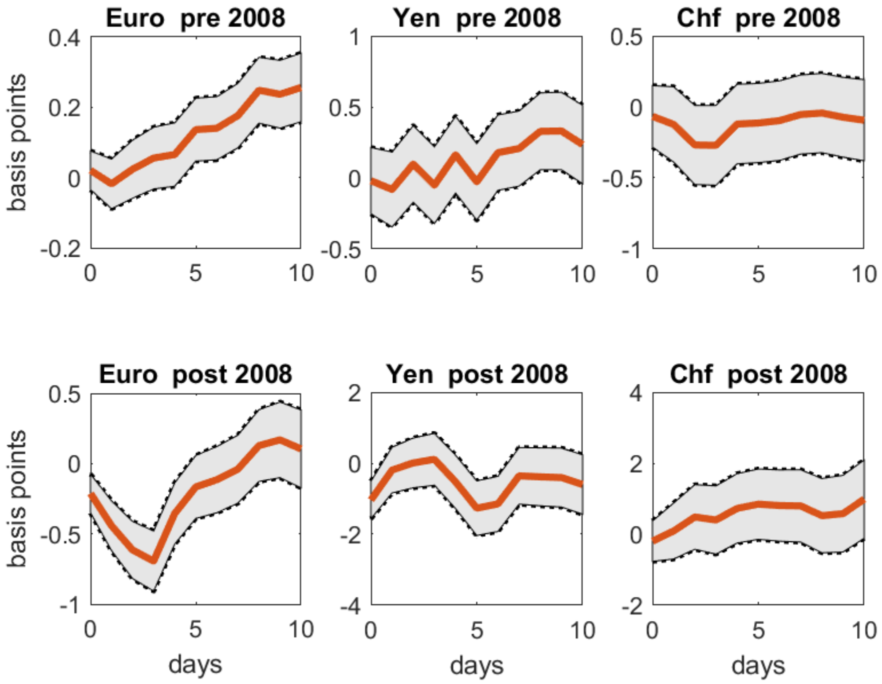


Note: Left axis, cumulative order flow for euro/$ yen/$ and chf/$ pairs for cross-currency swaps at 5 year maturity. Right axis, 5 year cross-currency basis

## B: Unconditional Shock to Order Flow: Local Projections

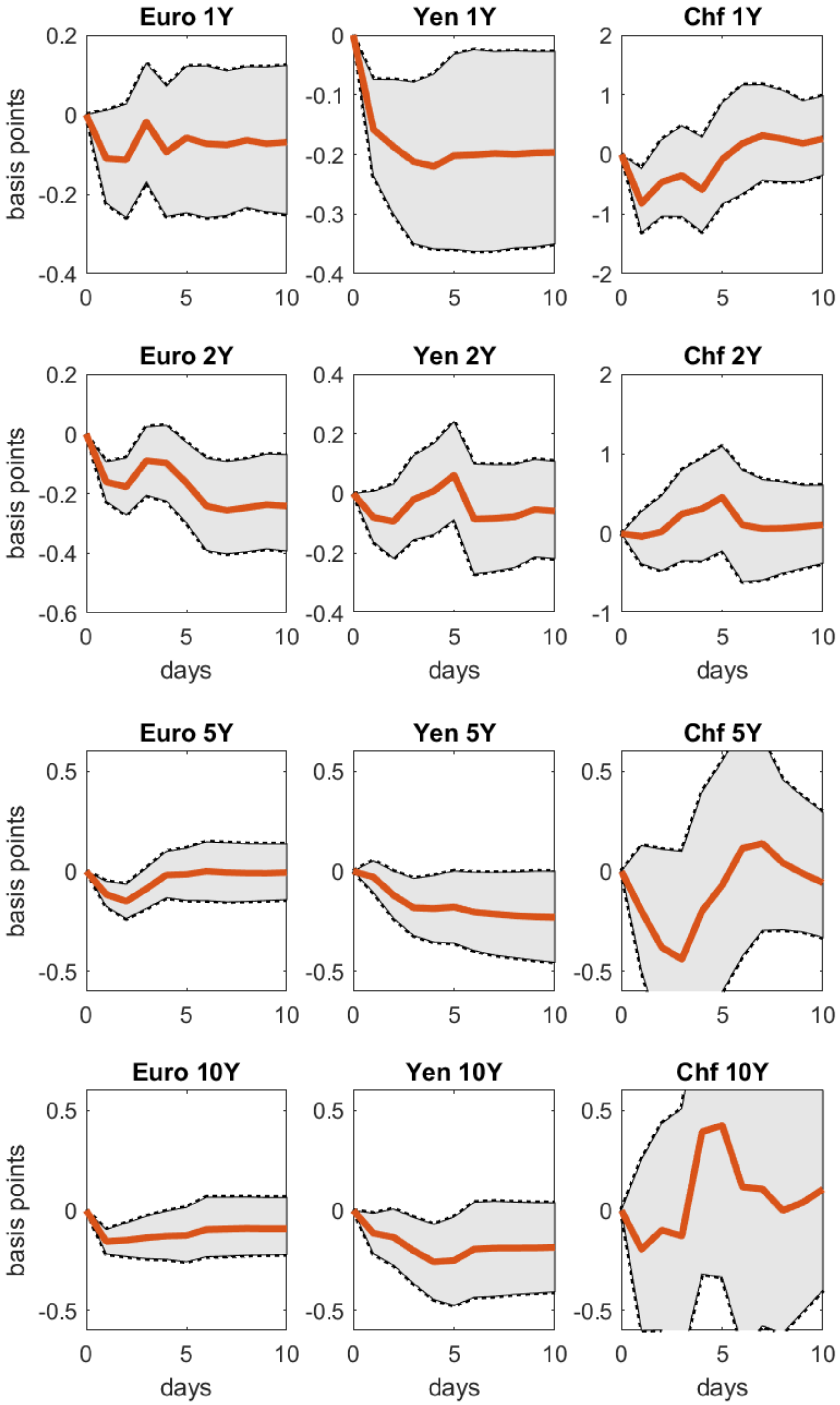
Jorda Projections is an alternative method to a structural VAR, and we project CIP deviations at different horizons on a series of lagged order flow and CIP to obtain an estimate of $\{\beta_0, \beta_1, \beta_2, ...\beta_h\}$, which are the marginal effects of order flow on CIP deviations at periods 1,2,3,...h ahead. We use $L = 6$ and daily CIP deviations and order flow in the following regressions.

$$Y_{t+h} = \alpha_0 + \beta_h OF_t + \sum_{l=1}^{L} \delta_l OF_{t-l} + \sum_{l=1}^{L} \gamma_l Y_{t-l} + \epsilon_t, \ \ h = 0, 1, 2, ....9$$



Note: This plot uses Order flow from Reuters D2000-2 platform contains swap maturities <1m, from 2005-present. We implement a +1 count order flow shock for periods pre and post 2008. We use 1 month CIP deviations as a benchmark maturity corresponding to the order flow measure.

Figure 2.20: Response of Euro/\$, Yen/\$ and Chf/\$ Cross-Currency Basis to a \$1B USD shock in volume order flow, for tenors 1Y, 2Y, 5Y and 10Y



Note: This plot uses Order flow from Bloomberg SDR which contain maturities 1 year, 2 year, 5 year and 10 year, from 2013-present. We implement a +1B shock to volume order flow, and use the corresponding maturity of CIP deviations.

# Chapter 3

# International Monetary Policy Spillovers: A High-Frequency Approach

## 3.1 Introduction

The subject of international monetary spillovers is at the core of recent policy discussions in both international macroeconomics and finance. A recent literature suggests monetary policy by the U.S. Federal Reserve is a fundamental driver of global asset prices, bank leverage, and the availability of credit (Rey et al., 2013; Miranda-Agrippino and Rey, 2015). This view has generated a debate on the nature of monetary policy's real spillovers, and whether a surprise monetary announcement made by the Federal Reserve propagates to both small and open economies, as well as to foreign emerging markets. For instance, the 2013 "Taper Tantrum" in which Ben Bernanke, then Federal Reserve Chairman, announced a tapering of central bank asset purchases, led to both a decline in equities and a rise in bond yields in emerging markets. This had ensuing, contractionary real effects on emerging markets.

This chapter attempts to identify both financial and real spillovers of monetary policy with use of high-frequency identification of monetary announcements from major central banks. Our approach uses changes in interest rate futures around scheduled monetary announcements as a measure of the *unanticipated* component of monetary policy. While high-frequency shocks have been used to identify asset price effects, they have low statistical power when used to identify their effects on a low-frequency variable, such as real gross domestic product (GDP). Identification is additionally difficult, considering a host of non-monetary factors affect real GDP in real-time. Most relevant critiques focus on whether monetary surprises at a high-frequency are useful in explaining low-frequency variables.

As a solution to the frequency mismatch between exogenous monetary surprises and real GDP, we make use of economic tracking portfolios (ETPs) recently implemented in Lamont (2001), Vassalou (2003), and Hébert and Schreger (2016). This method allows us to replicate real GDP growth with a set of base assets, including a country's equity, treasury and corporate bond indices, as well as relevant bilateral exchange rates. This portfolio of base asset returns has high explanatory power for real GDP growth, therefore replicating real GDP growth at a quarterly frequency. We use this portfolio of base assets to construct a high-frequency analogue of real GDP growth by utilizing information on base asset returns around monetary announcements. Taking the estimated, unconditional loadings of the tracking portfolio's base assets at a quarterly frequency, we construct a counterfactual change in real GDP growth around monetary announcements. We call this real GDP-tracking news.

Our constructed measure enables us to trace out the impact of monetary surprises on real GDP growth. Adjusting the replicating portfolio's horizon enables us to trace out and quantify the effects of monetary policy on real GDP-tracking news at different points in time. This provides an alternative to conventional impulse response functions when analyzing the long-run dynamics of a monetary shock on real GDP growth. Our assumed direction of causation rests on an exogenous monetary surprise affecting real GDP *through* movements in the set of base asset returns.

Primarily, our approach measures the effect of a monetary surprise by the U.S. Federal Reserve, as well as by the Reserve Bank of Australia and the Bank of Canada. To construct monetary surprises, we use changes in interest rate futures on the underlying central bank rate around scheduled monetary announcements to measure monetary news. The identifying assumption rests on changes in the futures rate responding, solely, to monetary news following announcements.

In addition to using interest rate futures on the underlying central bank rate, we exploit changes in treasury yields as an indicator of monetary policy's long-term stance. Longer-term measures are relevant in the present context, given that short-term futures have exhibited little change in countries affected by the zero lower bound (ZLB) in nominal interest rates. Measures of unconventional monetary policy implemented by the Federal Reserve, such as quantitative easing (QE), involved significant asset purchases of Treasury bonds which compressed long-term yields.[1] Therefore, following the methodology in Gurkaynak et al. (2004), we decompose monetary surprises into three components: *timing*, *level*, and *slope* components.

*Timing* and *level* components measure the short-term stance of monetary policy. *Timing* is a transitory surprise that leaves expected interest rates after the next FOMC announcement unchanged. The *level* component measures the change in interest rates typically at a three month horizon, and measures a parallel shift of interest rate expectations. The *slope* component is the residual change in long-term yields that is unexplained by the *timing* and *level* components. This component captures revisions to the expected pace of interest rate changes and the effects of unconventional monetary policy on the yield curve.

Equipped with this framework, we find changes in long-term interest rates, as measured by the*slope* component, lead to a contraction in real GDP-tracking news for Australia, Canada, and the United States. This holds for ETPs measured at various horizons, ranging from

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[1] Another example is the Federal Reserve's 2011 "Operation Twist" policy, which involved buying and selling government bonds in an effort to provide monetary easing for the U.S. economy. This policy was characterized by $400 billion (USD) purchases in bonds with maturities of 6 to 30 years, and sells in bonds with maturities less than 3 years. The policy's goal was targeting the long end of the yield curve, by compressing the difference between short- and long-term yields.

1 to 12 quarters. This result is consistent with empirical work finding a decline in real GDP over the long-run, following a contractionary monetary announcement (Romer and Romer, 1989, 2004; Gertler and Karadi, 2015). Interestingly, our results are mostly driven by the *slope* component. This is intuitive, considering changes in longer-term yields are crucial determinants of the long-run, causal impact of monetary policy. For example, when an economy enters a recession, long-term yields fall as central banks pursue expansionary policies to bolster the economy out of said recession. In contrast, tightening of monetary policy in a boom period, due to concerns of high inflation, lead to higher long-term yields, which dampen a heating economy.

Our second key finding focuses on the effect of U.S. monetary policy on periphery countries, such as Australia and Canada.[2] Traditional models predict the effects of a U.S. monetary contraction lead to an exchange rate depreciation in a small, open economy with an expansion in net exports via expenditure switching effects. However, a recent literature on financial spillovers suggests a U.S. monetary contraction leads to a decline in global banking credit.[3] Our approach documents how a contractionary monetary surprise by the Federal Reserve leads to negative Australian real GDP-tracking news at most horizons. We find mixed results for Canada's real GDP-tracking news across different horizons.

While we offer a methodological contribution to identifying the causal effects of monetary policy, there are two major econometric concerns. First, we require the ETP to have sufficient explanatory power in replicating real GDP growth. To demonstrate the robustness of our replicating portfolio approach, we find the adjusted $R^2$ of our ETPs capture a significant fraction of the unconditional variation in real GDP growth. Furthermore, out-of-sampling fit tests indicate our replicating portfolios consistently outperforms a random walk at all horizons.

Second, the key econometric assumption made in our analysis is that the unconditional loadings of base assets in the ETPs are the same as the loadings conditional on a monetary shock. This assumption may be unrealistic if, for example, the base asset weights are of a different sign when the economy is hit by a series of non-monetary shocks, such as oil supply or technology shocks. Nonetheless, we take a crucial step toward providing both a new and refined method for identifying the international dimensions of the monetary transmission mechanism.

## 3.2 Related Literature

This chapter draws on extensive literature which uses high-frequency identification of monetary policy shocks (Kuttner, 2001; Gurkaynak et al., 2004, Bernanke and Kuttner,

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[2] Our choice of these countries as an analysis for spillovers is the availability of high frequency data to accurately measure spillovers. It is documented in recent papers (Curcuru et al., 2018; Kearns et al., 2018) that U.S. monetary policy has significant effects on asset prices of these countries. In addition, both have high trade shares with the United States.

[3] An alternative theory of exchange rates, known as the "financial channel," suggests an appreciation of the U.S. dollar leads to an increase in U.S. dollar-denominated debt for banks in a foreign country borrowing in dollars. Thus, if banks are subject to regulatory leverage constraints, they reduce lending, which leads to contractionary real effects.

2005; Gertler and Karadi, 2015; Nakamura and Steinsson, 2018). High-frequency identification methods rely on tick-by-tick interest rate futures data, coupled with an event-study approach for measuring changes in interest rate futures in a window around central bank announcements. While this approach is valid for measuring monetary surprises during periods of sufficiently positive interest rates, there is a concern about the method's validity when rates are near the ZLB. There is also a concern regarding whether the method captures the effects of unconventional monetary surprises, such as those arising from quantitative easing and forward guidance.

To quantify monetary surprises in the period of unconventional monetary policy, Gurkaynak et al. (2004) and Swanson (2015) examine the impact of monetary policy on asset prices using a factor structure. This methodology analyzes the response in a set of interest rate futures at different horizons, as well as treasury yields of varying maturity, to Federal Reserve announcements around a pre-specified intraday window. Using this variation, their measured first principal component is defined as a “target" factor, such as the Federal Funds rate. Their measured second principal component is called a “path" factor and quantifies the effects of both forward guidance and unconventional policy measures aimed at influencing longer-term rates.[4]

In this chapter, we implement an alternative method for capturing the effects of unconventional monetary policy. Specifically, we decompose changes in the term structure of interest rates using the method in Gurkaynak (2005). This approach rests on partitioning changes in both interest rate futures and treasury yields into a *timing*, *level*, and *slope* component. These components provide a measure for the stance of monetary policy at the short and long ends of the yield curve. With this method, we will infer the effects of surprises in monetary policy on a high-frequency measure of real GDP news.[5]

To construct real GDP news, we draw on Lamont (2001), Vassalou (2003), as well as Hébert and Schreger (2016). These papers provide a useful methodology for linking asset returns to news about macroeconomic fundamentals. We follow a methodology similar to Hébert and Schreger (2016). In their paper, they use high-frequency changes in default probabilities on Argentina's sovereign debt and find increases in these default probabilities lead to a decline in Argentinian asset returns. By constructing a portfolio that replicates real GDP, they are able to trace out the effect of an exogenous rise in default probability on Argentina's real GDP growth. In this chapter, there is a clear parallel to their paper. Specifically, we trace out the macroeconomic effect of monetary surprises (in comparison to surprises in default probability) on real GDP growth through a portfolio of assets that “replicates" real GDP growth.

Our chapter also speaks to the literature on identifying the financial and macroeconomic effects of U.S. monetary policy, both domestically and across borders. High-frequency studies

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[4] For more details, we refer the reader to the methodology outlined in Swanson (2015). The principal components are effectively rotated so the first factor is perfectly correlated with the change in Federal Funds futures, while the second factor is orthogonal to changes in Federal Funds futures. Thus, the latter provides a measure of the effects of unconventional policies, such as QE and forward guidance.

[5] In contrast, using a factor approach to decompose interest rate surprises is difficult to interpret economically when examining the effect of the factors on macroeconomic indicators.

of FOMC announcements (Curcuru et al., 2018; Kearns et al., 2018) have identified significant cross-border effects of U.S. monetary policy on bond yields and stock indices. In particular, the aforementioned authors find that measures of the degree of trade and financial linkages with the U.S. can explain cross-country variation in response to U.S. monetary policy. We contribute to this strand of work by using asset returns around monetary announcements to identify an analogous high-frequency measure of real GDP growth.

In addition to financial spillovers, a series of papers use a structural vector autoregression (SVAR) approach to identify macroeconomic effects (Gertler and Karadi, 2015; Dedola et al., 2017b; Bhattarai et al., 2015). For example, Gertler and Karadi (2015) first use high-frequency monetary shocks as an instrument for policy rate residuals in a traditional SVAR with financial variables. Based on their identification, they examine the effects of policy rate shocks on credit costs and real GDP growth. Using a similar SVAR approach, Dedola et al. (2017b) find a contractionary monetary policy surprise in the U.S. results in a depreciation of most economies' currencies, a contraction in real GDP, as well as a decline in inflation, especially for advanced countries. Another notable example can be found in Bhattarai et al. (2015). These authors instrument for QE using balance sheet growth of the Federal Reserve following key FOMC announcements. In the period from 2008 to 2012, they find significant effects on asset prices of emerging markets in response to U.S. monetary easing.

The approaches taken in these and similar papers rely on the use of an SVAR, which requires restrictive assumptions about the timing of events. Using high-frequency monetary shocks in an SVAR also poses several problems. Most notably, using high-frequency monetary shocks as an instrument for the policy rate has relatively low power in predicting significant long-run responses of real GDP and other macroeconomic variables. We circumvent these and related issues by exploiting the fact monetary shocks at the high-frequency have relatively more power in explaining movements in asset returns. This variation can then be used to replicate real GDP growth.

This chapter is outlined as follows: Section 3.3 introduces the methodology used for constructing a high-frequency measure of real GDP news via a “tracking" or replicating portfolio approach. In Section 3.4, we describe the data used to construct monetary policy surprises and the set of base assets used in our replicating portfolios. Section 3.5 then presents our key findings. These findings include domestic policy effects on real GDP news, as well as macroeconomic spillover effects of Federal Reserve announcements on our measure of real GDP news for both Australia and Canada. Finally, Section 3.6 concludes.

## 3.3 Methodology of Real GDP-Tracking Portfolios

We devise a method for identifying the effects of high-frequency monetary surprises on real GDP growth. In general, this is challenging because real GDP growth is observed at a low-frequency. While many studies find significant asset price effects around monetary announcements, high-frequency monetary surprises have low power for estimating effects of monetary policy on macroeconomic outcomes over long horizons.

Our method addresses this challenge by bridging the gap between both monetary policy and asset prices – both observed at a high frequency – and a low-frequency variable like real

GDP growth. We operationalize this by implementing a simple two-step procedure. First, we replicate real GDP growth at a low-frequency using a large set of economically relevant base asset returns. We then examine the response of the replicating portfolio around monetary announcements to construct a measure of real GDP news at a high frequency. Secondly, we use our constructed measure of real GDP news via the replicating portfolios to infer the effects of monetary announcements on real GDP growth.

### Constructing High-Frequency Real GDP-Tracking News

We define the return on a given base asset from time $t$ to $t+k$ as $R_{i,t+k}$, and real GDP growth over the same period as $\Delta y_{t+k}$. Our base asset return, $R_{i,t+k}$, is a function of idiosyncratic news as well as systematic news, which includes the state of the economy. We capture the latter using the change in real GDP growth $\Delta y_{t+k}$, and other fundamentals, denoted by $F_t$.

$$R_{i,t+k} = \alpha_i \Delta y_{t+k} + \beta_i F_t + v_{i,t} \tag{3.3.1}$$

Here, $v_{i,t}$ represent an idiosyncratic disturbance. To the extent asset returns co-move with real GDP growth, we can use asset returns to construct a portfolio which replicates real GDP growth. We do so by regressing changes in real GDP over a horizon $k$ on a set of concurrent base asset returns, which is given by (3.3.2). The key assumption for replication is that the portfolio of asset returns strongly co-moves with real GDP growth, $\rho(\widehat{\Delta y_{t+k}}, \Delta y_{t+k}) \approx 1$. To optimize the replicating portfolio, we use a wide range of base assets, comprising of exchange rates, stock and commodity indices, treasury yields, as well as corporate bond spreads:

$$\Delta y_{t+k} = \sum_{i=1}^{j} \gamma_{i,k} R_{i,t+k} + u_{t+k} \tag{3.3.2}$$

We use the loadings estimated in (3.3.2) and construct a counterfactual measure of real GDP news around monetary announcements. We first estimate actual changes in base asset returns around monetary announcements, which we denote by $R_t^m$. Using the predicted weights $\hat{\gamma}_1, \hat{\gamma}_2, ..., \hat{\gamma}_j$, we construct a high-frequency analogue of real GDP news, which we denote by $\widehat{\Delta y^m_{t+k}}$ (see (3.3.3)).

$$\Delta \hat{y}^m_{t+k} = \sum_{i=1}^{j} \widehat{\gamma}_i R^m_{i,t} \tag{3.3.3}$$

### Effects Of Monetary Surprises on Real GDP Growth

To infer the causal effects of monetary policy, we regress our measure of high-frequency real GDP news on measures of monetary surprises that span information across the term structure of interest rates (3.3.4). Following Gurkaynak (2005), we construct *timing*, *level*, and *slope* monetary surprises around scheduled monetary announcements. These components measure surprises at different horizons. *Level* represents monetary news at a medium-run horizon, *slope* represents monetary news at the long-end of the yield curve, and *timing* reflects the residual transitory news not captured in the *level* component.[6]

$$\widehat{\Delta y^m_{t+k}} = \Phi_1 timing_t + \Phi_2 level_t + \Phi_3 slope_t + u_{t+k} \tag{3.3.4}$$

We then measure the causal effect of these three monetary shocks on real GDP growth at different horizons. Decomposing interest rate responses in this manner helps capture the effects of the "term structure of monetary policy" on real GDP news. Moreover, it helps quantify the varying effects of unconventional policies during ZLB periods.

Finally, we use this methodology to examine spillover effects of U.S. monetary policy to periphery countries such as Australia and Canada. This entails first constructing real GDP-tracking news for both Australia and Canada using a set of domestic base asset returns around FOMC announcements. This object is then regressed on monetary surprises around FOMC announcements to infer the effect of U.S. monetary policy on the measured real GDP-tracking news of Australia and Canada.

### Econometric Concerns

While we do offer a novel methodology for obtaining a counterfactual measure of real GDP growth at a high-frequency, there are some potential concerns. First, we assume the loadings $\{\gamma_i\}$ from (3.3.2) to be time-invariant. That is, we assume real GDP growth responds to asset returns with the same elasticity at an intra-day or quarterly frequency.

If firms base their decisions to hire or invest on market news at a low frequency, while stock traders respond to a monetary announcement for reasons orthogonal to long-term trends in a company (for example, due to speculation or herding motives), then estimated loadings constructed via the replicating portfolio may not be applicable at a high-frequency.

As a robustness test, Section 3.5 demonstrates the adjusted $R^2$ of the GDP-tracking portfolio is sufficiently high such that our set of base assets capture significant unconditional variation in real GDP growth. Additionally, as a check of our estimates' stability, we test the out-of-sampling fit of our replicating portfolio by computing Root Mean Square Errors (RMSE) at increasing $k$-step horizons.

Second, the loadings estimated in (3.3.2) are unconditional and measure the elasticity of real GDP growth to base asset returns. For identification, we require variation in real GDP growth due to monetary news. In practice, it is likely that non-monetary news has systematic effects on asset returns. For example, stock returns can increase in response to high productivity growth, while an oil price shock could have negative effects on stock prices of firms that rely on oil inputs. For the unconditional loadings to be an accurate predictor of how real GDP growth reacts to monetary news, we require the base assets to respond similarly to both monetary and non-monetary news shocks. For a formal proof of the conditions required for the loadings estimated in (3.3.3) to be unbiased, we refer the reader to Appendix **??**.

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[6] For a more detailed description of how these three shocks are measured, we refer the reader to the Section 3.4

## 3.4 Data

### High-Frequency Identification of Monetary Policy Shocks

Consistent with the work of Kuttner (2001), Gurkaynak et al. (2004), and Bernanke and Kuttner (2005), among others, we define a U.S. monetary policy shock as the component of monetary policy unanticipated by market participants. Specifically, this shock is constructed using interest rate futures for the U.S. Federal Funds rate traded on the Chicago Mercantile Exchange (CME). These financial instruments are contracts with payouts at maturity based on the average effective Federal Funds rate during the month of expiration. Prices of these liquid contracts are directly tied to expectations of target U.S. Federal Funds rates, rendering them crucial for policy analysis. They provide a good signal of what investors anticipate the future path of interest rates may be with high likelihood, as well as a prediction of the outcome for future FOMC meetings. Changes in the futures rate during a short time window around an FOMC announcement provide a measure of the unanticipated component of the change in the Federal Funds rate.

This market-based approach rests on the identifying assumption that the Federal Funds futures contract is a valid instrumental variable for monetary policy. Specifically, the futures price must be sufficiently correlated with the "true" monetary policy stance. Moreover, during an FOMC announcement, the contract price must only respond to news about monetary policy. This market-based measure must not be correlated with any other news, such as news related to the state of economy during the announcement window.

Following Gurkaynak et al. (2004), we construct the intraday change in the futures rate 15 minutes prior to and 45 minutes after the FOMC announcement (see Figure 3.1):

$$\Delta f1_{US,t} = f1_{US,t+45} - f1_{US,t-15} \tag{3.4.1}$$

In analyzing the current-month contract, it is worth noting the contract settlement price is based on what investors think the monthly Federal Funds rate is for the current month. For an event taking place on day $d_0$, the day of the closest FOMC announcement, with $D_0$ days in that month, the surprise target Federal Funds rate change is calculated from the change in the rate implied by the current-month futures contract. The change in the implied 30-day futures rate $\triangle f1_{US,t}$ must be scaled up by a factor related to the number of days in the month affected by the change, which is equal to $D_0 - d_0$ days.[7]

$$MP1_{US,t} = \frac{D_0}{D_0 - d_0}\Delta f1_{US,t} \tag{3.4.2}$$

While using near-month interest rate futures contracts for the underlying policy rate enable us to construct monetary surprises in short-term interest rates, these contracts are limited in use during episodes of unconventional monetary policy. Changes in near-month

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[7] We can also construct surprises in changes of expected rates at longer horizons. For example, surprises in the expected Federal Funds rate after the $2^{nd}$ and $3^{rd}$ FOMC announcements are given by $MP2_{US,t} = \left[\Delta f2_t - \frac{d_2}{D_2} MP1_t\right] \frac{D_2}{D_2 - d_2}$ and $MP3_{US,t} = \left[\Delta f3_t - \frac{d_3}{D_3} MP2_t\right] \frac{D_3}{D_3 - d_3}$, respectively.

futures contracts do not exhibit sufficient variation resulting from constraints imposed by the ZLB. Furthermore, Federal Reserve policies such as quantitative easing, which have typically involved central bank asset purchases of long-term bonds, as well as forward guidance, which anchor long-term interest rates to be low for a considerable period of time, are insufficiently captured by the short-end of the futures contract's term structure.

A more useful way to measure unanticipated monetary policy shocks *across* the maturity space is to augment the CME contracts with U.S. Treasury yields. Along with the futures rate contracts, we use changes in 3-month and 2-year U.S. Treasury bond yields around FOMC announcements. These changes are also taken 15 minutes before and 45 minutes after the FOMC's decision is made public. Consistent with the methodology in Gurkaynak (2005), we decompose U.S. monetary policy shocks into three surprise components: *timing*, *level*, and *slope*.

The *level* surprise measures a parallel shift in interest rate expectations over a horizon of 3 to 6 months. This measure uses the change in the 3-month U.S. Treasury yield around FOMC announcements:

$$\Delta US3MT_{i,t} = level_t \tag{3.4.3}$$

*Timing* is then estimated as the residual of the near-month 30-day futures contract $MP1_{US,t}$ in an ordinary least squares estimation procedure which regresses $MP1_t$, defined in (3.4.2), on the *level* component (3.4.3). *Timing* captures shocks to the stance in U.S. monetary policy not already incorporated in the 3-month U.S. Treasury yield. It therefore captures transitory news unaccounted for within a 3-month policy horizon, i.e.

$$MP1_{US,t} = \alpha_1 + \beta_1 level_t + \underbrace{timing_t}_{\text{residual}} \tag{3.4.4}$$

Lastly, *slope* is constructed to be orthogonal to both *level* and *timing*. *Slope* captures revisions to interest rate changes at the long-end of the yield curve, with horizons ranging from 2 to 10 years. Therefore, *slope* captures a decline in the term premium as well as whether unconventional monetary policy exerts a significant flattening of the yield curve through a compression in yields. We estimate the *slope* component as the residual in a linear regression of changes in 2-year U.S. Treasury yields (around FOMC announcements) against *timing* and *slope*. This is shown in the specification below:

$$\Delta US2YT_{i,t} = \alpha_2 + \gamma_2 timing_t + \beta_2 level_t + \underbrace{slope_t}_{\text{residual}} \tag{3.4.5}$$

For the two other countries in our analysis, Australia and Canada, we implement a similar procedure, albeit with some changes. Because, there do not exist liquid futures contracts tied to the policy rates of the Reverse Bank of Australia (RBA) and the Bank of Canada (BOC), as is the case with the U.S. Federal Reserve, we compute surprises in futures contracts whose underlying is the yield in the RBA's and BOC's 90-day/3-month interbank rate.[8] The use of

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[8] In fact, outside of the U.S., there do not exist liquid contracts analogous to the 30-day Federal Funds futures instrument.

futures contracts tied to both the RBA's and BOC's 90-day/3-month interbank rate is not new and supported in past works (e.g. Ranaldo and Rossi, 2010; Brusa et al., 2016).

For both Australia (AUS) and Canada (CAN), equations for *timing*, *level*, and *slope* are similarly defined, with the sole difference being the use of 90-day interest rate futures contracts in the construction of *timing*. Generalizing to a given country $c \in \{US, AUS, CAN\}$, $\Delta c3MT_t$ and $\Delta c2YT_t$ denote changes in 3-month and 2-year government Treasuries 15 minutes prior to and 45 minutes after country $c$'s central bank announces its policy:

$$MP_{c,t} = \alpha_1 + \beta_1 level_{c,t} + timing_{c,t} \tag{3.4.6}$$

$$\Delta c3MT_t = level_{c,t} \tag{3.4.7}$$

$$\Delta c2YT_t = \alpha_2 + \beta_2 level_{c,t} + \gamma_2 timing_{c,t} + slope_{c,t} \tag{3.4.8}$$

A brief description of interest rate futures for a given central bank's policy rate is provided in Table 3.1. Summary statistics for the *timing*, *level*, and *slope* surprises are displayed in Table 3.2.

## Base Assets Used in Replicating Portfolios

The list of financial base assets used in the construction of our replicating portfolios for the U.S., Canada, and Australia are provided in Tables 3.3, 3.4, and 3.5. All data at the daily frequency are from Global Financial Data (GFD). For high-frequency data (i.e. tick-by-tick data), such as government (Treasury) yields, exchange rates, equities, and commodity indices, we use Thomson Reuters Tick History.

We select the base asset set by starting with an unfiltered list of asset returns for each country. Some assets, such as major equity indices of small, mid, and large market capitalization firms, major exchange rates, commodities, and government Treasury yields, are selected automatically as part of the portfolio. The remaining variables are optimally selected based on maximizing the adjusted $R^2$ of the in-sample fit.[9]

We now provide evidence of asset price responses around monetary policy announcements. Table 3.6, documents the high-frequency response of a set of U.S. base assets to the *timing*, *level*, and *slope* surprises around FOMC announcements. A contractionary shock to *level* causes an appreciation of the US Dollar/Euro exchange rate.[10] The term spread ($TERM^{US,10Y-2Y}$), defined as the difference between 10-year and 2-year U.S. Treasury yields, responds negatively to *slope*. The two major U.S. stock indices, the S&P500 and Dow Jones Industrial Average (DJIA), respond negatively only to *timing*. Their response is similar in magnitude to the baseline estimates of FOMC surprise effects on stock prices documented in Bernanke and Kuttner (2005).

The effects of Australia's monetary surprises on a set of its base assets are presented in Table 3.7. Table 3.8 provides analogous results for Canada. For Australia, a contractionary surprise in *slope* results in an appreciation of the AUD/USD exchange rate, a rise in the term

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[9] Additionally, we allow the set of base assets to change for replicating portfolios at different horizons. However, for brevity we only report the relevant replicating portfolio for the 1-quarter horizon.

[10] Exchange rates are expressed as Dollars/per Euro. For brevity the Dollar/Euro exchange rate is shown, however similar results hold for other currencies vis-á-vis the dollar.

spread, and a contraction in the ASX50 Mid Cap index. For Canada, a contractionary *slope* results in a decline in its stock and commodity return indices, as well as a decline in the term spread between 10- and 2-year government bonds.

We also find significant effects of FOMC announcements on the same set of base assets studied for Australia and Canada. Specifically, a one basis point rise in *timing* results in a ten basis point decline in Canada's stock prices, a two-and-a-half basis point depreciation of the Canadian dollar, and a significant decline in the term spread as short-term rates rise by more than long-term rates. All three responses are statistically significant at the 5% significance level. We also observe similar responses in Australia's asset returns. Altogether, these findings are consistent with recent empirical studies documenting a significant effect of U.S. monetary surprises on bond yields and stock indices in a wide set of countries (Curcuru et al., 2018; Kearns et al., 2018).

## 3.5 Empirical Evidence

In this section, we first present robustness tests of the replicating portfolio methodology described in Section 3.5. We demonstrate the adjusted $R^2$ of the GDP-tracking portfolios are sufficiently high. In addition, the portfolios perform reasonably well out-of-sample. We then test for the effects of domestic monetary policy surprises on real GDP-tracking news for the U.S., Australia, and Canada. We find changes in *slope* have significant effects on real GDP-tracking news, and are consistent with other empirical studies on the effects of monetary policy. Lastly, we examine the spillovers of FOMC announcements to Australia and Canada through the response of these two countries' real GDP-tracking news measures to U.S. *timing*, *level*, and *slope*.

### Real GDP-Tracking News: Performance of Replicating Portfolios

The first step of our real GDP-tracking approach is presented in Table 3.11. We estimate (3.3.2), which is the real GDP replicating portfolio at a quarterly frequency for horizon $k = 1$ through horizon $k = 12$. We demonstrate the robustness of our replicating portfolios by computing the adjusted $R^2$ of the real GDP-tracking portfolio measures. This provides one way of assessing whether we capture sufficient unconditional variation in real GDP growth through our financial base assets.

For all three countries, the replicating portfolios tend to perform reasonably well at longer horizons, with adjusted $R^2$ increasing from 0.61 to 0.99 for the U.S. as we move from $k = 1$ to $k = 12$ quarters. Similar result are obtained for both Australia and Canada: adjusted $R^2$ rises from a minimum of 0.4 (0.5) at $k = 1$ to 0.94 (0.98) at $k = 12$.

We then conduct out-of-sampling fit tests by comparing the fit of our tracking/replicating portfolios to a random walk at horizons $k = 1$ through $k = 12$. The equation for Root Mean Square Error (RMSE) at horizon $k$ is given in (3.5.1), where $k$ is the forecast horizon, $N_k$ is the total number of forecasts in the projection period, $\Delta\widehat{y_{t+s+k}}$ is the fitted values of the real GDP-tracking portfolio, and $\Delta y_{t+s+k}$ is realized real GDP growth. The construction of the RMSE ratios involves taking the ratio of $rmse_{realGDP}$ to the RMSE obtained from a random walk, in which the current quarter's real GDP growth forecast is taken to be the previous quarter, with similar forecasts made at different horizons.

The results are provided in Table 3.11. For the U.S., the RMSE ratio is 0.72 at $k = 1$ and slightly increases to 0.79 at $k = 12$, while for Australia and Canada the RMSE ratio is 1.2 and 0.23 at $k = 12$, respectively. Underlying this trend is the fact that at longer horizons, the rolling regression sample is vastly reduced in comparison to a shorter horizon.

$$rmse_{rGDP} = \left( \frac{\sum_{s=0}^{N_k - 1} \left[ \widehat{\Delta y_{t+s+k}} - \Delta y_{t+s+k} \right]^2}{N_k} \right)^{\frac{1}{2}} \tag{3.5.1}$$

## Response of Real GDP-Tracking News to Domestic Monetary Announcements

Having established robustness of the replication portfolio methodology, we estimate (3.3.4) by regressing the high-frequency, real GDP-tracking news measure (for each country) on domestic *timing*, *level*, and *slope* coefficients to infer the causal effect of monetary policy shocks on real GDP growth. Our results for a contractionary one-percent surprise in each of the three surprise components for the U.S., Australia, and Canada are provided in Tables 3.6, 3.8, and 3.7, respectively. The change in long-term spreads captured by *slope* has a negative impact on news at most horizons, with peak sensitivity for the replicating portfolio at a horizon of 6 quarters for the U.S., and 10 quarters for both Australia and Canada. The U.S. result is consistent with findings in previous studies (Romer and Romer (1989, 2004); Gertler and Karadi (2015)). These earlier studies find a peak response of output following a monetary policy shock occurs after 6 to 9 quarters.

Given these estimates, a shock in the Federal Reserve *slope* component of one percent results in approximately a 1.9 percent decline in real GDP growth. Since the *slope* component has a sample standard deviation of 7 basis points, this suggests a rather quantitatively small effect of monetary announcements on real GDP growth. However, our estimates are within range of results documented in other papers. For example, Gertler and Karadi (2015) estimate impulse responses of industrial production growth with respect to a 25 basis point shock in the 1-year bond rate and find a significant effect on industrial production of approximately 0.3 to 0.5 percent 15 to 20 months after the impact.

For both the RBA and BOC monetary announcements, the domestic *slope* coefficient is similar in magnitude. The effect of *slope* on output growth peaks after 6 quarters, with a one percent contraction in *slope* resulting in a 1.3 to 1.5 percent cumulative decline in real GDP-news growth over that horizon (see Tables 3.6 and 3.8).

Interestingly enough, the results are predominantly driven by each country's *slope* component, as opposed to the *level* or *timing* components of monetary policy. Intuitively, *slope* predominantly matters since changes in longer-term Treasury yields are more important for determining the long-run causal impact of monetary policy. As an economy enters a recession, long-term yields fall as central banks pursue expansionary policies to bolster the economy out of a recession. In contrast, tightening of monetary policy in a boom period, due to concerns of high inflation, lead to higher long-term yields in order to dampen high economic growth. To show robustness, we plot the slope coefficients of domestic monetary announcements at different horizons for the U.S., Australia, and Canada in Figures 3.2, 3.3, and 3.4.

## Response of Australia and Canada's Real GDP-Tracking News to Federal Reserve Announcements

We now test for the international spillover effects of U.S. monetary policy. As before, we estimate (3.3.4), but with a notable difference: we construct real GDP-tracking news for both Australia and Canada based on asset returns around FOMC announcements.

Results for Australia are summarized in Table 3.15. Our findings suggest that at most horizons, the *level* component of U.S. monetary policy has a significantly strong negative impact on Australia's real GDP-tracking news. Quantitatively, we find that a one basis point rise in medium-term interest rates results in a 0.3 percent decline in Australia's real GDP-tracking news after four quarters. These spillover effects are quantitatively smaller than domestic effects, which is intuitive given that opposing channels (such as expenditure switching) are likely to attenuate the response.

These results, taken at face value, yield supportive evidence of the theory set forth in Rey et al. (2013). This theory posits that a hike in U.S. interest rates can lead to a contraction in global bank credit, leverage and asset prices. In this case, even with a flexible exchange rate regime, Australia can only obtain sovereign monetary policy if it imposes capital controls. Otherwise, the economy's credit flows are driven by U.S. monetary policy, which in turn has real macroeconomic effects. This evidence is consistent with other recent papers on spillover effects, such as Dedola et al. (2017b). In that paper, the authors use an SVAR to estimate the effects of U.S. monetary policy shocks on a set of advanced and emerging markets. For both economy types, they document that a one standard deviation surprise tightening in U.S. monetary policy results in a peak decline of approximately 0.2 percent in real GDP growth after four quarters.

Results for Canada are provided in Table 3.16; they are mixed. While the effects at a short horizon suggest a contraction in the U.S. results in an expansion of Canada's real GDP growth, with a one basis point decline in short-term interest rates resulting in a one basis point rise in real GDP-tracking news, the results at longer horizons are unclear. To explain the short-term expansionary effect for Canada, conventional theory is based on expenditure switching effects of an exchange rate depreciation. As the Canadian dollar depreciates, this lowers the price of exports and raises the price of imports, leading to expenditure switching effects as foreigners demand more exports. The expenditure switching effects are likely to dominate as Canada is heavily reliant on trade with the United States. An aggregate measure of trade exposure suggests that up to 50% of trade in exports and imports for Canada is with the U.S. (Dedola et al., 2017b).

To summarize our results, we plot the coefficients of the FOMC *level* component on Australia's real GDP-tracking news in Figure 3.5, and the FOMC *slope* component on Canada's real GDP news in Figure 3.6.

## 3.6 Conclusion

We provide a novel method for estimating real GDP-tracking news based on a set of base asset returns. Our real GDP-tracking method offers a novel way for thinking about the causation of monetary policy to real GDP growth. By replicating real GDP growth via a portfolio of assets at a low frequency, we construct a proxy for high-frequency real GDP-tracking news based on the replicating portfolio's responses around monetary announcements.

Our procedure enables us to not only examine domestic effects, but also spillover effects from a center country's monetary announcements to a country in its sphere of influence. We illustrate this by considering the effects U.S. Federal Reserve monetary policy exerts on both Australia and Canada's real GDP-tracking news measures. First, we find that contractionary shocks in the U.S., Australia, and Canada result in declining real GDP growth. Specifically, in response to a one basis point rise in long-term yields, output growth falls between 1.5 to 2.0 basis points after six quarters. These estimates are in line with other empirical studies using SVAR methods to quantify the effects of monetary policy on real GDP growth (e.g. Gertler and Karadi (2015)).

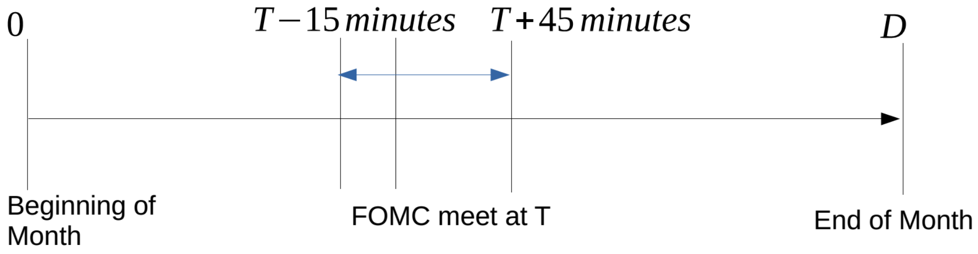
Secondly, we test for whether FOMC announcements result in significant changes to the real GDP-tracking news measures of both Australia and Canada. For Australia, we find that a rise in U.S. interest rates results in a contraction of Australia's real GDP-tracking news at most horizons. This lends support to the theory of the global financial cycle put forth in Rey et al. (2013), in which a contraction in U.S. monetary policy results in declining bank asset prices, global leverage, and consequently, declining credit to periphery countries.

Contrarily, for Canada, a rise in U.S. short-term interest rates results in expansionary effects in the short-run. This suggests expenditure switching effects may be the dominating channel following U.S. monetary policy. Specifically, contractionary policy by the U.S. Federal Reserve, which results in the depreciation of the Canadian dollar, results in the expansion of net exports.

Going forward, the methodological contribution in this chapter can also be used to study the effects of U.S. monetary policy on emerging markets. While it is intuitive that U.S. monetary policy has a significant effect on Australia and Canada, a similar regime of influence may exist in Europe with the European Central Bank (ECB) potentially exerting similar effects on periphery countries outside the Eurozone. Understanding these effects are feasible with our approach. This analysis will provide crucial insights into the effectiveness of monetary policy, which further aids in setting optimal policy.

# Figures

Figure 3.1: Computing U.S. Federal Funds Rate Shocks



*Note:* Following Gurkaynak et al. (2004), we construct a “wide" window around each FOMC announcement at time $T$ to compute the futures rate change. Intraday changes are based on the change in the futures rate 15 minutes *prior* to and 45 minutes *after* the announcement.

Figure 3.2: Response of U.S. Real GDP-Tracking News to FOMC *slope*

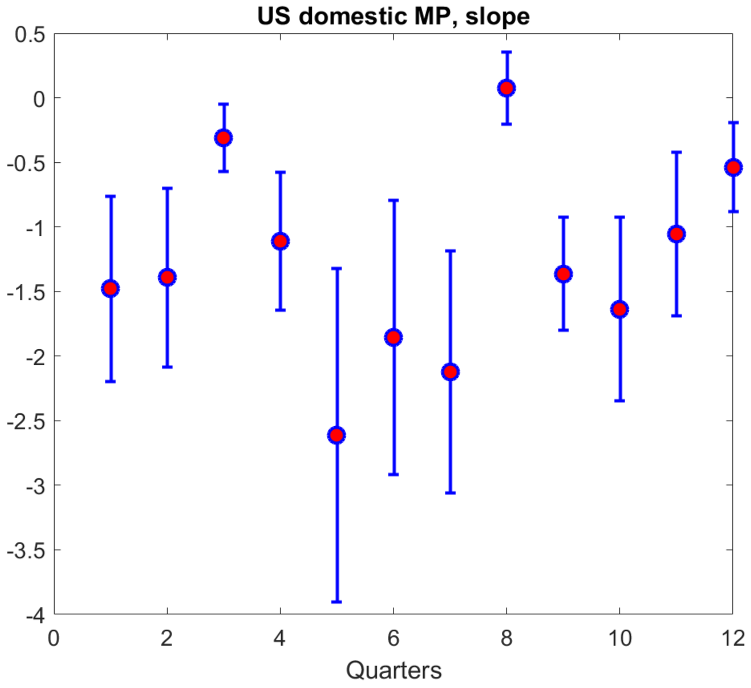


Figure 3.3: Response of Australia's Real GDP-Tracking News to RBA *slope*

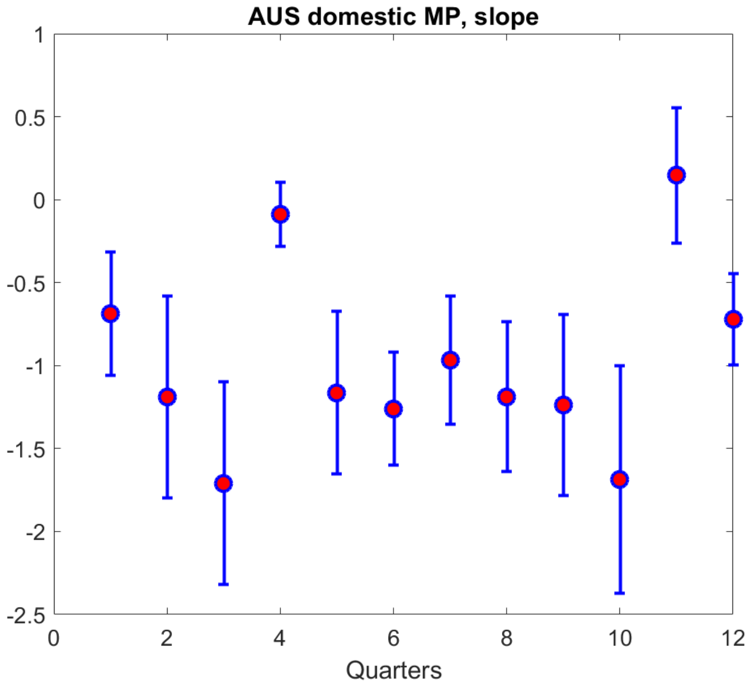


Figure 3.4: Response of Canada's Real GDP-Tracking News to BOC *slope*

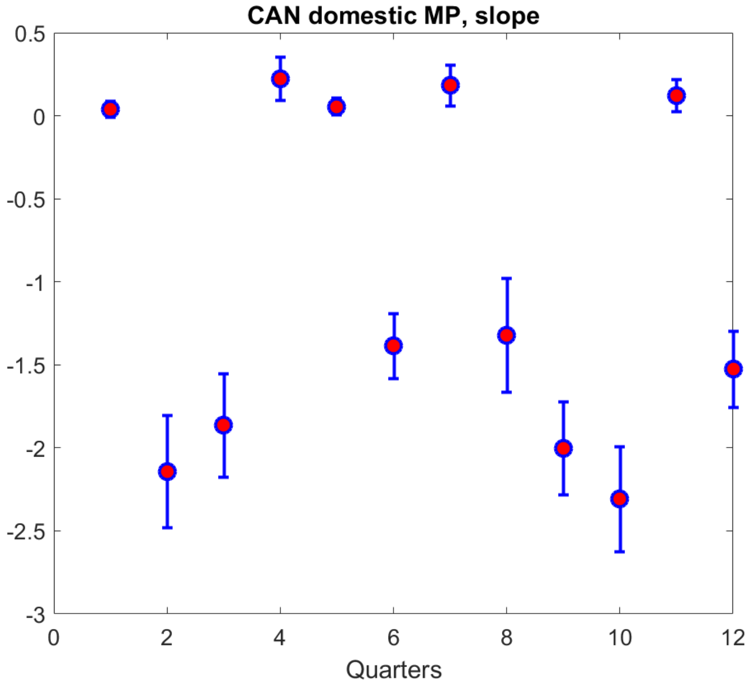


Figure 3.5: Response of Australia's Real GDP-Tracking News to FOMC *level*

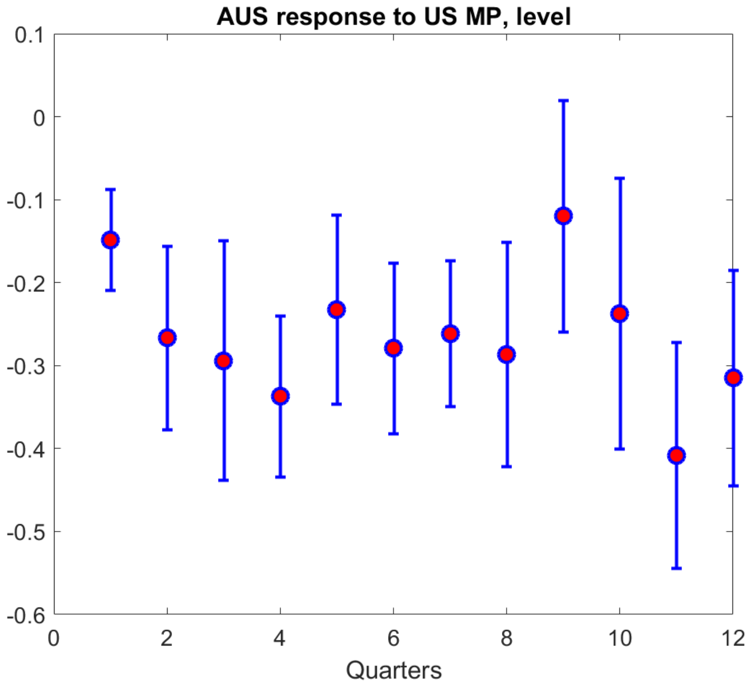
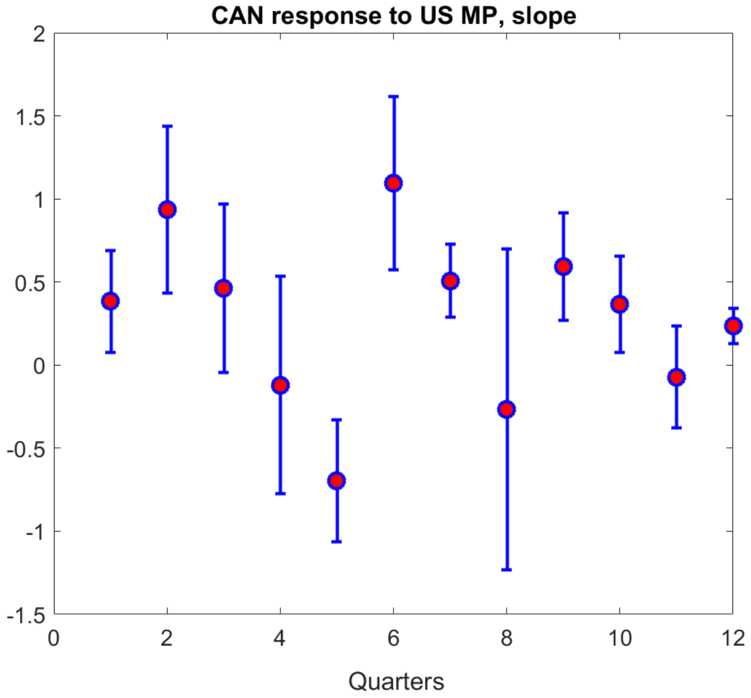


Figure 3.6: Response of Canada's Real GDP-Tracking News to FOMC *slope*



# Tables

Table 3.1: Interest Rate Futures Contracts for the U.S., Australia, and Canada

| Country | Underlying Policy Rate | Monetary Policy Shock |
|---|---|---|
| US | Federal Funds Rate | $MP1_{US,t} = \frac{D}{D-d} \Delta f1_{US,t}$ |
| AUS | SFE 90-day Bank Accepted Bill Rate | $MP_{AUS,t} = \Delta f1_{AUS,t}$ |
| CAN | ME 90-day Bankers' Acceptance Rate | $MP_{CAN,t} = \Delta f1_{CAN,t}$ |

Table 3.2: Monetary Policy Surprises for the U.S., Australia, and Canada - Summary Statistics

| | **Mean** | **SD** | **p5** | **p25** | **Median** | **p75** | **p95** | **Announcements** |
|---|---|---|---|---|---|---|---|---|
| $timing_{\mathrm{US}}$ | 9.6e-11 | .044 | -.077 | -.006 | .00067 | .0088 | .081 | 184 |
| $level_{\mathrm{US}}$ | -.021 | .14 | -.16 | -.016 | -.0025 | .005 | .11 | 185 |
| $slope_{\mathrm{US}}$ | 5.3e-11 | .07 | -.12 | -.029 | .004 | .033 | .11 | 184 |

U.S. Federal Reserve scheduled announcements from 2/1994 to 12/2016.

| | **Mean** | **SD** | **p5** | **p25** | **Median** | **p75** | **p95** | **Announcements** |
|---|---|---|---|---|---|---|---|---|
| $timing_{\mathrm{AUS}}$ | -.00013 | .019 | -.027 | -.0065 | .0011 | .0086 | .021 | 255 |
| $level_{\mathrm{AUS}}$ | .0026 | .052 | -.06 | -.01 | 0 | .02 | .05 | 255 |
| $slope_{\mathrm{AUS}}$ | .00028 | .069 | -.12 | -.025 | .0027 | .035 | .11 | 222 |

RBA scheduled announcements from 3/1990 to 12/2016.

| | **Mean** | **SD** | **p5** | **p25** | **Median** | **p75** | **p95** | **Announcements** |
|---|---|---|---|---|---|---|---|---|
| $timing_{\mathrm{CAN}}$ | 2.2e-12 | .0089 | -.012 | -.0052 | -.00021 | .0048 | .012 | 130 |
| $level_{\mathrm{CAN}}$ | .0005 | .02 | -.03 | -.01 | 0 | .01 | .03 | 130 |
| $slope_{\mathrm{CAN}}$ | 2.8e-10 | .18 | -.12 | -.048 | -.016 | .019 | .11 | 130 |

BOC scheduled announcements from 12/2000 to 12/2016.

Table 3.3: Base Assets for the U.S.

| Currency | Stock Indices | Commodities | Bond Yields/Other |
|---|---|---|---|
| EUR/USD | S&P500 | ICE Brent Crude Oil | Treasuries: 3m, 6m, 2Y, 5Y, 10Y, 30Y |
| GBP/USD | S&P Banks | NY MEX Nat Gas | Treasury spreads: 10Y-2Y, 30Y-2Y |
| CNY/USD | S&P Retail | COMEX Gold | Corp: 1-10Y |
| MXN/USD | S&P Healthcare | COMEX Silver | Corp: 10+Y |
|  | S&P Industrials | S&P GSCI Agr | S&P500 VIX |
|  | S&P Financials | S&P GSCI Livestock | ML 1m-Vol (MOV) |
|  | DJ Transports | S&P GSCI TR |  |
|  | DJ Banks | S&P GSCI Pmetals |  |
|  | DJ Utilities | S&P GSCI Imetals |  |
|  | DJ Oil & Gas |  |  |
|  | DJ Real Estate Index |  |  |
|  | Russell 2000 |  |  |
|  | Nasdaq Composite 100 |  |  |

Table 3.4: Base Assets for Australia

| Currency | Stock Indices | Commodities | Bond Yields/Other |
|---|---|---|---|
| AUD/USD | ASX200 All Ord | ICE Brent Crude Oil | Treasuries: 3m, 2y, 5y, 10y, 15y |
| AUD/JPY | ASX50 Large Cap | NY MEX Nat Gas | Treasury spreads: 10Y-2Y, 15Y-2Y |
| AUD/EUR | ASX50 Mid Cap | COMEX Gold | Corp: 1-10Y |
| AUD/GBP | ASX200 Small Ord | COMEX Silver | Corp: All maturities |
|  | ASX200 Banking | S&P GSCI Agr | S&P500 VIX |
|  | ASX200 Energy | S&P GSCI Livestock | ML 1m-Vol (MOV) |
|  | ASX200 Utilities | S&P GSCI TR |  |
|  | ASX200 Materails | S&P GSCI Pmetals |  |
|  | ASX200 Small Ord | S&P GSCI Imetals |  |

Table 3.5: Base Assets for Canada

| Currency | Stock Indices | Commodities | Bond Yields/Other |
|---|---|---|---|
| CAD/USD | CDNX Comp, TSX300 Comp | ICE Brent Crude Oil | Treasuries: 3m, 6m, 2Y, 5Y, 10Y, 30Y |
| CAD/EUR | TSX300 Comp | NY MEX Nat Gas | Treasury spreads: 10Y-2Y, 30Y-2Y |
| CAD/CNY | TSX60 Large Cap | COMEX Gold | Corp: 1-10Y, 5-10Y, 15Y |
| CAD/JPY | TSX Banks | COMEX Silver | Corp: 10+Y |
| CAD/MSXN | TSX Gold | S&P GSCI Agr | S&P500 VIX |
|  | TSX60 Large Cap | S&P GSCI Livestock | ML 1m-Vol (MOV) |
|  | TSX Energy | S&P GSCI TR |  |
|  | TSX IT | S&P GSCI Pmetals |  |
|  | TSX Materials | S&P GSCI Imetals |  |
|  | TSX Consumer Disc |  |  |

Table 3.6: Response of U.S. Asset Returns to FOMC Announcements

|  | S&P500 | EURUSD | $TERM^{\text{US,10-2Yr}}$ | S&P500 Vol | S&P GSCI TR |
|---|---|---|---|---|---|
| $timing_{\text{US}}$ | -5.7*** | -2.7*** | -.35** | 6.5*** | -3 |
|  | (-3.5) | (-2.8) | (-2.2) | (2.9) | (-1.2) |
| $level_{\text{US}}$ | 1 | -.35* | -.059** | -1.2 | .33 |
|  | (1.1) | (-1.8) | (-2.2) | (-1.2) | (.69) |
| $slope_{\text{US}}$ | -1.2 | -2.3*** | -.36*** | .48 | -2.8* |
|  | (-1.1) | (-3.8) | (-3.1) | (.39) | (-1.8) |
| adjusted $R^2$ | .14 | .14 | .19 | .1 | .027 |
| Events | 168 | 183 | 184 | 168 | 184 |

*t*-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 3.7: Response of Australia's Asset Returns to RBA Announcements

| | ASX50 MCap | AUDUSD | $SPREAD^{\text{AUS,allYr}}$ | S&P GSCI TR |
|---|---|---|---|---|
| $timing_{\text{AUS}}$ | -1.1 | -.97 | .68 | .88 |
| | (-.32) | (-.2) | (1.6) | (.1) |
| $level_{\text{AUS}}$ | -1.3 | -.18 | -.12 | .21 |
| | (-.88) | (-.09) | (-1.1) | (.038) |
| $slope_{\text{AUS}}$ | $-2^{***}$ | $3.1^{***}$ | $.25^{**}$ | -.56 |
| | (-3.1) | (3.1) | (2.5) | (-.31) |
| adjusted $R^2$ | .097 | .074 | .21 | .00079 |
| Events | 222 | 222 | 211 | 222 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 3.8: Response of Canada's Asset Returns to BOC Announcements

| | MSCI-Can ETF | CADUSD | $TERM^{\text{CAN,10-2Yr}}$ | S&P GSCI TR |
|---|---|---|---|---|
| $timing_{\text{CAN}}$ | 16 | 4.8 | $-1.8^{**}$ | -13 |
| | (.89) | (.96) | (-2.2) | (-1) |
| $level_{\text{CAN}}$ | 9.1 | 2.6 | $-.91^{*}$ | $12^{**}$ |
| | (1.4) | (1.3) | (-1.8) | (2.2) |
| $slope_{\text{CAN}}$ | $-.59^{*}$ | .47 | $-1.9^{***}$ | $-.75^{***}$ |
| | (-1.8) | (.8) | (-10) | (-2.7) |
| adjusted $R^2$ | .041 | .051 | .93 | .041 |
| Events | 130 | 129 | 130 | 130 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 3.9: Response of Australia's Asset Returns to FOMC Announcements

| | ASX50 MCap | AUDUSD | $SPREAD^{\text{AUS,allYr}}$ | S&P GSCI TR |
|---|---|---|---|---|
| $timing_{\text{US}}$ | -.048 | -2.8$^{***}$ | -.013 | -3 |
| | (-.11) | (-2.8) | (-.13) | (-1.2) |
| $level_{\text{US}}$ | -.0088 | -.3$^{*}$ | -.071$^{*}$ | .33 |
| | (-.095) | (-1.7) | (-2) | (.69) |
| $slope_{\text{US}}$ | -.18 | -3.1$^{***}$ | .0027 | -2.8$^{*}$ |
| | (-1.3) | (-3.9) | (.063) | (-1.8) |
| adjusted $R^2$ | .0085 | .13 | .039 | .027 |
| Events | 168 | 183 | 160 | 184 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 3.10: Response of Canada's Asset Returns to FOMC Announcements

| | MSCI-Can ETF | CADUSD | $TERM^{\text{CAN,10-2Yr}}$ | S&P GSCI TR |
|---|---|---|---|---|
| $timing_{\text{US}}$ | -9.5$^{***}$ | -2.5$^{***}$ | -.32$^{***}$ | -3 |
| | (-4.4) | (-3.7) | (-3.3) | (-1.2) |
| $level_{\text{US}}$ | .38 | -.066 | -.043 | .33 |
| | (.44) | (-.57) | (-1.2) | (.69) |
| $slope_{\text{US}}$ | -1.8 | -1.9$^{***}$ | -.099$^{*}$ | -2.8$^{*}$ |
| | (-1.3) | (-3.3) | (-1.7) | (-1.8) |
| adjusted $R^2$ | .15 | .12 | .016 | .027 |
| Events | 167 | 183 | 168 | 184 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 3.11: $1^{st}$-Step Results - RMSE and adjusted $R^2$ for Replicating Portfolios

| **Country** | | $k = 1$ | $k = 2$ | $k = 4$ | $k = 6$ | $k = 8$ | $k = 10$ | $k = 12$ |
|---|---|---|---|---|---|---|---|---|
| **US** | $\overline{R^2}$ | .61 | .77 | .91 | .96 | .98 | .98 | .99 |
| | RMSE | .72 | .95 | .66 | .54 | .86 | .75 | .79 |
| | N | 88 | 87 | 85 | 83 | 81 | 79 | 77 |
| **Australia** | $\overline{R^2}$ | .4 | .54 | .8 | .9 | .89 | .93 | .94 |
| | RMSE | .6 | .92 | .87 | .84 | 1.8 | 1.5 | 1.2 |
| | N | 82 | 81 | 79 | 77 | 75 | 73 | 71 |
| **Canada** | $\overline{R^2}$ | .5 | .8 | .94 | .94 | .98 | .97 | .98 |
| | RMSE | .71 | .79 | .55 | .5 | .73 | .7 | .23 |
| | N | 77 | 76 | 74 | 72 | 70 | 68 | 66 |

Table 3.12: Response of U.S. Real GDP-Tracking News to Domestic *timing*, *level*, and *slope*

| | $k = 1$ | $k = 2$ | $k = 4$ | $k = 6$ | $k = 8$ | $k = 10$ | $k = 12$ |
|---|---|---|---|---|---|---|---|
| $timing_{\mathrm{US}}$ | -1.2 | -.85 | -.67 | -1.6 | .3 | -1.5 | .057 |
| | (-1.2) | (-.87) | (-.83) | (-1.1) | (.62) | (-1.3) | (.1) |
| $level_{\mathrm{US}}$ | -.13 | -.21$^{*}$ | -.2$^{**}$ | -.39$^{**}$ | .022 | -.092 | .079 |
| | (-1.1) | (-1.8) | (-2.2) | (-2.3) | (.26) | (-.71) | (.84) |
| $slope_{\mathrm{US}}$ | -1.5$^{**}$ | -1.4$^{**}$ | -1.1$^{**}$ | -1.9$^{*}$ | .075 | -1.6$^{**}$ | -.54 |
| | (-2.1) | (-2) | (-2.1) | (-1.7) | (.27) | (-2.3) | (-1.6) |
| $R^2$ | .032 | .029 | .03 | .021 | .0034 | .042 | .017 |
| Events | 184 | 184 | 184 | 184 | 184 | 184 | 184 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.1$, $^{**}$ $p < .05$, $^{***}$ $p < 0.01$

Table 3.13: Response of Australia's Real GDP-Tracking News to Domestic *timing*, *level*, and *slope*

| | $k=1$ | $k=2$ | $k=4$ | $k=6$ | $k=8$ | $k=10$ | $k=12$ |
|---|---|---|---|---|---|---|---|
| $\textit{timing}_{\text{AUS}}$ | -1.7 | -3.6$^{*}$ | -.31 | -1.4 | -1.1 | -2 | -.25 |
| | (-1.2) | (-1.8) | (-.33) | (-1.2) | (-.72) | (-1) | (-.19) |
| $\textit{level}_{\text{AUS}}$ | -.41 | -.55 | .028 | -1.1 | -1.1 | -1.5 | -1.1 |
| | (-.56) | (-.44) | (.057) | (-1.2) | (-.92) | (-.86) | (-1.4) |
| $\textit{slope}_{\text{AUS}}$ | -.69$^{*}$ | -1.2$^{*}$ | -.088 | -1.3$^{***}$ | -1.2$^{***}$ | -1.7$^{**}$ | -.72$^{***}$ |
| | (-1.8) | (-2) | (-.45) | (-3.7) | (-2.6) | (-2.5) | (-2.6) |
| $R^2$ | .027 | .027 | .0012 | .051 | .025 | .021 | .046 |
| Events | 222 | 222 | 222 | 222 | 222 | 222 | 222 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.1$, $^{**}$ $p < .05$, $^{***}$ $p < 0.01$

Table 3.14: Response of Canada's Real GDP-Tracking News to Domestic *timing*, *level*, and *slope*

| | $k=1$ | $k=2$ | $k=4$ | $k=6$ | $k=8$ | $k=10$ | $k=12$ |
|---|---|---|---|---|---|---|---|
| $\textit{timing}_{\text{CAN}}$ | -.09 | -2.6 | 2.1 | -2.2 | -.097 | -4.3$^{**}$ | -1.5 |
| | (-.11) | (-1.5) | (.91) | (-1.2) | (-.038) | (-2.1) | (-.97) |
| $\textit{level}_{\text{CAN}}$ | -.31 | -.72 | -2.2 | -1.5 | -3.6 | -1.5 | .56 |
| | (-.71) | (-.6) | (-1.2) | (-1.2) | (-1.5) | (-1.3) | (.71) |
| $\textit{slope}_{\text{CAN}}$ | .037 | -2.1$^{***}$ | .22$^{*}$ | -1.4$^{***}$ | -1.3$^{***}$ | -2.3$^{***}$ | -1.5$^{***}$ |
| | (.78) | (-6.3) | (1.7) | (-7.2) | (-3.9) | (-7.3) | (-6.6) |
| $R^2$ | .016 | .73 | .021 | .48 | .23 | .73 | .79 |
| Events | 130 | 130 | 130 | 130 | 130 | 130 | 130 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.

$^{*}$ $p < 0.1$, $^{**}$ $p < .05$, $^{***}$ $p < 0.01$

Table 3.15: Response of Australia's Real GDP-Tracking News to U.S. *timing*, *level*, and *slope*

| | $k = 1$ | $k = 2$ | $k = 4$ | $k = 6$ | $k = 8$ | $k = 10$ | $k = 12$ |
|---|---|---|---|---|---|---|---|
| $timing_{\text{US}}$ | .46 | 1.1 | -.28 | .08 | 1.3 | 1.6 | -.65 |
| | (.56) | (.67) | (-.62) | (.071) | (.9) | (.71) | (-.99) |
| $level_{\text{US}}$ | -.15$^{**}$ | -.27$^{**}$ | -.34$^{***}$ | -.28$^{***}$ | -.29$^{**}$ | -.24 | -.31$^{**}$ |
| | (-2.4) | (-2.4) | (-3.5) | (-2.7) | (-2.1) | (-1.5) | (-2.4) |
| $slope_{\text{US}}$ | .27 | .47 | -.74$^{**}$ | -.15 | .5 | 1.1 | -.81$^{*}$ |
| | (.71) | (.66) | (-2.4) | (-.28) | (.77) | (1.1) | (-2) |
| $R^2$ | .0085 | .0093 | .056 | .0056 | .013 | .012 | .038 |
| Events | 184 | 184 | 184 | 184 | 184 | 184 | 184 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.
$^{*}$ $p < 0.1$, $^{**}$ $p < .05$, $^{***}$ $p < 0.01$

Table 3.16: Response of Canada's Real GDP-Tracking News to U.S. *timing*, *level*, and *slope*

| | $k = 1$ | $k = 2$ | $k = 4$ | $k = 6$ | $k = 8$ | $k = 10$ | $k = 12$ |
|---|---|---|---|---|---|---|---|
| $timing_{\text{US}}$ | .87$^{**}$ | 1.2$^{*}$ | .69 | 1.1 | .78 | .29 | .3 |
| | (2.2) | (1.9) | (.79) | (1.4) | (.63) | (.61) | (1.6) |
| $level_{\text{US}}$ | -.017 | -.018 | -.21$^{*}$ | .15 | -.32$^{**}$ | .095 | .026 |
| | (-.28) | (-.17) | (-1.9) | (1.3) | (-2) | (1.4) | (.55) |
| $slope_{\text{US}}$ | .38 | .93$^{*}$ | -.12 | 1.1$^{**}$ | -.27 | .37 | .24$^{**}$ |
| | (1.2) | (1.9) | (-.18) | (2.1) | (-.27) | (1.3) | (2.2) |
| $R^2$ | .056 | .033 | .0068 | .03 | .008 | .0068 | .022 |
| Events | 184 | 184 | 184 | 184 | 184 | 184 | 184 |

$t$-statistics in parentheses. Heteroscedasticity-consistent and robust standard errors.
$^{*}$ $p < 0.1$, $^{**}$ $p < .05$, $^{***}$ $p < 0.01$

# Appendix

## Construction of Real GDP-Tracking News via Replicating Portfolios

The error term in (3.3.2) can be characterized as a function of a series of monetary and non-monetary shocks hitting the aggregate economy. We denote monetary shocks by $\epsilon_{mp,t}$ and non-monetary shocks, such as productivity or oil price shocks, by $\epsilon_{-mp,t}$.

$$u_t = f(\epsilon_{mp,t}, \epsilon_{-mp,t}) \tag{3.6.1}$$

In practice, non-monetary news may have systematic effects on the returns of various asset classes. For example, stock returns can rise in response to high productivity growth, while an oil price shock could have negative effects on the stock price of firms heavily relying on oil inputs.

To identify the loadings $\{\gamma_i\}$ in (3.3.2), we require that real GDP-tracking news, constructed via replicating portfolios based on underlying monetary and non-monetary shocks, have close to equivalent loadings. Formally, this can be shown as follows: we first construct two separate real GDP-tracking portfolios, one based on monetary news, the other on non-monetary news. Taking the conditional expectation of real GDP growth with respect to monetary and non-monetary news, we can use the use the portfolio of base assets with weights $\{\gamma_i\}$ and $\{\alpha_i\}$, respectively (see (3.6.2) and (3.6.3)):

$$E[\Delta y_{t+k}|\epsilon_{mp,t}] = \sum_{i=1}^{j} \gamma_i R_{i,t+k} \tag{3.6.2}$$

$$E[\Delta y_{t+k}|\epsilon_{-mp,t}] = \sum_{i=1}^{j} \alpha_i R_{i,t+k} \tag{3.6.3}$$

Now, assume $u_t$ incorporates monetary news with probability $p$ and non-monetary news with probability $1-p$. Taking the unconditional expectation of real GDP growth in (3.6.4) yields:

$$E[\Delta y_{t+k}] = p \times \sum_{i=1}^{j} \gamma_i R_{i,t+k} + (1-p) \times \sum_{i=1}^{j} \alpha_i R_{i,t+k} \tag{3.6.4}$$

The portfolio weights estimated (unconditionally) in (3.3.2) are an unbiased estimator of $\gamma_i$ if and only if $\alpha_i = \gamma_i$. In other words, the covariance between asset returns and real GDP growth *conditional* on monetary and non-monetary shocks are equal. This is stated formally below:

$$\alpha_i = \gamma_i \equiv cov(R_{i,t+k}, E[\Delta y_{t+k}|\epsilon_{mp,t}]) = cov(R_{i,t+k}, E[\Delta y_{t+k}|\epsilon_{-mp,t}]) \tag{3.6.5}$$

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