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Evidence on the Effects of the Lender of Last Resort

Saleem Bahaj and Ricardo Reis

Discussion Paper No. 2019-E-9

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Central Bank Swap Lines:
Evidence on the Effects of the Lender of Last Resort

Saleem Bahaj* and Ricardo Reis**

Abstract

Theory claims that central-bank lending programs put ceilings on private lending rates, reduce ex post funding risk, and encourage ex ante investment. Testing for these effects is challenging. Most programs either have long precedents or were introduced in response to large shocks with multiple effects. Swap lines between advanced-economy central banks are a significant new policy through which a source central bank provides source-currency credit to recipient-country banks using the recipient central bank as the monitor and as the bearer of the credit risk. This paper shows that, in theory, the swap lines should put a ceiling on deviations from covered interest parity, lower average market funding costs, and increase inflows from recipient-country banks into assets denominated in the source-country's currency. Empirically, these are tested using difference-in-difference strategies that exploit variation in the terms of the swap line over time, variation in the central banks that have access to the swap line, variation in the exposure of different securities to foreign funding, and variation in banks' exposure to dollar funding risk. The evidence suggests that the lender of last resort is very effective.

*Bank of England (E-mail: saleembahaj@gmail.com)
** London School of Economics (E-mail: r.a.reis@lse.ac.uk)

1 Introduction

At least since Bagehot (1873), it has become widely accepted that central banks should be lenders of last resort to attenuate funding crises and prevent crashes in investment. Whether these lending facilities were crucial in preventing a depression in 2007-08, or whether they created the seeds of future crises through moral hazard, is up for debate. Common to both sides of the argument is a presumption that the lender of last resort is effective. This paper uses a new facility, central bank swap lines, whose terms were experimented with and that had implications for financial assets only in certain denominations, in order to provide credible evidence that the lender of last resort has a large effect on financial prices and investment decisions.

Central bank swap lines are interesting in their own right. They became prominent in 2007 when European banks, which over the preceding decade had become reliant on U.S. money markets, needed liquidity assistance. In December, a $20bn swap line was arranged between the Fed and the ECB and, within one year, with a dozen other central banks. The lines came into use between September 2008 and January 2009, with the amount drawn peaking at $586bn; see figure 1. The swap lines were formally reintroduced in May 2010 and in October 2013 were made into permanent standing arrangements of unstated sizes between the Fed and five advanced-country central banks: the Bank of Canada, the Bank of England, the Bank of Japan, the European Central Bank, and the Swiss National Bank.[1] Similar arrangements were made involving other currencies and other central banks so that, by 2019, there is a wide ranging network of around 160 bilateral swap lines that can generate official cross-border capital flows in excess of the resources of the IMF. Today, central bank swap line receive significant attention in discussions of the global financial architecture, of the role of IMF, or of monetary policy coordination across borders, but still only a small academic literature formally characterizing their properties and credibly identifying their effects.[2]

This paper provides an analysis of the role played by central bank swap lines, and uses them to test the effectiveness of central bank lending programs. It is composed of three parts focussing on: central bank balance sheets and operations; financial markets and the transmission of policies; and the macroeconomy through investment decisions. We provide an integrated model of banks, forward exchange-rate markets, and bond-financed investment, and an empirical identification strategy that relies on a change in the terms of the swap line that affect different currencies, banks, and bonds differentially. The conclusion is that central bank swap lines lowered funding costs of banks and, in doing so, increased funding to firms across borders.

We start by describing the terms and operation of the swap contracts. In short, a swap line is a loan of source-country currency by the source-country central bank to a recipient-country central bank, keeping the recipient-country currency as collateral during the duration of the loan. We show

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[1] The other swap lines between the Fed and other central banks have expired, with the exception of a limited arrangement with the Banco do Mexico.

[2] For discussions of the role that the swap lines may play in the international financial architecture see di Mauro and Zettelmeyer (2017); Eichengreen, Lombardi and Malkin (2018); Gourinchas, Rey and Sauzet (2019).

Figure 1: Federal Reserve dollar lending through its swap lines
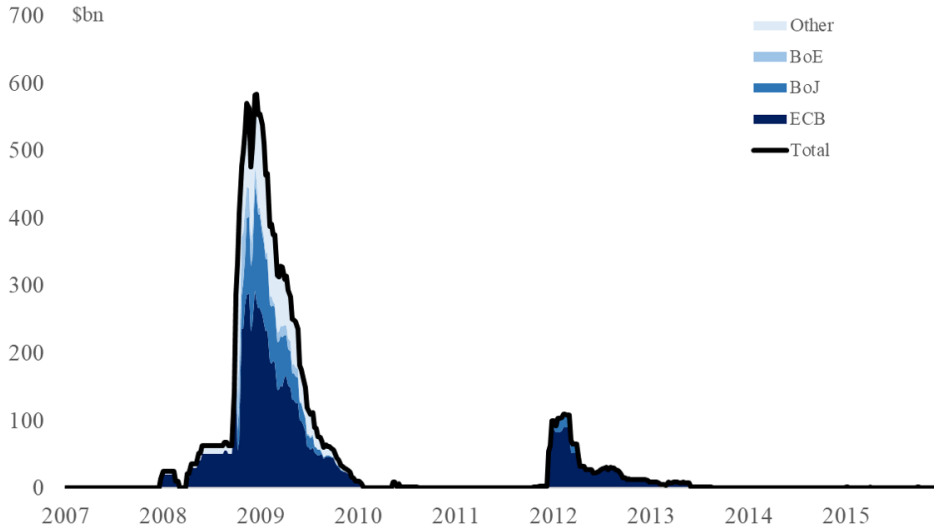
that the swap lines provide a substitute for lending by the source central bank to the recipient-country banks, using the recipient central bank as an agent that bears the credit risk. As such, the swap lines are consistent with controlling inflation and the lender of last resort role, and they are not, at least directly, tied to intervening in exchange rates, bailing out or transferring wealth to foreigners, or nationalizing private risk. We discuss why they arose as a supplement to traditional lending facilities, or to using private funding markets. This description complements discussions in policy papers and speeches of how the swap lines were adopted as a package of responses to general funding pressures during the financial crisis.[3]

Turning to the transmission of this policy in financial markets, we prove that the sum of the gap between the swap rate and the interbank rate in the source country, and the gap between the central bank's policy rate and its deposit rate in the recipient country, provides a ceiling on the deviations of covered interest parity (CIP) between the two currencies. Breaking this ceiling would give rise to an arbitrage opportunity. We embed this arbitrage argument in a model of financial intermediaries that supply forward contracts to show how this affects the distribution of price quotes in the forward market. We then allow for the collateral and regulatory requirements associated with the central bank swap lines, generating new predictions on when the ceiling can appear to be broken that can be tested in the data.

We then turn to the data on CIP deviations, as measured from individual quotes in the FX swap market, to confirm these predictions. While the creation of these swap lines was clearly endogenous to market prices, we first exploit a cut in the Fed's swap line rate which had a timing that is plausibly

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[3]For instance Kohn (2014), or Goldberg, Kennedy and Miu (2011).

exogenous to the CIP deviations in the days preceding it. This allows for difference-in-differences tests to confirm the prediction that the right tail on the distribution of CIP deviations, as well as the mean, both shifted to the left as a result. A second complementary test uses daily data over a wider time period and exploits the variation in domestic interest rates to show that CIP deviations fall with reductions in the ceiling. Additionally, we exploit the spikes in CIP at the end of the quarter that have happened since the start of 2016 (Du, Tepper and Verdelhan, 2018). These spikes are consistent with the binding collateral and regulatory requirements that we allow for in our theory. We show that the timing of the spikes and their persistence provides a third test of the ceiling prediction. Namely, the ceiling is typically broken only on the days where there is no swap line operation. At quarter-ends, the period where CIP deviations spike is precisely bracketed in the window between swap line operations. On the day when the final operation before quarter-end is settled, and so the ceiling should bind, CIP violations fall sharply.

Then, we turn to the economic effects of the swap lines. We embed our partial-equilibrium model of financial markets into a general-equilibrium model of global banks that finance investment subject to cross-border funding shocks. The model predicts that the swap line reduces funding risk. A fall in the swap-line rate increases investment by recipient-country banks in source-country currency-denominated assets.

We test this prediction on a new dataset of net purchases of corporate bonds transacted in Europe. Our identification strategy relies on a change in the dollar swap-line rate, which should have an effect on the choices of financial institutions under the jurisdiction of a central bank with access to these swap lines and on USD denominated corporate bonds, relative to banks not covered and to non-dollar bonds. We adopt a triple-difference strategy, over the time of the swap rate changed, over banks covered by the swap line and those that are not, and between USD investments and bonds denominated in other currencies. This allows us to control for bond specific factors, like shocks to the issuer's credit worthiness, and to identify shifts in preferences among banks for bonds of different denominations. We find strong evidence that an increase in the generosity of the swap line induces banks to increase their portfolio flows into USD-denominated corporate bonds. Beyond the study of swap lines, these estimated large effects of liquidity policies on investment choices are of independent interest.

A follow-up difference-in-difference strategy shows that these portfolio shifts led to an increase in the price of the USD corporate bonds held by European financial institutions relative to other dollar bonds. This is consistent with the swap line providing lending of last resort that prevents large price drops in the origin-country asset markets.

A final triple-difference strategy finds that, around the date where the swap-line terms became more generous, banks outside the United States with access to a central bank with a swap line that also had significant exposure to the United States, experienced excess returns. This is consistent with their funding risk being lower. This final result, though, is statistically weaker than the

previous ones.

All combined, we find that the lender of last resort works in the direction predicted by theory. Moreover, our estimates support an important role for the swap lines in the global economy: (i) they perform the function of liquidity provision and lender of last resort with a particular form of cooperation between different central banks; (ii) they have significant effects on exchange-rate markets, especially on the price of forward contracts; (iii) they incentivize cross-border gross capital flows and they potentially avoid crises in source-country financial prices and in recipient-country financial institutions.

Relative to the literature, our model and results point to the need to incorporate global banks and multiple central banks into models of liquidity shocks in the tradition of Holmström and Tirole (2011) and Poole (1968), or more recently as in Bianchi and Bigio (2018), Piazzesi and Schneider (2018), or de Fiore, Hoerova and Uhlig (2018). Empirically, our strategy relies on high-frequency transactions in financial markets and the associated prices to identify causal effects, similar to the large macroeconomic literature that in the past decade has studied the effect of conventional and unconventional monetary policies (e.g., Gertler and Karadi, 2015).

Ivashina, Scharfstein and Stein (2015) show that, during the Euro-crisis, U.S. money market funds lent less to European banks. In turn, European banks participated less in USD syndicated loans. Their finding complements ours that cross-border and currency funding matters for the macroeconomy and that deviations from CIP are a measure of these funding difficulties. But, while their focus was on syndicated lending, our focus is on purchases of corporate bonds in secondary markets. This is by design: the syndication process occurs over a time period, and it takes several weeks to even assemble the syndicate. At lower frequencies, the intensifying crisis in Europe, and corresponding policy interventions by the ECB, make it impossible to isolate the effect of the swap line alone. By using high-frequency transactions in financial markets, we eliminate these confounders. Moreover, focusing on corporate bonds as opposed to syndicated loans is arguably more relevant for the European banks that dominate our sample. In 2017, European banks held on average on their balance sheets debt securities issued by foreigners or domestic non-bank corporates of 39% of their total loans to the global corporate sector, whereas the equivalent percentage for syndicated loans is 9%.[4] We also differ from Ivashina, Scharfstein and Stein (2015) by studying a policy tool that can affect cross-border funding and by linking outcomes in markets for currency, corporate borrowing, and bank stock prices.

Over the past decade, a growing literature documented deviations from CIP (Du, Tepper and Verdelhan, 2018) and proposed explanations for them, tied to capital regulation (Borio et al., 2016; Avdjiev et al., 2018; Cenedese, Corte and Wang, 2019) or to debt overhang and the cost of unsecured funding (Andersen, Duffie and Song, 2019; Rime, Schrimpf and Syrstad, 2019), and studied how some policies affect them (Natraj, 2019). Our model of financial frictions in forward

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[4]Sources: ECB Statistical Bulletin, MFI Balance Sheets, tables 2.4.1, 2.4.3 (loans) and 2.6.1 (debt securities). Syndicated loan volumes, ECD SDW series BSI.M.U2.N.A.A20S.A.1.U2.2240.Z01.E

contracts builds on this work to generate CIP deviations in equilibrium. We add the result that central bank swap lines put a ceiling on CIP deviations, and show theoretically and empirically how this affects the average size and distribution of both market prices and contract quotes. Moreover, we link these deviations to funding and investment choices with macroeconomic consequences.

On central bank swap lines, Baba and Packer (2009) document a partial correlation between the quantity of dollars lent out under the swap lines and one particular measure of CIP deviations. Instead, we provide a concrete explanation of how the swap lines work, a theory that tightly links the swap line rates and one specific mesure of CIP deviations, identification strategies to identify causal effects, theory to link swap line and funding and investment decisions, and a test of this link with novel data on investment choices, bond prices, and equity returns. Finally, an older literature studied central bank swap lines with developing countries that were employed to peg their currencies to the dollar (see Obstfeld, Shambaugh and Taylor, 2009, for a recent example). The arrangements we study are instead between floaters, all of which are large, advanced economies.

2 Role in central banking: how the swap lines work

We start by describing the features of the dollar swap lines between the Federal Reserve and other central banks. These accounted for the bulk of activity during and after the financial crisis, and it helps to focus on them for concreteness. Then, we discuss their place in the central bank toolkit.

2.1 The swap-line contract

The typical properties of a dollar swap line are as follows: the Fed gives dollars to another central bank and receives an equivalent amount of their currency at today's spot exchange rate. At the same time, the two central banks agree that, after a certain period of time (typically one week or one month), they will re-sell to each other their respective currencies, at the same spot exchange rate that the initial exchange took place at. The Fed charges an interest rate that is set today as a spread relative to the USD overnight index swap (OIS) rate, paid at the fixed term, and settled in USD.[5] This is a pre-approved lending program, so that the recipient central bank can ask for any amount from the Fed at the announced interest rate, although each request is individually approved by the Fed.

The recipient central bank then lends the dollars out to financial institutions in its jurisdiction for the same period of time, charging the same rate that the Fed charges it. It asks for the same high-quality liquid assets as collateral that it asks for in other liquidity facilities. The recipient central bank is in charge of collecting payment, and if the financial institutions default, then it either buys dollars in the market to honor the swap line or, if it misses payment, it loses the

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[5]An OIS is an interest rate swap agreement whereby one can swap the overnight interest rate that varies over a period for a fixed interest rate during that period.

currency that was being held at the Fed.

From the perspective of the Fed, the end result is a loan of dollars to foreign banks. From the perspective of these banks, the collateral requirements and the terms of the loan are similar to credit from their central banks through domestic lending facilities. What is novel is the presence of the recipient central bank doing the monitoring, picking the collateral, and enforcing repayment.

2.2 Monetary policy implications and risks

After a drawing of the swap line, the currency in circulation of the source country increases. Because this meets an increase in demand for that currency by the recipient-country banks, in principle it is consistent with the control of inflation. Moreover, the swap-line rate is set as a spread over the short-term interest rate used for inflation control, so when the latter moves, so does the swap-line rate, again with no direct implications for source-country inflation. On the side of the recipient central bank, its currency never enters in circulation, being held and returned by the source central bank, and none of its policy rates change, so there is no direct effect on inflation.

In terms of the risks borne by each central bank, for both there is no exchange rate risk or interest rate risk, as the terms are set when the contract is signed. For the source central bank, there is negligible credit risk since it is solely dealing with the recipient central bank, with its reputation at stake. For the recipient central bank, there is credit risk, similar to that in any other liquidity facility to its banks. The recipient central bank makes no profits from the operation since it pays the source central bank what it receives, while the source central bank profits insofar as it charges a spread over the rate on reserves.

As important as what they do and what risks they entail, is what the swap lines are not. First, they are not direct exchange rate interventions. Central bank swap lines have been used in the past, especially during the Bretton Woods regime, as a way to obtain the foreign currency in order to sustain a peg.[6] Yet, with the current advanced-economics swap lines, the source-country currency is not used right away to buy recipient-country currency and affect its price. Rather, the source-country currency is lent out to banks that could instead have borrowed from the recipient central bank in its currency. The large bulk of dollars lent out by the Fed went to the ECB, the Bank of England, and the Bank of Japan (see figure 1), all of which did not have explicit targets or policies for intervening in the value of their currency vis-a-vis the dollar.

Second, the swap lines are not a response to current account imbalances in the way that IMF loans are. They are a short-term liquidity program that emerged because of the expansion of global banks with large gross positions in the source-country assets, usually funded in source-currency. The swap line funding replaces private funding, with little effect on net positions, and it is reverted in a short period of time, with no policy conditionality.

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[6]The Fed operated a reciprocal swap system from 1962-1998. This was partly motivated by the desire to maintain fixed exchange rates. However, this historical arrangement was also used to resolve liquidity shortages in offshore dollar markets (McCauley and Schenk, 2019).

Third, the swap lines do not lead the recipient central bank to absorb exchange-rate risk or bad foreign assets from its banks. The recipient central bank has only credit risk, as in any lender of last resort operation, and can apply its standard criteria for eligible collateral. The banks under its jurisdiction have their funding needs met, not their risk nationalized.

Finally, the swap line is not a subsidy from the source central bank to foreigners. It is a liquidity program where, so long as the interest rate charged is the same as that charged in domestic lending facilities, all banks, domestic or foreign, face similar terms. Insofar as the source central bank is charging a spread over the overnight rate, but the recipient central bank bears the credit risk, then the source central bank is actually receiving a transfer from foreigners in risk-adjusted terms.

2.3   The division of tasks and alternatives

With a swap line, the source central bank provides liquidity in response to a funding crisis, while the recipient central bank judges which banks are eligible for the assistance. This division of tasks and risks arises because this liquidity operation involves the source-country monetary base, but the banks that are borrowing are regulated by the recipient central bank, which should have superior information on their solvency, the quality of their collateral, and the potential for moral hazard in ex ante bank risk-taking.

There are three alternatives to the swap lines that under efficient financial markets would be equivalent: foreign banks borrowing directly from the Fed, foreign central banks borrowing dollars in private markets, and foreign banks borrowing domestic currency from their central banks and converting them into dollars. Different financial frictions account for their difference and justify why the swap lines were not perfect substitutes with existing arrangements and so had an impact.

First, with respect to borrowing directly from the Fed, most major foreign banks have a U.S. branch or subsidiary, so they could go to the discount window. If information about the financial health of the borrowing bank was public, and there were no constraints in enforcing contracts and seizing collateral, these two programs might be equivalent. However, in the case of the swap line, because the Fed is officially lending to the recipient central bank, there are no mandatory disclosure procedures when it comes to which foreign banks receive the currency. Thus, the stigma that has been associated with the discount window does not apply, since the recipient central bank can keep the anonymity of the borrower for a longer period of time. Even today, the ECB does not make public the identity of the financial institutions that borrowed dollars from it. Moreover, the amounts lent were very large relative to the size of the U.S. branches or subsidiaries of foreign banks.[7] Given the Fed's limited monitoring ability over foreign banks outside its jurisdiction, the swap lines allow the use of the recipient central bank's monitoring and selection on the financial health of the borrower. Finally, the recipient bank's assets in the source country were often held

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[7]For example, in 2008Q3 the total assets of foreign banking offices in the US were \$1169bn (U.S. Flow of Funds, table L.111), compared to the peak swap line drawing a few weeks later of \$586bn.

at the level of the recipient's parent. Hence, the required funding needs were large relative to the branch/subsidiary's balance sheet and would require collateral transfers from the parent, which recipient-country regulators might be uneasy with.[8]

The second alternative would be for the recipient central bank to borrow dollars in private markets, and then lend them out to its banks. A similar swap contract could be written with private lenders as it was with the Fed. However, these private institutions are reluctant to serve as intermediaries in a crisis (Avdjiev et al., 2018). The financial frictions that make financial institutions raise the price charged for hedging exchange-rate fluctuations to private clients likely apply to central banks as well. Two further properties of central bank swap lines are that they automatically increase the dollars in circulation, thus accommodating the increase in demand, and (more speculatively) the recipient central bank may be less likely to default on the origin central bank than on private financial intermediaries.

A third and final alternative is for recipient-country banks to get their own currency from the recipient central bank, and swap them into source-country currency using a derivatives contract removing the exchange-rate risk. Even at the height of the financial crisis, the foreign exchange market for dollars never closed. The seller of dollars in the spot market will be a U.S. institution that can in turn obtain them from the Fed's domestic lending facilities. Usually this option is available, which perhaps explains why swap lines had little role to play in the decade prior to 2007. But this private operation has a cost, which the next section expands on.

3 The financial market effects of the swap lines

Having established that the swap lines are a foreign-oriented central bank lending program, we now show how this monetary policy tool transmits through financial markets onto a key asset return.

3.1 Theory: the CIP ceiling on market prices

Consider the following trade: a recipient-country bank borrows foreign currency from its central bank through the swap line that it must pay back with interest at rate i_t^s, at the end of the fixed term. The bank then buys its domestic currency with this foreign currency at today's spot rate s_t, while it signs a forward contract to exchange back domestic for foreign currency at a locked exchange rate of f_t for the same duration as the swap line. It deposits this domestic currency at

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[8]In regular times, with smaller shocks, global banks use internal capital markets for funding, as documented by Cetorelli and Goldberg (2012). However, when it comes to emergency funding after large shocks, the swap lines are preferred to the discount window. An alternative was the Term Auction Facility (TAF), which ran from December 2007 to March 2010, allowing many foreign banks to get dollars from the Fed directly, albeit a smaller set of banks than the ones that have access to their own-country swap line and subject to a narrower set of accepted collateral. Unlike the swap line, the TAF kept the credit risk and the need for monitoring at the Fed.

its central bank's deposit facility, earning the interest on reserves i_t^{v*}.[9] Because reserves are usually overnight, while the swap-line loan is for a fixed term, the bank buys an OIS contract that converts the interest on reserves into a fixed rate for the fixed term in order to match the maturity of the funding and the investment. This costs $i_t^* - i_t^{p*}$, where i_t^* is the OIS rate for this fixed term, while i_t^{p*} is the reference rate for the OIS contract, which is usually an overnight interbank rate very close to the policy target of the central bank. Because all the lending and borrowing involves the recipient central bank, this trade involves no risk beyond: (i) the negligible counterparty risk in the forward and swap contracts, and (ii) the risk of movements in the spread between i_t^{p*} and i_t^{v*}, which rarely changes, and typically only at some policy meetings. While the OIS rate is used, there is no direct lending or borrowing between banks in this trade.

The principle of no arbitrage opportunities implies that, in logs of gross returns:

$$i_t^s \geq s_t - f_t + (i_t^{v*} + i_t^* - i_t^{p*}). \tag{1}$$

In turn, the deviations from covered interest parity (CIP) are given by:

$$x_t = s_t - f_t + i_t^* - i_t. \tag{2}$$

If CIP holds, then $x_t = 0$. The negative of x_t is sometimes called the cross-currency basis. Combining the two expressions gives the result:

Proposition 1. *Deviations from covered interest parity (x_t) have a ceiling given by the spread between the source swap and interbank rates plus the difference between the recipient central bank policy and deposit rates:*

$$x_t \leq (i_t^s - i_t) + (i_t^{p*} - i_t^{v*}). \tag{3}$$

It is well known that a standard central bank domestic lending rate puts a ceiling on the interbank rate. Otherwise, there would be an arbitrage opportunity whereby banks could borrow from the central bank and lend in the interbank market making an arbitrage profit. The proposition follows from the same no-arbitrage logic. The proposition is precise in the sense of indicating the right measures of i_t and i_t^* to calculate the relevant CIP deviation: they are the OIS rates at the relevant maturity as these both match the pricing of the swap line and the cost of hedging the interest rate risk at the deposit facility.[10]

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[9]For concreteness, take the term to be one week since this is the duration of the most-used swap lines that we will focus on in the empirical work. Note that when we refer to overnight interest rates, like the interest on reserves or the policy rate, these are more accurately risk-neutral expectations of these rates over the week. Since policy rates are changed infrequently at policy meetings, in most weeks the risk-neutral expectation and the actual rate are the same.

[10]Du, Tepper and Verdelhan (2018) find that different measures of safe rates lead to very different estimates for x_t. This does not undermine our result: letting x_t^{libor} be the LIBOR CIP deviations, the result in the proposition becomes: $x_t^{libor} \leq (i_t^s - i_t) + (i_t^{p*} - i_t^{v*}) + (i_t - i_t^{libor}) - (i_t^* - i_t^{libor*})$, again a precise ceiling.

If CIP holds, the ceiling will never bind, as both terms on the right-hand side of the equation in the proposition are non-negative. Up until 2007, CIP deviations rarely exceeded 0.1% for more than a few days. Forward markets worked well and there was little need for a central bank swap line, perhaps explaining why there was no such policy facility. However, following the collapse of Lehman Brothers, there was a large spike in x_t that persisted. This created the need for a ceiling as banks have found it expensive to respond to funding shocks in other currencies.

3.2 Theory: the CIP distribution of price quotes

A virtue of proposition 1 is that it holds no matter what gives rise to CIP deviations. A vice is that it refers to a single CIP deviation market-price per period, when in fact the FX market for forwards works over the counter so at any date there is a distribution of transaction prices for a distribution of lenders and borrowers. This section introduces a simple model of the market for foreign exchange swap contracts that captures the two leading theories for why CIP stopped holding after 2007. Perhaps unsurprisingly, the ceiling result applies to either of them. More interesting, the focus of the model on swap transactions between different counterparties provides results on the whole distribution of CIP deviations and so allows for sharper empirical predictions.

Consider a world in which there is one representative intermediary quoting prices $s_t - f_t$ for a swap contract that converts funding between recipient currency and source currency. This intermediary is composed of many atomistic risk-neutral traders, each of whom gets matched in an over-the-counter market with a bank that needs to convert funding between currencies. In a frictionless market, an individual trader would be able to supply one unit of protection by borrowing source-currency at the secured rate i_t, sell the swap contract at rate $s_t - f_t$, and deposit the resultant recipient-currency at zero risk in a frictionless reserves market at the deposit rate i^{v*}. As long as: $i_t^{v*} + s_t - f_t - i_t \geq 0$, the trader would find it profitable to supply the swap. Free entry and zero profits by traders would imply that in a frictionless equilibrium $x_t = i_t^{p*} - i_t^{v*}$. With a satiated market for reserves, this difference in interest rates is by definition zero, so CIP would hold.

We assume that the traders face two frictions. These apply at the intermediary level and, hence, the atomistic traders take them as given. First, following Gârleanu and Pedersen (2011), assume that a fraction m of the operation must be financed with the intermediary's own-equity. This margin requirement is commonly enforced by the counterparties in these markets. An alternative justification, following the evidence in Du, Tepper and Verdelhan (2018), is that this is a binding leverage requirement imposed by regulators. Either way, the cost of own-equity is $i_t + \Delta_t^e$, higher than the secured funding rate by a spread Δ_t^e. Second, following Andersen, Duffie and Song (2019), assume that a fraction of the amount borrowed to produce the swap must use unsecured funds, because of a haircut with a cash ratio of ζ. Therefore, the trader must make a funding value adjustment of $(1 - \zeta)\Delta_t^u$ to account for the spread the intermediary must pay for unsecured borrowing Δ_t^u. These two frictions—capital requirement and margins, together with funding value

adjustments—are the two leading theories put forward to explain CIP deviations.

The profit per unit of operation to the trade would now be:

$$i_t^{v*}+s_t-f_t-m(i_t+\Delta_t^e)-(1-m)[\zeta i_t+(1-\zeta)(i_t+\Delta_t^u)] = x_t-(i_t^{p*}-i_t^{v*})-m\Delta_t^e-(1-m)(1-\xi)\Delta_t^u, \quad (4)$$

where the equality follows from the definition of x_t in equation (2). Let $h_t \equiv m\Delta_t^e+(1-m)(1-\zeta)\Delta_t^u$ denote the extra cost to traders relative to the frictionless benchmark. Perfect competition by traders would now drive the CIP deviation relative to the frictionless case to h_t.

The literature focusing on these financial frictions predicts that the two spreads, Δ_t^e and Δ_t^u, are each increasing in the volume of trading in swap contracts V_t. Therefore, $h_t = h(V_t)$ is an increasing function, for two separate reasons. First, if there is an alternative use of own-equity that has decreasing returns to scale, then the intermediary will require of its traders a Δ_t^e that is rising in V_t (Gârleanu and Pedersen, 2011). Second, if the intermediary has assets net of secured borrowing, A_t, unsecured borrowing L_t, a probability of default θ_t, which for simplicity is independent from the activity of its swap traders, and in case of default only a share κ gets recovered by the creditors, then *pari passu* rules on unsecured creditors imply that under risk-neutrality they would charge: $\Delta_t^u = \theta_t[L_t+V_t(1-m)(1-\zeta_t)-\kappa(A_t+V_t(1-m)(1-\zeta_t)]/[L_t+V_t(1-m)(1-\zeta_t)]$ (Andersen, Duffie and Song, 2019). For a fixed margin, this is again increasing in V_t.

Because the forward market is over-the-counter, we assume that each trader gets matched with a bank every period, and they bargain over the terms of the forward contract. Indexing an individual bank by a, its Nash bargaining weight is δ_a, and in the population of banks there is a distribution function $F(\delta_a)$ with $\mathbb{E}_a(\delta) = \bar{\delta}$. Each bank's outside option is, of course, to go to the central bank swap line, paying i^s for funding as opposed to $i_t + (i_t^{p*} - i_t^{v*}) + h_t$. The outcome of the bargain is therefore that the bank negotiates a forward price with the trader such that its associated bank-specific CIP deviation $x_{a,t}$ is:[11]

$$x_{a,t} = (i_t^{p*} - i_t^{v*}) + \delta_a h_t + (1 - \delta_a)(i_t^s - i_t). \quad (5)$$

If banks have all the bargaining power, then traders' profits are driven to zero, and the CIP deviation is h_t, driven by the need for margins and unsecured funding in the intermediary's operations. If traders have all the bargaining power, then the CIP ceiling in proposition 1 binds. In between, different bargaining powers across banks lead to a distribution of CIP quotes $F(x_{a,t})$.

Equilibrium in the market for exchange-rate derivatives is affected by the central bank swap lines as follows:

Proposition 2. *A decrease in the policy choice $(i_t^s - i_t) + (i_t^{p*} - i_t^{v*})$ leads to:*

i. A lower ceiling in the distribution of bank-specific CIP quotes, since $F(i_t^s - i_t + i_t^{p*} - i_t^{v*}) = 1$.

---

[11]Of course, $h_t \leq i_t^s - i_t$, otherwise equilibrium in the market for forward contracts would have zero traders, and all borrowing would happen through the swap line.

ii. A lower mean of the distribution of CIP deviations: $\mathbb{E}_a(x_{a,t}) = i_t^{p*} - i_t^{v*} + \bar{\delta}h_t + (1 - \bar{\delta})(i_t^s - i_t)$.

Proposition 2 turns the ceiling result in proposition 1 into empirical predictions on the CIP distribution arising from quotes in the swap market. It predicts that reducing the central bank swap line truncates the distribution rightwards, and shifts its mean to the left. The two interest-rate spreads in the two parentheses are chosen by policy and have different sources of variation. The first interest-rate spread is exogenously set by the source central bank. The second interest-rate difference is instead set by the recipient central bank. It is zero if the central bank is running a floor system, where the market for reserves is satiated so the opportunity cost of holding them is zero, and it is positive otherwise.[12] The empirical work exploits these two potentially independent sources of variation to test the proposition.

3.3 Theory: collateral and regulation

The two propositions so far ignored bank regulation and the collateral involved in using the swap line. We now discuss their role, because they make predictions on when the ceiling might be broken, that we can later take to the data.

The loans to banks from the central bank through the swap line are secured and a haircut applies to the collateral. Letting ξ^c denote the cash coefficient applied to the collateral offered by the bank, the cost of borrowing from the central bank is $\xi^c i_t^s + (1 - \xi^c)i_{a,t}^u$ where $i_{a,t}^u$ is the unsecured financing rate in dollars facing bank a; if $\xi^c = 1$, then we recover the analysis in the proposition. Alternatively, the bank could get dollars in the private market, at a different rate and potentially different collateral requirements. Letting that alternative contract have rate and cash coefficient (i_t^o, ξ^o) then, in the propositions, the i_t^s term would be replaced by $\min\{\xi^c i_t^s + (1 - \xi^c)i_{a,t}^u, \xi^o i_{a,t}^o + (1 - \xi^o)i_{a,t}^u\}$. There is still a ceiling, and similar considerations apply as we discussed above, but the effect of the swap rate on CIP deviations is now potentially non-linear (but still monotonic) across banks. Moreover, there are extra predictions regarding the shifting of collateral between the central bank and markets.

Our focus is the period after the financial crisis, during a time when foreign banks had shifted their dollar funding from the U.S. money markets to instead getting synthetic dollars by swapping recipient-country currency funding into dollars. This implies that, during our sample period, the alternative to the swap line was to borrow recipient-country currency from the central bank at the local secured rate $(i_t^{p*} \approx i_t^*)$ and buy forward contracts, resulting in the funding cost: $i_t^o = i_t + x_{a,t}$. Moreover, the collateral requirements for borrowing from the central bank either domestic currency

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[12]Strictly speaking, i_t^{p*} is the overnight interbank rate used as the reference for the OIS contracts, but this is often the target of central bank policy. Importantly, whenever the central bank policy rate moves, which is the source of variation we will empirically use in one of our tests, the overnight interbank rate moves monotonically (and almost exactly by the same amount). Finally, there may be an interest-rate risk premium associated with the gap between overnight LIBOR and in the interest on reserves, but this is both tiny and likely close to orthogonal to the sources of variation that we use.

or foreign currency through the swap lines were very similar, so $\xi^c \approx \xi^o$.[13] Thus, if the alternative source of funding is also the recipient-country central bank, but in recipient-country currency that is turned into synthetic dollars, banks would choose to not borrow from the swap line as long as $x_{a,t} \leq i_t^s - i_t$. This is, of course, consistent with our ceiling result.

Turning to regulation, deposits at the central bank have a zero risk weight in capital adequacy calculations and, in some jurisdictions, do not count towards leverage ratio requirements. The Basel III leverage ratio requirements that became binding at different dates starting in 2016, the use of FX derivatives, and the evaluation of stress tests, may result in the trade that we describe requiring partial funding with capital. In this case, using the swap line would add an extra cost term, say $\psi_{a,t}$, which is bank-specific depending on the shadow value of relaxing the relevant regulatory capital constraint. There is still a ceiling, and lowering the swap-line rate still tightens it, but there is an extra term capturing the cost of capital.

Combining the different arguments in this discussion, a revised proposition that takes into account both collateral and capital regulation is (the proof is in the appendix):

Proposition 3. *Bank-specific deviations from covered interest parity ($x_{a,t}$) have a ceiling given by the spread between the source swap and interbank rates, plus the difference between the recipient central bank policy and deposit rates, plus the shadow value of collateral, plus the shadow cost of regulation on banks that is triggered by borrowing and lending from their central bank:*

$$x_{a,t} \leq (i_t^s - i_t) + (i_t^{p*} - i_t^{v*}) + (1 - \xi^c)(i_{a,t}^u - i_t^s) + \psi_{a,t}. \tag{6}$$

Collateral and regulation considerations add a third possible source of variation to the ceiling on bank quotes, one that is bank-specific. Note that some large investors, notably the safest banks, will have enough safe assets that their unsecured and secured funding rates are the same, so $i_{a,t}^u = i_t^o$. Likewise, for banks in at least some jurisdictions, there are no regulations involved in borrowing and lending from the central bank, so for them $\psi_{a,t} = 0$. Thus, for these banks, the market ceiling will be $x_{a,t} \leq (i_t^s - i_t) + (1/\xi^c)(i_t^{p*} - i_t^{v*})$, which reduces to proposition 1, as expected, when $\xi^c = 1$.

Brought together, propositions 1-3 also show the extent to which our ceiling results are loose or tight. The trade under which we derived them have minimal interest-rate and counterparty risk and no differential collateral requirements. Across propositions, the tightest ceiling is $x_t \leq i_t^s - i_t$, which would bind if the central bank runs a floor system and the marginal bank can freely borrow and deposit at the central bank. Exogenous variation in $i_t^s - i_t$ will be the focus of most of our empirical work.

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[13]All central banks have the same collateral eligibility criteria between domestic and foreign currency operations. The haircuts are also the same for the SNB and for the ECB at one-week maturity; the ECB charges an additional haircut on non-USD denominated collateral for the longer-dated swap line loans. The BoE and BoJ charge an extra haircut on non-USD denominated collateral used to borrow from the swap line.

3.4 Data

Maintaining our focus on USD swap lines, our sample starts on 19th of September 2008 when swap lines were put in place between dollars and British pounds, Canadian dollars, European euros, Japanese yen, and Swiss francs to form the nucleus of what became the current multilateral swap-line network.[14] We complement data on these swap-line network currencies with a series of currencies for which swap lines lapsed after 2009: Australian dollar, Danish krone, New Zealand dollar, Norwegian krone, and Swedish krona.

The five central banks within the swap line network with the Fed have carried out regular USD operations from September 2008 until present day (with a short gap between February 1st and May 9th 2010 when the swap agreement lapsed). Exactly how the recipient central banks go about lending the dollars to their banking sector has evolved over the sample. As currently implemented, the swap line funds weekly dollar operations providing loans of one-week maturity to the recipient banking sector at the terms described in the previous section. There is coordination on the timing of each operation. The ECB, the Bank of England and the SNB carry out a one-week dollar operation every week at the same time, typically bids are taken on Wednesday morning and the operation is settled on Thursday. The bids for the Bank of Japan's operation are typically taken one day before but settled on the same day as the European operations, although this timetable can vary due to differences in holidays and other local factors.[15] The Bank of Canada has full access to the swap line but does not conduct regular USD operations, consistent with our theory, since CAD-USD CIP deviations are relatively small.[16]

However, when the swap line first became available, the dollar operations were more ad hoc. The operations were not necessarily synchronized across central banks and there were operations at other maturities beyond one week: for instance, at certain points, operations at a three month maturity also occurred at a monthly frequency (these were discontinued in 2014). For the purpose of our empirical analysis, we will focus on one-week maturities as these operations were the most commonly tapped, they were conducted throughout our sample, and were what the central banks in the network finally settled and coordinated on after a few years experimenting. Moreover, a one-week maturity has the closest parallel to other central bank lending facilities.

Correspondingly, the correct CIP deviation for our purposes is for one week. We build $x_{j,t}$ for currency j using the one-week forward rate or swap rate to measure $f_{j,t}$. Like most of the literature on CIP, we use data from Datastream, which reports daily forward and spot exchange rates. These

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[14]Our results are robust to starting on the 13th October 2008 when the swap line drawings became full allotment, fixed rate operations. There were dollar swap lines in place with the ECB and the SNB starting on the 12th December 2007, but for limited amounts ($20bn and $4bn, respectively) and, in the case of the ECB, there was no volume in weekly operations until September of 2008.

[15]The Bank of Japan prefers a two-day settlement cycle for an operational reason, to make sure there is always sufficient time for communication between central banks during working hours given the time difference.

[16]See Terajima, Vikstedt and Witmer (2010) for a discussion of the Canadian context. One explanation provided for lower CIP deviations is the presence of a stable USD deposit base in Canada.

Figure 2: CIP deviations and the swap line ceiling
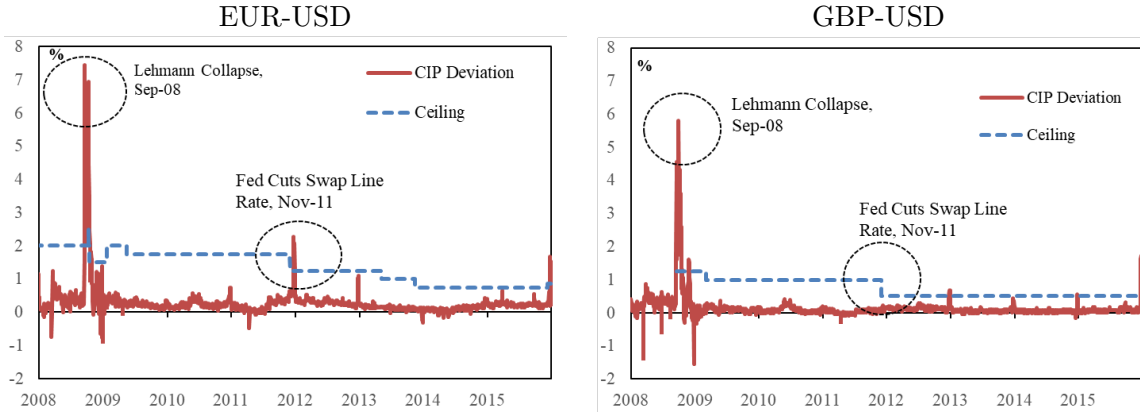
can be seen as draws from the distribution of quotes, probably with some reporting bias towards the mean of the distribution. We complement these data in what follows with OIS one-week rates to compute the CIP deviations based on the argument in the previous section that these replicate our no-arbitrage trade. The exception is in section 3.6 when we consider currencies outside the swap network where, due to data limitations, we rely on LIBOR rates for all currencies (see appendix C.1 for details of all data used in this section).

Figure 2 plots the one-week OIS euro-dollar and sterling-dollar CIP deviations together with the ceiling stated in proposition 1 until the end of 2015 (see appendix B.1 for other currencies). The period from 2015 onwards will be separately studied in section 3.8. The shock to the CIP deviations from the Lehman failure in September of 2008 is clearly visible, as well as the persistent deviations over the sample period. The ceiling has held well, with only exceptions around year end in 2011 for euro-dollar and in year end 2012 and 2014 in sterling-dollar.[17] The time-series variation in the ceiling for the sterling-dollar since March 2009 is all driven by the gap $i_t^s - i_t$, because the Bank of England operated a floor system. The ceiling was 100 basis points between September 2008 and November 2011, and 50 basis points afterwards. In the case of the ECB, the gap $i_{j,t}^{p*} - i_{j,t}^{v*}$, which is the difference between the short-term repo policy rate and the deposit facility rate, has had some time-series variation due to relative movements in the deposit facility and main policy rates. Among the control group, Denmark provides auxiliary evidence for the ceiling. The Danish krone has a stable exchange rate peg to the euro but the Danmarks Nationalbank's swap line with the Federal Reserve lapsed on October 30, 2009. Without it, one-week DKK-USD CIP deviations exceeded the counterfactual ceiling on 23 trading days through to the end of 2015, excluding year-end periods.

A second source of data, matching the discussion in sections 3.2 and 3.3, measures bank-specific

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[17]These year-end deviations do not reject the presence of a ceiling, because both the ECB and the Bank of England suspend their one-week operations for one week at the end of the year. More on this in section 3.8

CIP deviations, $x_{a,t}$. These more granular data are created from tick data on the quotes of foreign exchange swap contracts. Similar to Cenedese, Corte and Wang (2019), we collect the quoted price of every one-week FX swap versus the USD contained within Refinitiv Datascope for the 10 currencies in our sample, and calculate an implicit CIP deviation using the spot exchange rate in the minute of the quote and the relevant daily interest rate fixings. This provides over 1.7 million observations across November 2011 through January 2012.

3.5 An identification strategy

On November 30, 2011, the Fed unexpectedly announced that, for swap line operations from December 5th onwards, it would lower $i_t^s - i_t$ from 1% to 0.5% in the swap line contracts it has with the Bank of Canada, Bank of England, Bank of Japan, European Central Bank, and the Swiss National Bank. The minutes of the meeting (FOMC, 2011) reveal that the motivation for the change was to normalize the operations of the swap line and to eliminate stigma that became associated with the previously high rate. There were long-standing concerns with dollar funding in international money markets, and a deepening sovereign crisis in the Euro-area, leading to growing funding difficulties of foreign banks. The swap line rate change was, like almost every policy change, endogenous with respect to these long-standing concerns.

Crucially for identification though, the change appears to have been *exogenous with respect to the behavior of one-week CIP deviations in the week or month before.* The minutes of the meeting have no mention of the one-week currency basis. The timing of the change as discussed in the minutes seems rather to have been determined by the outcome of lengthy discussions with foreign central banks. The change affected all central banks that had established swap line arrangements with the Federal Reserve, despite the fact that negotiations and concerns were focused on the Euro-area in the treated group and the Nordic counties in the control group.

Moreover, the size of the change seems to have been partly random. The minutes show a serious discussion on whether to set the new rate at 0.75%, with the choice for 0.5% driven by a previous agreement with foreign central bankers, in spite of reservations raised by some Fed governors. Judging by news reports in the Financial Times, this change came as a surprise to markets, so there is little anticipation effect.

Lastly, our measures of $x_{j,t}$ while elevated for some currencies, were not on a particular trend (see figure 10 in the appendix): for instance, one-week EUR CIP deviations had held in a similar range since September, despite the worsening of the crisis. That said, there is quite a bit of heterogeneity in $x_{i,t}$ both through time and across currencies (see table A7 in the appendix). Some currencies have positive deviations while others have negative. Likewise, the underlying interest differentials are of differing signs. Some currencies are European and possibly more affected by the crisis, while others are not. Given the limited number of currencies in our sample, in our baseline we combine them together. This maximizes statistical power. However, we will also consider different

subsamples, which helps determine what factors are driving our results.

In conclusion, the size and timing of the change in the swap line rate was exogenous with respect to the CIP deviations in the few weeks before, validating the exclusion restriction in a difference-in-difference empirical strategy that compares CIP deviations before and after the date of the change, for treated and control currencies. Across all three propositions, the ceiling falls.[18] Even though there are only 5 currencies in each group, there are thousands of observations per day on price quotes $(x_{a,t})$, with which to test propositions 2 and 3. We combine them into one week of data, comparing the pre-announcement week of 23-29 November, with the week after the first operations in USD at the new rate had taken place, that is 8-13 December. There are no significant *common* policy changes by all central banks in either the treatment or control groups during this time.[19]

An alternative is to use instead the daily data for CIP deviations, that is more commonly used in the literature. In this case, a one-week window is not enough, since there are only 10 observations of $x_{j,t}$ per day. We instead build a window of one month before and after December (so January versus November). One virtue of this wider window is that it allows us to test whether swap line rate change had a longer lasting effect. Moreover, CIP deviations are usually volatile around year end, so leaving the very end of December out avoids spikes potentially biasing the results.

3.6   A difference-in-differences test

Each row of figure 3 shows an implementation of our test by comparing histograms of CIP deviations before and after the policy change, for treated versus non-treated currencies. In the first row is our baseline comparison of price quotes on CIP in the week before the cut in the swap line rate and the week after the first auction under the new terms. The shift to the left of the distribution is clear, as is the effect that the reduced ceiling has in almost entirely eliminating any observations between the new and old ceiling. No such effect is visible for the non-affected currencies.[20]

The second row expands the comparison to the month of November versus the month of January in order to both provide histograms with more observations and to see whether the effects appear to be permanent as the theory suggests. This shows even more starkly that the right mass beyond the ceiling is almost entirely cut out by the swap line.

The third row shows the effect on daily data. With a single draw from the distribution of quotes per day, observations near the ceiling are rarer. Yet, it is still clearly visible that the CIP deviations

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[18]This date is well before regulations being discussed and approved that could interfere with the swap line, so the considerations on regulation discussed in the extended proposition 3 should not apply. Moreover, the reduction in the swap-line rate comes with potential higher use of the central bank facilities, which tend to have more generous treatment of collateral, thus lowering the shadow value of collateral, so the ceiling would still unambiguously fall in proposition 3.

[19]The ECB and the Danmarks Nationalbank cut rates on the 8th, and the Riksbank and Norges Bank one week later on the 15th. The ECB also announced its LTRO on December 8th. So we will also consider the robustness of the results to one week before and after ending the sample on the 7th.

[20]A few very large deviations from CIP may reflect quotes where either no trade took place or between banks that are highly collateral or capital constrained as in proposition 3.

in currencies affected become smaller on average and in variability relative to the CIP deviations for currencies which do not have a swap line or whose terms did not change.

Table 1 formally tests for this difference presenting numerical estimates and their associated standard errors. The first column uses the baseline sample, corresponding to the first row in the figure. The fall in the ceiling by 0.5% lowered the average CIP deviation price quote by 0.28 percentage points relative to currencies not covered by these swap lines. The next three rows show the effects on different percentiles of the distribution. As the theory would predict, the effect is larger the higher the percentile in the distribution. In the top decile of the distribution, the 0.5% fall in the swap-line ceiling lowered the average CIP price quote deviation by 0.59 percentage points.

The next column looks instead at the week after the announcement rather than after the policy came into effect. On the one hand, the anticipation of the change should have an effect on prices, but on the other hand without actual operations the arbitrage argument behind the propositions need not strictly hold. The estimates are as expected smaller, but still relevant.

Column (3) corresponds to panel (b) in figure 3. With the wider window, there is more variation and a possible assessment of more permanent effects. Interestingly, the point estimate on the mean is very similar. Across these first columns, the predictions of proposition 2 are confirmed.

Columns (4)-(6) explore the extent to which the treated and control groups are comparable. On December 8th, there was also a relevant policy announcement by the ECB with regards to its LTRO program. Column (4) therefore excludes the euro in case the effect of the LTRO are driving the results. With 4 treated and 5 control currencies, the estimated effects on the mean and on the 90th percentile are still large and statistically significant at the 5% level. Column (5) instead shows that the results are still present (but estimated less precisely) when we make the treatment and control groups more similar by focussing solely on currencies in Europe. Column (6) deals with both the LTRO concern and the similarity of treated and control at the same time, by looking at an even smaller sample, that includes only four currencies in Europe that had the most elevated CIP deviations prior to the announcement and were likely all affected similarly by ECB policy. The support for proposition 2 is robust.

Finally, column (7) present the regression results matching panel (c) in figure 3, using only the daily market-close CIP deviation. As these draws are not so close to the ceiling, the effect on the top decile is quantitatively only half of that on the price quotes, but it is still large and statistically significant. On average, a cut in the swap line ceiling lowers observed market CIP deviations by 0.18 percentage points.

The appendix shows that our results are robust to the following: (i) reweighing observations by currencies as we have more quotes for some currencies than for others; (ii) looking only at non-European countries; (iii) measuring CIP deviations using the interest on excess reserves at the central bank or using OIS rates and just focusing on currencies with access to the swap line; (iv) enlarging the monthly window to 2 or 3 months with daily data. Moreover, five falsification tests

Figure 3: CIP deviation histograms for treated and non-treated currencies

(a) Price quotes in 23-29 of November versus 8-13 December
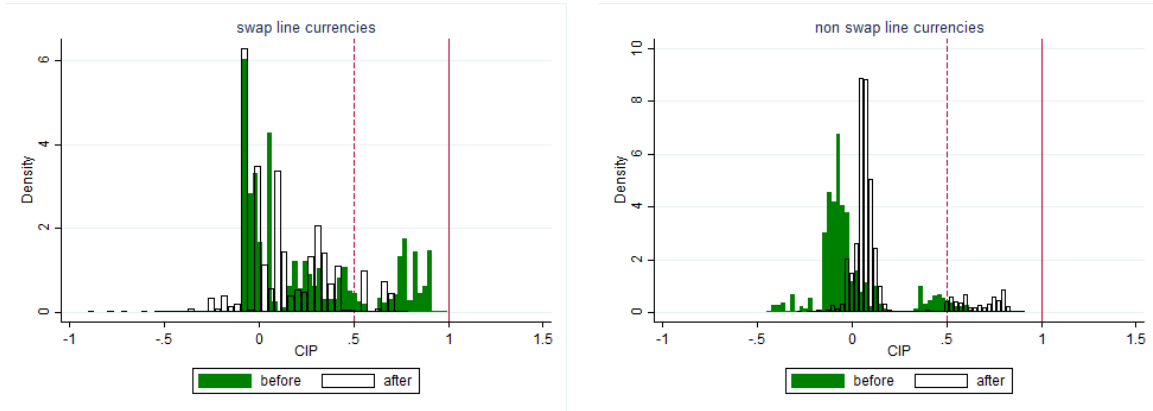
(b) Price quotes in November versus January
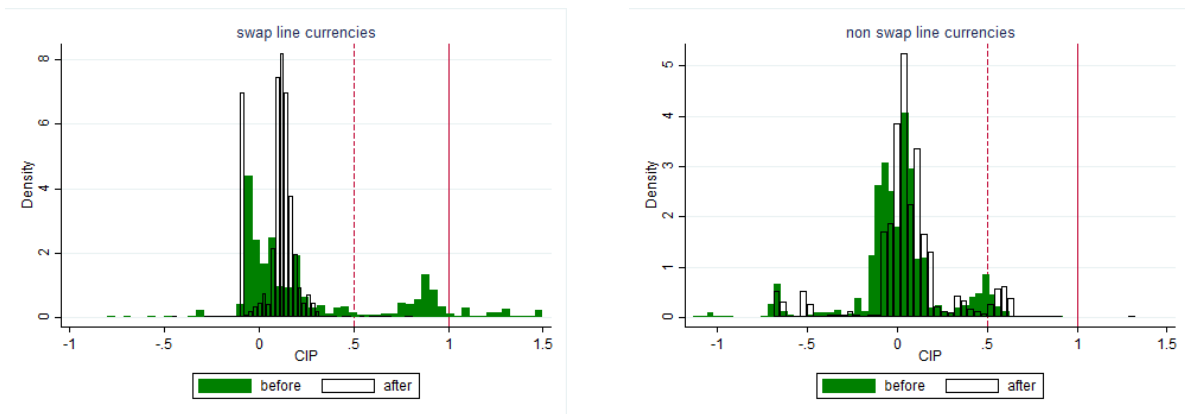
(c) Daily data in November versus January

Table 1: The effect of the swap line rate change on CIP deviations: difference-in-differences estimates

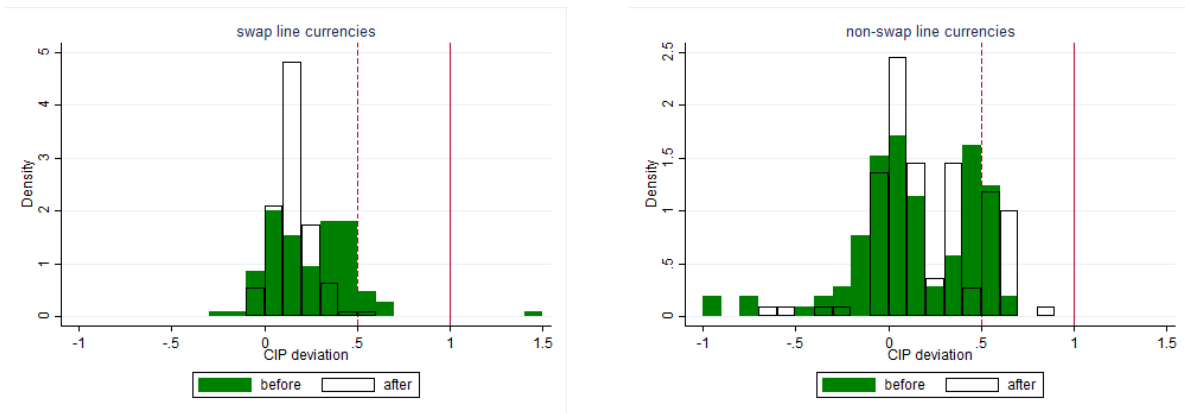|	(1) Baseline: 23/11-29/11 vs 8/12-13/12, Quotes	(2) 23/11-29/11 vs 1/12-7/12, Quotes	(3) Nov vs Jan, Quotes	(4) 23/11-29/11 vs 8/12-13/12, No Euro, Quotes	(5) 23/11-29/11 vs 8/12-13/12, European Currencies, Quotes	(6) 23/11-29/11 vs 8/12-13/12, EUR, CHF vs DKK, NOK, Quotes	(7) Nov vs Jan Daily Data
Mean	-.281***	-.225***	-.285***	-.212**	-.118	-.452***	-.184**
	(.108)	(.084)	(.110)	(.098)	(.143)	(.070)	(.092)
Median	-.208	-.197	-.015	-0.187	-.024	-.375***	-.146
	(.195)	(.167)	(.169)	(.127)	(.208)	(.138)	(.147)
75 %tile	-.286	-.283**	-.407	-.223	-.491**	-.608***	-.155
	(.220)	(.141)	(.289)	(.142)	(.199)	(.087)	(.113)
90 %tile	-.586***	-.207*	-.703*	-.354**	-.401**	-.522***	-.281***
	(.174)	(.111)	(.382)	(.148)	(.180)	(.109)	(.090)
N	288374	283932	1228637	253889	120555	95434	430

Notes: Swap Line Currencies refers to EUR, GBP, CAD, JPY, CHF (treatment group). Non-swap line currencies refers to AUD, NZD, SEK, NOK, DKK (control group). Column (1): Compares CIP deviations from all quotes in the FX swap market recorded between 23/11-29/11/11 versus 8/12/11-13/12/11. Column (2): Changes the post announcement window to 1/12/11-7/12/11, covering the 5 trading days through to the first European auctions at the new rate. Column (3): Extends the event windows to monthly and compares November 2011 to January 2012. Column (4): As Column (1) but Euro excluded from sample. Column (5): As Column (1) but excludes JPY, CAD, AUD and NZD from the sample. (6): As Column (1) but restrict sample to EUR, CHF versus NOK, DKK. Column (7): As Column (3) but uses daily data on CIP deviations based on prices at close in FX forward and spot markets. Standard errors, block bootstrapped at the currency level, in brackets. *** denotes significance at the 1% level; ** 5% level; * 10% level.

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following the same methodology find no significant effect. The first was a placebo that compared August to October. The other four used dates of announcements of extensions of the swap line arrangements, on May 9th 2010, December 21st 2010, June 29th 2011 and December 13th 2013. The policy change we used in our main specification contained both a change in the rate and an extension of the arrangement of the swap lines, so these results suggest that the key variation comes from changes in the swap line rate, as highlighted by the ceiling expressions in the propositions. In a similar vein, we also show that constructing standard errors by bootstrapping alternative event windows as well as currencies leads to the same conclusion.

3.7   A test using time-series domestic variation

The previous estimates used only U.S.-driven variation in the ceiling, which was useful insofar as this was plausibly exogenous with respect to the CIP deviations. As figure 2 shows for the Euro, and is true for other currencies, there is additional variation in the ceiling because of national monetary policy changes. This comes from changes in central bank deposit rates, which rarely were directly associated with movements in CIP. If times when CIP deviations are larger are also times of national financial turmoil, and this triggers cuts in the difference between policy and deposit rates, then this reverse causality would bias the estimated average effect of the ceiling on the CIP deviations downwards towards zero.

The baseline regression is:

$$x_{j,t} = \alpha_j + \beta c_{j,t} + \varepsilon_{j,t} \tag{7}$$

where α_j are currency fixed effects, and $c_{j,t}$ is the ceiling on the right-hand side of the equation in proposition 1 for currency j. We estimate this equation with the market-close daily data from September 19th, 2009, to December 31st, 2015, clustering standard errors by trading day and by currency.[21]

The first column of table 2 shows an estimated effect of a 1% reduction in the ceiling of 21bp on the CIP deviations. The second column instead estimates a censored regression, including only observations if the CIP deviations were in the 90th percentile of their sample distribution. As expected, the estimates are much larger: near the ceiling, a fall in 1% in the ceiling lowers the CIP deviations by 78bp. The third column adds a time fixed effect. This removes the variation from the Fed's actions, so that all that is left is the variation from changes in deposit rates by the recipient central banks. The estimate falls by half to 12bp, consistent with a downward bias due to reverse causality. The fourth column excludes the period between February and May 2010 when the swap line agreements lapsed. Including this period would attenuate the estimates according to the theory, and indeed excluding it the estimate is slightly higher at 23bp. The fifth column excludes the week before policy meetings so that the arbitrage trade is not exposed to the risk of changes

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[21]We also did block bootstrapping to deal with small cluster bias, and found the results to be unchanged.

Table 2: The effect of swap line ceiling on CIP deviations

	Baseline	Censored	Time Fixed Effect	Exc. Feb-Apr 2010	Exc. week b/f policy mtg	Allotment days
	(1)	(2)	(3)	(4)	(5)	(6)
Ceiling (c_{it})	0.211***	0.777**	0.118	0.229***	0.1805**	0.2312*
	(0.041)	(0.239)	(0.059)	(0.043)	(0.052)	(0.091)
N	9500	950	9500	9150	7666	1900
Adjusted R^2	0.08	0.16	0.67	0.67	0.08	0.08

Standard errors clustered by currency and day level in parentheses

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

Notes: Estimates of equation (7). The dependent variable is the 1-week CIP deviation of the CAD, CHF, EUR, GBP, and JPY vis-a-vis the USD. The sample runs from 19th September 2008 (the date of the first multilateral Federal Reserve swap agreement) through to 31st December 2015. All regressions include currency fixed effects. Column (1): panel least squares estimator. Column (2): panel least squares estimator conditional on $x_{j,t}$ being in the 90th percentile of the unconditional distribution. Column (3): includes time fixed effects. Column (4): Removes observations between Febuary and April 2010 when the swap line was suspended. Column (5): Excludes weeks before policy meeting. Column (6): Wednesdays only when European operation are alloted. Standard errors, clustered by currency and date, are in brackets. *** denotes statistical significance at the 1% level; ** 5% level; * 10% level.

in $i_t^{p*} - i_t^{v*}$ as discussed in section 3. The coefficient falls by a negligible amount to 0.18. The sixth column reflects the fact that the swap line operations happen once a week, with allotments typically on Wednesday. Considering only that day of the week, so cutting the sample to 1/5 of its size, slightly increases the point estimate but, as expected, it also increases the standard errors by a factor of 2. The appendix shows results separately by currency: all point estimates are positive, ranging between 12bp and 28bp.

Also using daily variation, we show in the appendix that allotments at the regular swap-line operations are increasing in the CIP deviation. This downward-sloping demand curve has a similar slope as that for domestic liquidity from the traditional domestic lending facilities.[22]

3.8 Apparent violations of the ceiling since 2015: a test

Since the start of 2016, there have been clear spikes in CIP deviations at the end of most quarters across many currencies, as reported in the appendix.[23] These spikes could be driven by regulatory constraints arising at these dates, as compliance with regulations in some jurisdictions is applied using end-of-quarter positions. Du, Tepper and Verdelhan (2018) found support for this regulatory explanation for CIP deviations. If so, then even though the spikes exceed the hypothetical swap

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[22]We estimate the demand for USD liquidity by foreign banks at the swap line, by regressing data on the allotment at USD operations by the ECB and the BoJ against $x_{j,t}$. Because banks could obtain as much funding as they wanted at the pre-announced rate, the supply of dollars was horizontal and known so this regression identifies the demand curve for central bank liquidity.

[23]End-of-quarter spikes start in 2015 in the case of the yen, and are much less prominent for the Canadian dollar.

line ceiling, they do not contradict the results in section 3. As proposition 3 showed, the actual ceiling would rise with the shadow value of the regulatory constraints. Supporting this explanation that bank-specific shadow values rise, there are also spikes in interbank and money market interest rates.

More importantly, the swap lines are not a standing facility. Unlike the discount window, they are not available at any time, on demand. Rather, as described before, there are weekly operations in USD. When there is no operation, the ceiling does not have to strictly apply as the arbitrage trade behind the three propositions is not available. The end-of-quarter ceiling deviations turn out to align with the timing of the swap line operations providing a different test of our propositions.

Figure 4 plots in panel (a) the positive differences between the CIP deviations and the swap line ceiling for the 5 currencies, together with their median, in the days before and after the end of the 2nd quarter of 2017 as an example (figures for other quarters with sustained ceiling violations are in the appendix). The first dashed vertical line show the date of the bid on the second-to-last European operation of the quarter, while the second dashed vertical line is the settlement date for the final operation of the quarter of the two nearest auctions to the end of the quarter, one before and one after. The plot shows that when an operation happens the ceiling is not violated. Only in between the two auctions do the CIP deviations spike. They do so immediately after the second-to-last opportunity to bid for dollars from the swap line in the quarter, consistent with potential regulatory window-dressing. But they spike down below the ceiling once the next swap-line operation is settled, consistent with the propositions we derived.

Panel (b) of the figure shows only the median across currencies, but now for all quarter ends (excluding year ends as no swap line auction takes place). The final operation of the quarter in Europe is always settled on a Thursday, regardless of the date, so figure 4 does not align with time to quarter-end. A similar pattern is visible. The ceiling is violated only when the arbitrage trade behind proposition 3 is not available.[24]

We conduct a more formal test of the theory through a regression. Using the daily market price data on CIP deviations from the start of 2016 until April 17th 2019, we estimate the probability that the ceiling is violated for currency j date $t + h$ conditional on it being violated at date t. We do so over two samples: one in which a swap line auction was settled between t and $t + h$ and one in which it was not. More formally, we estimate the linear probability model for each currency j:

$$\mathbf{1}(viol_{j,t+h}) = \beta_{j,0}^h \times (1 - \mathbf{1}(Settled_{j,t+h})) \times \mathbf{1}(viol_{j,t}) + \beta_{j,1}^h \times \mathbf{1}(Settled_{j,t+h}) \times \mathbf{1}(viol_{j,t}) + \varepsilon_{j,t+h}, \ (8)$$

where $\mathbf{1}(viol_{j,t})$ is indicator for whether the CIP deviation for currency j violated the swap line ceiling on trading day t and $\mathbf{1}(Settled_{j,t+h})$ is an indicator for whether a central bank of currency j settled a swap line operation between trading day t and $t + h$, ignoring operations where the bids

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[24]Note that bidding for the swap-line operations takes place in the morning, whereas our daily CIP data corresponds to daily close, so a spike on the day of the bidding is consistent with deviations spiking after bidding has taken place.

Figure 4: Daily CIP deviation minus swap line ceiling around quarter ends

(a) Five swap-line currencies and their median around the end of 2017Q2
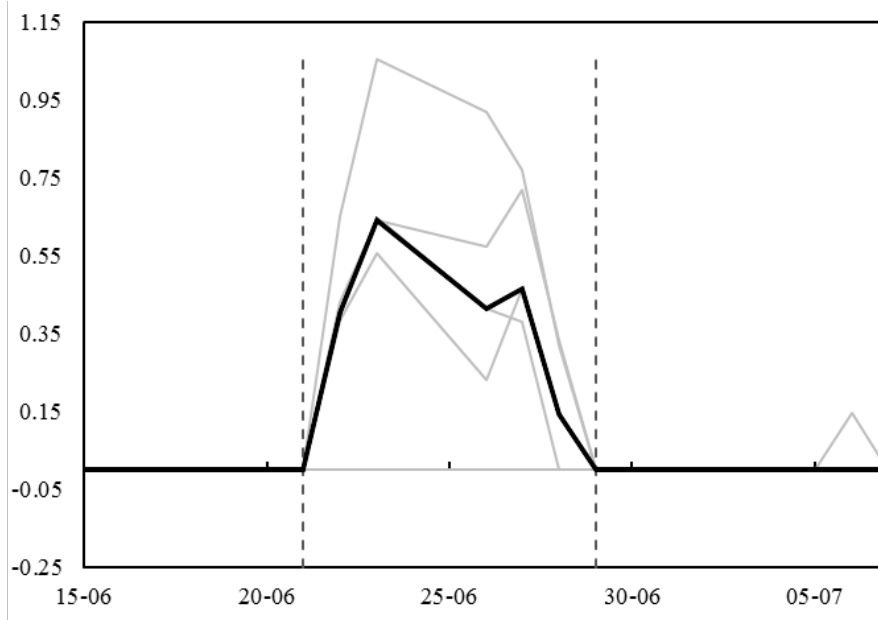
(b) Median across currencies for different quarter ends
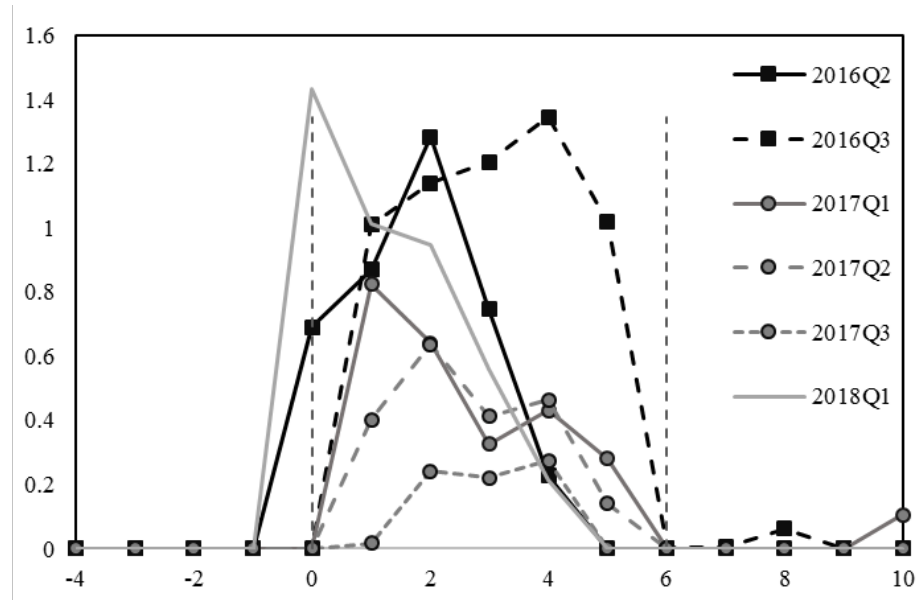
Notes: Ceilling violations around quarter end. Panel (a): Plots $max(x_{j,t} - (i_t^s - i_{j,t}) - (i_t^{p*} - i_{j,t}^{v*}), 0)$ where $x_{j,t}$ is the one-week OIS CIP deviation of the CAD, CHF, EUR, GBP, and JPY vis-a-vis the USD (grey lines) and the black line is the median of the 5 currencies. Vertical lines correspond to the dates of swap line operations by the ECB, BoE and SNB. Panel (b): As the black line in panel (a) but for alternative quarter ends. Zero on the x-axis corresponds to the trading day when bids for the second to last European swap line operation of the quarter was taken. The next operation is settled on the 6th trading day after that.

were taken in trading day t or earlier. Since, during this time period, the operations were scheduled well in advance at regular dates, we can consider $Settled_{j,t+h}$ to be exogenous to $\varepsilon_{j,t+h}$.

Panel (a) of figure 5 plots the estimates of $\beta_{j,0}^h$ and $\beta_{j,1}^h$ with h on the horizontal axis for the EUR.[25] The difference between the days when the swap line is effectively present or not is visible. When USD can be obtained from the swap line, the probability of the ceiling being violated is sharply estimated to be zero: a ceiling violation at $t-1$ never persists through a swap line operation that settles at $t+1$. The spikes and associated violations emphasized in the work of Du, Tepper and Verdelhan (2018) only happen when the swap line is not in operation. Appendix B.7 reports similar results for the GBP and the CHF.[26]

A second formal test asks a related but different question. Conditional on there being a ceiling violation at date $t-i$, and given that the next operation settlement is at date t, then what is the probability of a ceiling violation in period h from $t-i$ onwards? Panel (b) of figure 5 shows the estimated answers varying h on the horizontal axis. The hypothesis in this paper is that at $h=0$, that is when a swap line operation is settled, then this probability should be zero. For the four cases plotted in the figure for the EUR, on whether a violation of the ceiling happened $i=2,3,4,$ or 5 days earlier, the probability of a violation of the ceiling is always very close to zero. As one moves away from the auction settlement, then the probability of there being a spike in CIP increases. The swap lines, when in operation, are effective at imposing a ceiling, as proposition 3 predicts.

In general, these exercises work less well for the JPY, where the estimates of $\beta_{j,0}^h$ and $\beta_{j,1}^h$ are not statistically significantly different from one another (see appendix B.7). Yen CIP ceiling violations also occasionally persist through the swap line operation at quarter end. One explanation for this is that the BoJ's longer settlement cycle (coupled with time differences) makes identifying the impact of the dollar operation and the point which the ceiling must bind much more difficult. Nonetheless, if the yen CIP deviation is elevated, it still tends to fall sharply once a BoJ operation takes place (see figure 14 in the appendix).

3.9   Summing up

A central bank swap line puts a ceiling on CIP deviations, which moves monotonically with the swap line rate and with the domestic policy rate relative to the deposit rate at the central bank. Theory predicts that this should (i) lower the average observed CIP deviation, (ii) shift the distribution of CIP quotes to the left, and (iii) be tight as a ceiling on the dates at which the swap line operations are settled. Three tests confirmed these predictions. First, when the swap line rate fell exogenously with respect to CIP deviations in the previous weeks, the distribution of quotes shifted to the left and their average were lower. Second, time-series variation driven by domestic policy changes lowered observed daily draws from the distribution of CIP deviations. Third, quarter-end spikes in

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[25]Because there is no constant in the regression, $\beta_{j,0}^h$ and $\beta_{j,1}^h$ should be interpreted as conditional probabilities rather than relative to the average probability of a violation.

[26]As the Bank of Canada does not conduct USD operations, a similar exercise for the CAD is not possible.

Figure 5: Linear probability estimates of CIP deviation for EUR breaking the ceiling

(a) Probability of breaking ceiling, conditional on breaking it at date 0, if there is swap-line auction settlement in between or not
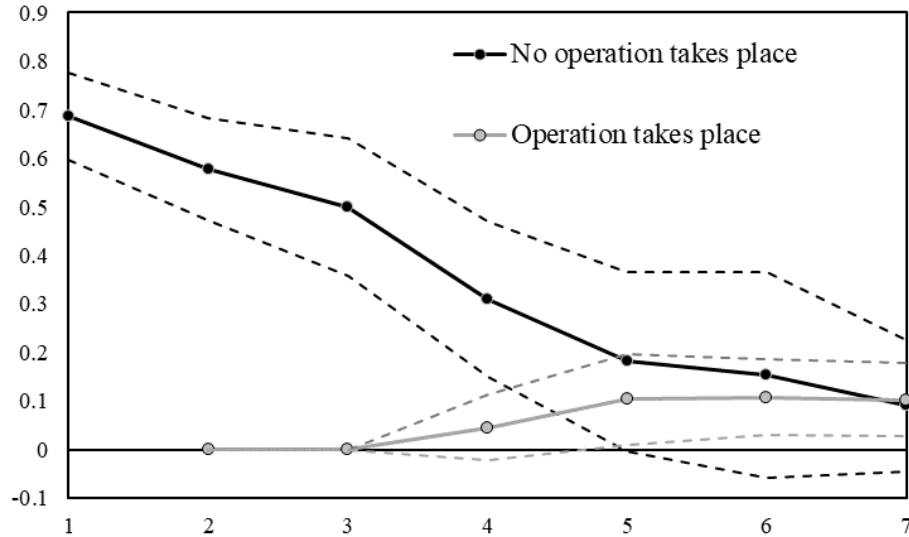
(b) Probability of breaking ceiling as move away from swap line settlement at date 0
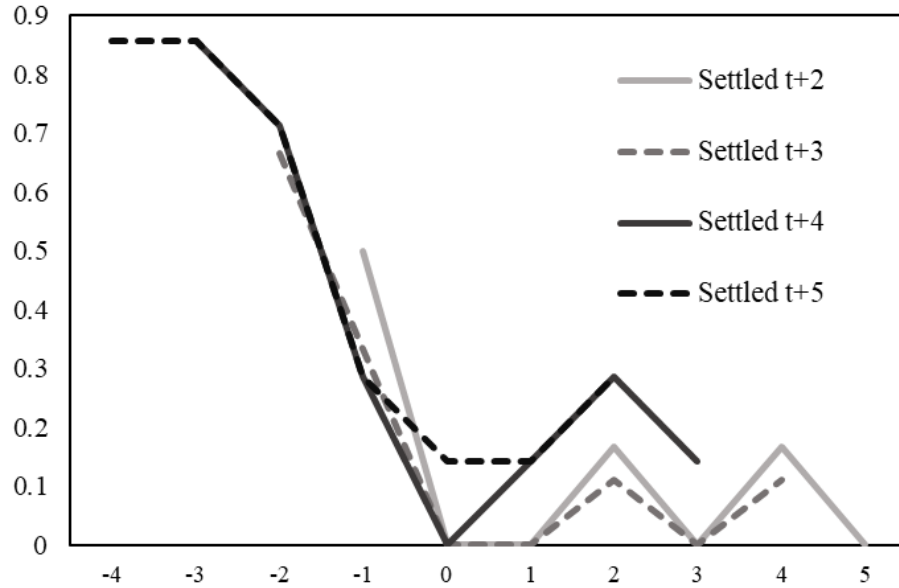
Notes: Panel (a): Estimates of equation (8) for the EUR using one-week OIS CIP violations vis-a-vis the USD. Black solid line is $\beta^h_{j,0}$, grey solid line is $\beta^h_{j,1}$; x-axis is h. Dashed lines are two Newey-West standard errors based on a 10-period window. Note that $\beta^1_{j,1} = 0$ by construction as no operation is settled at $t+1$ with bids taken after t so the estimate is omitted. Panel (b): See text.

CIP only break the ceiling in the days when the swap line is not available and, as soon as it is, the CIP deviation sharply falls below the ceiling predicted by the theory. In sum, the swap lines have a significant effect on the cross-currency basis market, in the direction that a lender of last resort was predicted to have.

4   The economic effects of the swap lines

We have so far established in theory and in the data that the central bank swap lines are a lending facility towards foreign banks, and that changes in the swap rate transmit through financial markets via the price of exchange-rate forward contracts and the associated deviations from CIP. This section shows, also in theory and in the data, that this has economic effects in the investment decisions of firms following financial institutions' funding decisions and the risks they face.

4.1   A model of global banks' investment decisions

To integrate our theory of banks, central banks, and exchange-rate derivatives markets in section 3 into a general-equilibrium model of funding risk and investment, we start by making some simplifications. All of these could be dispensed without changing the proposition below, but they avoid carrying around needless terms that will be absorbed by constants and fixed effects in the empirical work that follows. Namely, we assume that: (i) the recipient-country's monetary policy is running a floor system, so $i_t^{p*} = i_t^{v*}$, (ii) banks can fully collateralize their swap-line borrowing, so $\xi^c = 1$, (iii) regulatory capital requirements are not binding, so $\psi_{a,t} = 0$, and (iv) all banks are identical in their bargaining power with the intermediary so $\delta_a = \bar{\delta}$ and there is no heterogeneity in forward quotes. Thus, propositions 1 to 3 reduce to the simpler ceiling result that $x_t \le i_t^s - i_t$.

Consider a simple model of funding risk affecting banks that live for three periods, in the spirit of Holmström and Tirole (2011), but with global banks and cross-border funding.[27] There are two countries: a source country and a recipient country, with source and recipient currencies respectively. The source-country central bank provides a swap line, through which a recipient-country bank can borrow source currency at the rate i^s.

4.1.1   Investment in the first best

There is a representative source-country firm, whose output depends on source-country factors and capital, as well as on the capital it can attract from the recipient-country banks. This formulation captures the possibility that while source-country banks can provide capital to the firm, they are only able to attract funding subject to an upper bound, for instance on account of limited net worth and limited ability to commit.

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[27]We conjecture that similar results would follow in a Diamond-Dybvig setup following the exposition in Rochet and Vives (2010).

There are two initial investment periods, and k_0^* denotes long-term (2 periods) investment done in the first period, while k^* denotes short-term (1 period) investment in the second period in source-country firms by recipient-country banks. Output is realized in the third period according to the production function $F(k_0^*, k^*)$, and is then used to pay the firm's financiers. The marginal product of capital is positive and diminishing and the types of capital are complementary in production: $\partial^2 F(.)/\partial k_0^* \partial k^* > 0$. Following Holmström and Tirole (2011), we think of k_0^* as investment in long-term capacity, which must be employed and partly replenished with short-term investment k^* before output is realized. This creates a demand for funding to invest k^*.

Source-country households, having exhausted their willingness to fund source-country banks and firms directly, are willing to fund (in source-currency) recipient-country banks at rate i in the second period and at rate ρ in the first period. Without financial frictions, the standard first-order condition determining short-term recipient-country capital in source-country firms is: $\partial F(.)/\partial k^* = i$. Likewise, because the cost of funding in the first period is ρ, then the amount of long-term investment will satisfy $\partial F(.)/\partial k_0^* = \rho$. Together, these two optimality conditions define the first-best level of investments: $\hat{k}_0^*, \hat{k}^*$.

4.1.2 Funding shocks and sources of funding

However, in the second period, the representative recipient-country bank faces an upper bound in attracting source-country funders: $l^* \leq \bar{l} - \chi$. It is standard to justify these constraints on funding as a result of limited net worth and limited pledgability of assets. Importantly, χ is a random variable that captures a funding shock. This is common in crises, as flight to safety takes place, and foreign investments are treated as riskier, either by investor perceptions or by domestic regulations. The shock has distribution $G(\chi)$ and domain $[0, \bar{l}]$. We assume that $\bar{l} \geq \hat{k}^*$ so that if funding is plentiful, the recipient-country bank can finance its investment in source-country firms with source-country funding alone. High values of χ correspond to funding crises in which, as happened in 2007-10 when U.S. money market funds were unwilling to extend repo loans to European banks, the first-best investment cannot be funded through this route.

As an alternative source of funding, a recipient-country bank can borrow in recipient-country currency at rate i^*. The exchange rate at the time of the loan is normalized to one but by the time the output is produced and returns are delivered in source currency to the bank, the exchange rate could have changed and the bank could have more or less recipient currency with which to pay the recipient-country funders. Therefore, investment in source currency with recipient-currency funding comes with exchange-rate risk. We make an assumption that, while extreme, is not so far off in the data. We assume that banks are unwilling to carry any exchange-rate risk. This could be because of attitudes towards uncertainty, namely that banks are Knightian when it comes to exchange-rate risk, or it could be imposed by regulators, who require the exchange-rate exposure of bank lending to be entirely hedged away. As a result, if a bank extends foreign financing with

domestic funding in the second period, it must get rid of the exchange-rate risk in the last period, by buying a forward contract that locks the exchange rate.

The model for forward contracts is precisely as in section 3. Each bank gets matched with an intermediary selling it exchange-rate protection, so in equilibrium, the cost of this alternative source of funding is equal to $i + \bar{\delta}h(V) + (1 - \bar{\delta})(i^s - i)$. In this expanded general-equilibrium setup, the volume of hedging activity while the swap line is not in use is pinned down by: $V = k^* - \chi$. Thus, and defining the function $H(.) \equiv \bar{\delta}h(k^* + \chi - \bar{l}) + (1 - \bar{\delta})(i^s - i)$, the cost is: $i + H(k^* + \chi, i^s - i)$.

4.1.3   Equilibrium

Solving for equilibrium backwards in time, consider first the problem of the firm and its investors in the second period. The firm will still pick $\partial F(.)/\partial k^* = MC$, where MC is the marginal cost of funding, but this cost function now has different ranges. If the funding needs are small relative to the source-currency liquidity for recipient-country banks, or $\chi \leq \bar{l} - \hat{k}^* \equiv \underline{\chi}$ then $MC = i$. The recipient-country banks fund all their investment in source-country capital using source-country funding. If, however, $\chi > \underline{\chi}$, then the recipient banks must switch to recipient-currency funding, so now: $MC = i + H(k^* + \chi, i^s - i)$. The bank takes this cost as given, but it increases with the amount of investment in equilibrium, because the cost of hedging away the exchange rate risk is rising. Finally, if the funding crisis is too extreme, the bank switches to the swap line, so $MC = i^s$. At this point, investment is $\bar{k}^*$, which solves $\partial F(.)/\partial k^* = i^s$, and this minimum amount of investment is independent of the realization of the funding shock. The size of the funding shock at which this switch happens is $\bar{\chi}$, defined as the solution to $H(\bar{k}^* + \bar{\chi}, i^s - i) = i^s - i$.

The left-side panel of figure 6 presents the implications for CIP deviations as a function of the funding shock. When there is plentiful funding, CIP holds and in equilibrium there is no volume of trade in exchange-rate derivatives. As funding becomes scarcer, χ starts exceeding $\underline{\chi}$, and the exchange-rate intermediaries start operating at an increasing cost, which leads to rising CIP deviations. If the funding needs become more extreme, then banks start turning to the swap line and the swap line rate ceiling binds.

The right-side panel of figure 6 shows instead how profits in the second period depend on the funding shock.[28] For small funding shocks, the funding constraint is slack and profits are high as the marginal cost of funding is low. Once the funding shock gets higher, then the recipient-country banks start using their country's funding and exchange-rate hedging, so the marginal cost rises, and profits fall. If the funding shock gets high enough, then funding turns to the swap line, and both investment and profits become again independent of the size of the liquidity shocks. These ranges capture recent history: before the financial crisis, we were in the left range of shocks so CIP held and dollar financing came from U.S. money markets, while afterwards we moved to the range where fundings shocks are effectively larger because of new regulations, debt overhang, and

[28]So, $\pi(k_0) = \max_{k^*} \left\{ F(k_0^*, k^*) - ik^* - H(.) \max\{k^* + \chi - \bar{l}, 0\} - (i^s - i) \max\{k^* - \bar{k}^*, 0\} \right\}$.

Figure 6: CIP deviations and ex post profits as a function of funding shock

CIP deviation

Ex post profits
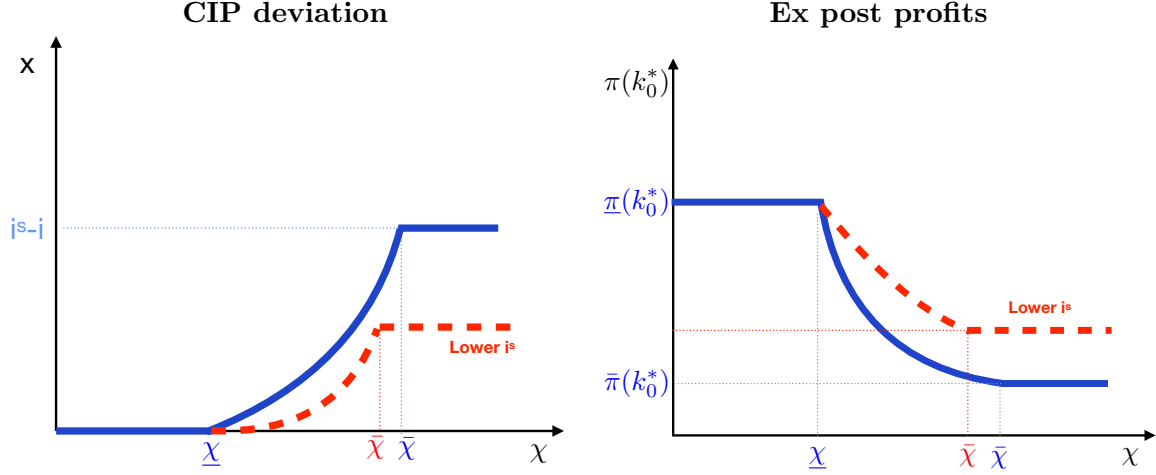
other funding market frictions, so that CIP does not hold and the swap-line ceiling has a significant effect.

4.1.4 The effect of the swap line on investment

Finally, consider the choice of long-term k_0 in the first period. The bank wants to choose k_0 to maximize $\int \pi(k_0, \chi) dG(\chi) - \rho k_0$. The first order condition is:

$$G(\underline{\chi})\underline{\pi}'(k_0^*) + (1 - G(\bar{\chi}))\bar{\pi}'(k_0^*) + \int_{\underline{\chi}}^{\bar{\chi}} \pi'(k_0^*, \chi) dG(\chi) = \rho \tag{9}$$

where $\underline{\pi}(.)$ and $\bar{\pi}'(.)$ are the profit functions, independent of χ, when the funding shocks are below $\underline{\chi}$ and above $\bar{\chi}$, respectively. By the envelope theorem, if there were no funding shocks, only the first term on the right-hand side would be non-zero, and this would reduce to $\underline{\pi}'(k_0^*) = \partial F(.)/\partial k_0^* = \rho$. The first-best level of capital would be reached. Otherwise, capital investment is now lower because, as figure 6 shows, for a range of realizations of the funding shock, the profits are lower. When recipient-country banks decide to invest in the source-country firm, they take into account that next period they may get hit by a large funding shock, leading to higher costs and lower profits.

A lower rate charged on the swap line has two effects. First, it lowers the $\bar{\chi}$ as banks switch from market to swap-line funding sooner. Second, it lowers the private rates that banks get in the market by improving their outside option relative to the traders. The effect on CIP deviations and on the profits of banks in period 2 are displayed in figure 6.

The lower the swap-line rate, the lower the expected costs from having to respond ex post to a funding crisis. Thus, the profits from investing abroad are weakly higher across the realization of

funding shocks. Because of the complementarity between the two types of capital in production, marginal profits for each unit of first period investment are also now higher. This raises long-run investment and expected profits across funding shocks. By introducing a source of backstop funding, the source-country central bank swap line lowers the expected costs of funding crises. This encourages more cross-border capital flows and investment, helping to boost source-country asset markets, while raising the value of the recipient-country banks in a crisis supporting financial stability abroad.

Collecting all the results gives the proposition:

Proposition 4. *An exogenous decrease in the swap-line rate $i^s - i$:*

i. *Lowers the ceiling and expected realization of CIP deviations, x;*

ii. *Raises investment by recipient-country banks in source-currency capital, k_0^*;*

iii. *Increases the expected profits of recipient-country banks that invest in source-currency capital.*

The first result mirrors proposition 2, already tested in section 3. We now turn to the data to test the other two results.

4.2 Data and empirical strategy

We start by testing the prediction that a lower swap-line rate, by lowering the costs of liquidity for recipient-country banks after a funding shock, will induce them to invest more in source-currency denominated assets. The start of our identification strategy to assess this prediction is again the Fed's decision to lower the interest rate on the swap line from a 1% to 0.5% spread over the OIS one-week rate on November 30th of 2011. As discussed before, the timing and size of this change was determined by negotiations with other central banks, and nowhere in the minutes does the behavior of purchases of USD assets in the previous week enter as a consideration for why the rate was lowered on this particular date. At the same time, the theory predicts an increase in USD asset purchases, not in purchases overall, by recipient-country investors. All combined, this leads to a triple difference strategy, that compares *across time*, before and after the swap-line rate change, *across banks*, between those whose terms for dollar funding changed and those for which they did not, and *across assets*, between corporate bonds that are denominated in dollars versus other currencies. Ultimately, the estimates answer the following question: for banks who had access to dollar swap lines through their central bank, how did the demand for dollar-denominated bonds change when the swap-line rate changed, relative to a control group of other financial institutions and non-dollar bonds?

We use data on the daily asset purchases by banks operating in Europe in corporate bonds to answer this question. The focus on corporate bonds to test the theory is motivated by several considerations. First, corporate bond holdings by banks in Europe are large, accounting for more

than one third of all their credit to the corporate sector. Second, unlike loans, bonds are continuously traded so financial investments can change daily, allowing for our high-frequency identification strategy. Third, by looking at a narrow window around the swap line announcement date, changes in bond issuance or in the characteristics of the firms behind these bonds are likely too small to bias our results.[29] Fourth, there are enough bonds traded that the several categories for our triple-diff strategy have enough observations to obtain precise estimates.

We use the ZEN database compiled by the UK Financial Conduct Authority. It covers the universe of all trades by EEA-regulated financial institutions in bonds that are admitted to trading on regulated markets, and issued by entities where the registered office is in the UK, plus all trades by UK-regulated financial institutions in bonds admitted to trading on regulated markets. A shorthand way of parsing these definitions is that the data cover the trading in corporate bonds of financial institutions operating in London, a major financial center. This will include UK banks alongside London subsidiaries of Euro Area, Japanese, Swiss and Canadian banks all of which could benefit from a cheaper dollar swap line. These are our treatment group. The data also contains information on the trades of the subsidiaries of, for example, Australian, Swedish and Russian banks whose home country central banks do not have access to dollar swap lines, and the subsidiaries of U.S. banks for whom the swap line is irrelevant. These form our control group.[30]

From these millions of observations on individual transactions, we aggregate to measure the net daily flow from *financial institution a* into a corporate *bond b* at each trading day *date t*. We scale this by the average of the absolute values of the daily flow from this financial institution towards all bonds over the 25 trading days centered around the 30th of November 2011 which form our sample period. This delivers our measure: $n_{a,b,t}$, which measures the demand by financial institution a for bond b at day t, relative to the typical activity of the institution.[31]

We impose the following restrictions for a financial institution or bond to be included in the sample: (i) the bond b must have been issued before November 14th 2011, so our results are not affected by the supply of corporate bonds; (ii) the bond b must be traded by at least one bank in the sample at least 50% of the days, so that we are considering relatively liquid bonds; (iii) the institution a must be a bank, and trade any bond at least 80% of the days, and trade on average four different bonds per day, so that we consider active traders. This leads to a sample with 26 banks of which 19 are headquartered in swap-line countries, and 790 bonds of which 69 are denominated in dollars. These sample selection criteria ensure that our sparse data is not dominated by zero

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[29]See Liao (2019) for how CIP deviations can affect the supply of bonds at lower frequencies.

[30]In principle a foreign subsidiary of, say, an Australian bank in London could access the swap line through the Band of England. However, this returns to the point raised previously that central bank lending facilities are not perfectly accessible for foreign banks, which motivates the existence of swap lines in the first place. Empirically, this would play against us and would weaken our results. Nonetheless, we obtain similar results comparing banks headquartered in swap line countries with only those based in the US.

[31]Specifically, let $\tilde{n}_{a,b,t}$ denote the daily net flow (in dollars) into bond b by bank a on day t; we define $n_{a,b,t} = \frac{\tilde{n}_{a,b,t}}{\frac{1}{25}\sum_{t=1}^{25}\sum_b |\tilde{n}_{a,b,t}|}$.

flows. Furthermore, it results in treatment and control groups that are comparable in the sense that the banks are all relatively large players in European corporate bond markets and that dollar and foreign currency denominated bonds have similar liquidity characteristics.

The data appendix contains more information on the ZEN dataset and our sample, including descriptive statistics. Across bonds, there are not meaningful differences between dollar and non-dollar denominated bonds in our sample in terms of liquidity, face-value, maturity, or rating. Across banks, in our sample they all have a presence in the US and are large institutions: the smallest had assets worth $40bn in 2011 and all but two had balance sheets exceeding $500bn. Because of the small number of institutions in the control group coupled with restrictions on the disclosure of confidential data, we cannot present separate summary statistics between the two types of banks' trading activities.

4.3   A test on quantities using bond flows

We start by estimating the following regression:

$$n_{a,b,t} = \beta_t \times SwapLine_a \times USDBond_b + \alpha_{a,t} + \gamma_{b,t} + \varepsilon_{a,b,t} \tag{10}$$

where $SwapLine_a$ is a dummy for whether institution a is headquartered in a country that has a central bank with a dollar swap line with the Fed, and $USDBond_b$ is a dummy for the currency of denomination of the bond being the dollar. The terms $\alpha_{a,t}$ and $\gamma_{b,t}$ denote bank-time and bond-time fixed effects. Figure 7 plots the cumulative coefficient estimates of β_t from the date of the swap line rate change onwards.

Prior to the announcement date, there was no meaningful difference in demand for dollar-denominated corporate bonds by banks headquartered in swap line countries. Right after the policy change, there is a clear shift in the portfolio of the treated group towards dollar bonds that is not present in the other bonds and the other banks. This shift towards USD-denominated corporate bonds by swap-line banks relative to banks outside the swap network or non USD bonds takes about one week to take place, and persists after that.

Our triple difference estimates are then statistical estimates of β in the regression:

$$n_{a,b,t} = \beta \times Post_t \times SwapLine_a \times USDBond_b + \alpha_{.,t} + \varepsilon_{k,j,t} \tag{11}$$

where $Post_t$ is a dummy variable for after the 30th November 2011, and $\alpha_{.,t}$ is a vector of fixed effects. Given the results in figure 7, we set the window length for the comparison as 5 trading days before and after. This is similar to the previous section testing for financial prices effects but, since bond flows can move in anticipation of the lower swap line rate, we restrict attention to the days right after the change, rather than to the windows after the lower rate became effective (as shown in table 1, column 2 the period immediately after the announcement was still associated with lower

Figure 7: Excess demand for USD bonds by treated banks around the announcement of the swap-line rate change
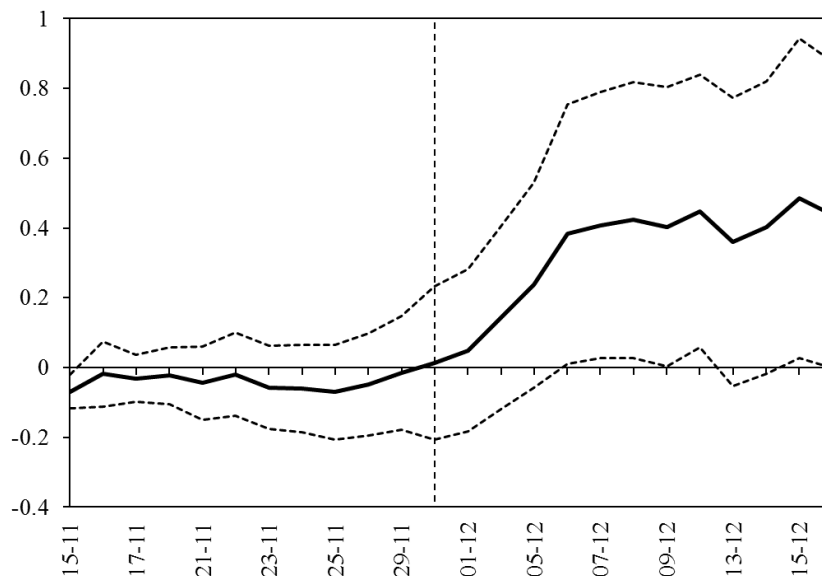
CIP deviations). Relative to the estimates in figure 7, aside from averaging the effect over the days in the window, we can now explore different combinations of fixed effects and calculate the associated standard errors, which are multiway clustered at institution, bond, and day level.

The first column of table 3 presents the results. The baseline estimate is that a 50 basis points cut in the swap-line rate, in the five days following the announcement, induced banks covered by this liquidity insurance to increase their net purchases of the average dollar denominated bond by 0.08% of the bank's average absolute daily flow.

The next three columns of the table deal with other possible omitted variables by using fixed effects. The second column adds a currency-period fixed effect to control for other factors that may have been differentially affecting bonds of different denomination. Moreover, it adds institution fixed effects, interacted with both period and currency, in case some bank characteristics like leverage or risk appetite may be correlated with denomination or period in time. Likewise, different financial institution may differ in their default risk, which would affect their relative funding costs, and they may have different available collateral, both of which could affect their willingness to use the swap line. Yet, the point estimate barely changes.

The third column controls for bond characteristics, using fixed effects on the issuer and the duration of the bond, interacted with both financial institution and time. This deals with possibly unobserved differences between USD bonds and the other bonds. One particular example would

be if different bonds would differ in their acceptability as collateral between the central bank and private lenders. Again, point estimates barely change.

The fourth column then estimates a fully saturated regression, with all interacted fixed effects, and this still has a negligible effect on estimates or standard errors.

The last three columns dig further by considering alternative samples. The fifth column drops from the criteria selecting the sample the requirement that the financial institutions must trade bonds frequently. Unsurprisingly, the estimate is now statistically insignificant at conventional levels since a series of zeros are added. Yet, the point estimate is similar. The sixth and seventh columns separate the bonds between those that have a high credit rating and those that do not. This shows that the portfolio tilting towards USD bonds occurs through both lower and higher rated bonds.

Among our sample of banks, some trade these bonds a lot, while others less so. Given the model's focus on financial investment decisions, we have estimated a specification that adds to the baseline a dummy variable interacting with the treatment for banks that have more than 50 trades per day in the sample. For frequent traders, the estimated coefficient is 0.04%, while for infrequent traders it is 0.11%, with only the latter coefficient statistically different from zero. Thus, banks that are more focussed on holding bonds as opposed to higher-frequency trading are more affected by the change in the swap line rate, as the model would suggest.

Finally, in the appendix, we present some robustness regressions that: (i) consider a falsification study using an event window four weeks previously, (ii) include the flow in the previous day to deal with possible inertia in portfolio adjustment, and (iii) collapse the sample into pre- and post announcement means and bootstraps errors at the bank level. These have no material impact on the results.[32]

How large are these effects? Within our sample, there are 69 USD denominated bonds, 19 banks, effects over 5 days, and the average absolute flow from a financial institution is $45 million. Multiplying all to our estimates gives an increase in gross flows of $230 million. This is 4.8% of the absolute flow over five days among the swap line banks in sample. Extrapolating out of sample, the net flow from foreigners into bonds issued by U.S. non-financial firms excluding the government in the 2017 flow of funds was $172bn, which multiplied by our aggregated estimate of 4.8% suggests a $8.31 billion shift in capital flows driven by a 0.5% change in the swap line rate. This is a large effect. It provides strong evidence that liquidity policies affect the purchase of financial assets significantly.

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[32]We also included a dummy variable for whether the USD bond was issued by a US or foreign firm. The coefficient was positive but statistically insignificant at conventional levels.

Table 3: Fixed-effects panel regression estimates of the effect of swap line rate changes on investment flows

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Fixed Effects			Alternative Samples		
	baseline	currency, bank	currency, bank, bond char.	saturated	include infrequently trading banks	high rating (A- and above)	low rating
$Post_t \times Swap_a \times USDBond_b$	0.077*	0.077*	0.077*	0.079*	0.103	0.076	0.076
	(0.035)	(0.038)	(0.037)	(0.039)	(0.055)	(0.056)	(0.046)
N	205227	205227	205227	205227	284225	101796	103431
$bank \times period$ f.e.	No	Yes	Yes	Yes	Yes	Yes	Yes
$bank \times currency$ f.e.	No	Yes	Yes	No	No	No	No
$bank \times issuer$ f.e.	No	No	Yes	No	No	No	No
$bank \times duration$ f.e.	No	No	Yes	No	No	No	No
$bank \times bond$ f.e.	No	No	No	Yes	Yes	Yes	Yes
$period \times currency$ f.e.	No	Yes	Yes	No	No	No	No
$period \times issuer$ f.e.	No	No	Yes	No	No	No	No
$period \times duration$ f.e.	No	No	Yes	No	No	No	No
$period \times bond$ f.e.	No	No	No	Yes	Yes	Yes	Yes

Notes: Estimates of equation (11). The dependent variable is $n_{a,b,t}$, bond level daily flows by bank scaled by the total absolute flow by bank. $Post_t$ is a dummy variable taking a value of 1 if t is after 30th of November 2011. $Swap_a$ is a dummy variable taking a value of 1 if the bank a is headquartered in swap line country. $USDBond_b$ is a dummy variable taking a value of 1 if bond b is dollar denominated. Column (1): triple difference estimator, including $Swap_a \times period$, $USDBond_b \times period$ and $Swap_a \times USDBond_b$ fixed effects. Column (2): adds bank specific and bond-currency specific fixed effects. Column (3): additionally adds issuer and duration (3-year window) fixed effects. Column (4): saturated regression. Column (5): includes in the sample banks who trade infrequently. Column (6): limits the sample to bonds that are rated A- and above. Column (7): limits the sample to bonds that are rated BBB+ and below. Standard errors, clustered at the bank, the bond and the trading day level, are in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.

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4.4 A test on prices using bond yields

Significant portfolio shifts, as the ones we just found, may be associated with changes in the relative prices of different assets. If so, this is of independent interest, since it reveals limits to arbitrage across these bonds in response to a very specific relative demand shock. More focussed on the question of this paper, price effects would show to what extent the liquidity provided by the central bank swap lines may prevent asset price drops and, potentially, fire sales in the asset markets of the source central bank.

For this test, we resort again to a difference-in-difference strategy where the first dimension of comparison is over time around the dollar swap-line rate change. The second dimension now compares USD-denominated corporate bonds that the recipient-country banks hold in large amounts to other similar USD-denominated corporate bonds that these foreign banks do not hold in their portfolios. We start from the sample of 5,474 dollar denominated bonds that were the constituents of the Bank of America/Merrill Lynch bond indices. We use our data on trades in corporate bonds from the previous section to identify the treated group of bonds that are actively traded by the recipient-country banks. Through this diff-in-diff strategy and by enlarging the sample of bonds considered, we can address the concern of whether there is something special about the bonds that are actively traded by foreign banks.

The treatment is not randomly assigned, so we use a nearest-neighbour matching procedure that weights observations to build treatment and control groups that have similar relevant bond level characteristics. Specifically we match on credit rating (converted to a numerical scale), log residual maturity, coupon, log of the face value outstanding, and average yield in the 5 days prior to treatment. We then consider the change in the average yield of the bonds in the 5 days after the announcement relative to the 5 days prior.[33] To implement this matching strategy, we use the bias-corrected matching estimator in Abadie and Imbens (2011) and present the average treatment effect.

The results are in table 4. The treatment of lowering the costs of emergency dollar funding to recipient-country banks by changing the swap-line rate lowered the yield on the USD corporate bonds that these banks invested in by 8.6bp.

One concern may be that the swap-line rate change, by improving the profitability and so the stability of the recipient country banks, works as a systemic shock to those economies, making all of their bond yields decline. Our results may be driven by USD-denominated bonds issued by Euro-area firms, that are both most likely to be held by Euro-area banks and benefit from this aggregate shock to their economies.[34] Column (2) of the table therefore changes the matching procedure to require exact matches on whether the bond is issued by a Euro-area company or not. This way, any

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[33]Reading the Financial Times issues in this narrow window revealed no other reference to news about corporate bond prices, beyond discussions about the swap line rate change.

[34]This was not a concern in the flow analysis in the previous sub-section, because the triple-difference strategy estimated effects within issuer. It is a concern here because of double differencing instead of triple.

Table 4: Yield Impact on Frequently Traded USD Denominated Bonds

	Nearest Neighbour	Exact Match on Euro Issuers	Exact Match on Industry
$frequentlytraded_b$	-0.086**	-0.122***	-0.080**
	(0.036)	(0.036)	(0.034)
N	5474	5474	2656

Notes: The dependent variable is the change in the average yield of the bond in the 5 trading days following the swap rate change on the 30th of November 2011, versus the 5 days before. The independent variable is a dummy for whether the bond is frequently traded by our sample of European banks. Column (1): nearest neighbor estimates, using Abadie and Imbens (2011) bias correction, that single matches on five bond characteristics: (i) credit rating, converted into a numerical scale, (ii) log residual maturity, (iii) coupon, (iv) log of the face value outstanding, and (v) average yield in the 5 days prior to 30th November. Column (2): includes exact match on whether the bond issuer is located in a Euroarea country. Column (3): includes an exact match on issuer industry, industry classification level 3 of 4 in the BAML dataset; control sample modified to overlap with the industry classifications in the treated sample; two treated bonds which appear uniquely in an industry classification dropped. Robust standard errors in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.

potential aggregate shock to the Euro-area economy affects both treatment and control equally, so the differential effect identified by the regression is due to the asset purchase flows. The estimate rises by one standard error to a 12.2bp price effect.

The third column instead matches bonds exactly using their issuer industry. This is an exact match, since industry is a discrete variable. We use the industry classification level 3 of 4 in the BAML dataset, and modify the control sample so as to only overlap with the industry classifications in the treated sample. This provides a different form of comparison relative to the estimates in column 1, but the results barely change.

To get a sense of the magnitude of these estimates, Gertler and Karadi (2015) estimate that in response to a conventional monetary policy shock that raises the one-year yield by 50bp, the commercial paper spread rises by 12.5bp. We find that an unconventional monetary policy shocks to the swap line rate of 50bp lowers the corporate bond yield by 12.2bp among our subset of corporate bonds. Such large effects may perhaps not be surprising from a financial-markets perspective given the large portfolio flows we already found. But, from the perspective of the effectiveness of the influence of the lender of last resort activities ex ante, before crises, they are striking and novel to the literature.

4.5 Third test: the effect of swap lines on bank valuations

Proposition 4 predicted that the value of foreign banks increases when the swap-line rate falls. In the model, this happens because cheaper access to the swap line reduces the risk that foreign banks will be forced to discontinue their investments when hit by a dollar funding shock.

We test this by asking whether banks in countries that receive dollar swap lines have excess

returns around the swap-rate change dates. Again, this is a triple-difference exercise, that compares: (i) the days before and after the swap-line rate change by the Fed, (ii) foreign banks in countries covered by the dollar swap lines and so affected by the rate change, and (iii) foreign banks with a U.S. presence versus foreign banks with no U.S. assets. The theory predicts that only the global banks with a U.S. presence should be affected by the change in the swap line terms.

Turning to the data, we define a bank as having a U.S. presence if it appears in the "U.S. Branches and Agencies of Foreign Banking Organizations" dataset compiled by the U.S. Federal Institutions Examination Council. Ideally, we would like to measure the exposure of a bank to dollar funding shocks, or its reliance on U.S. wholesale funding. The presence of a branch is only an imperfect proxy for this, so estimates will not be very precise.[35]

We match banks to their equity returns taken from Datastream. Excess returns are computed as the component of each bank's returns unexplained by the total market return in the country where the bank is based, where the relevant betas are computed over the 100 trading days ending on the 31st October 2011.[36] The window after the announcement over which the excess returns are cumulated is five days as in the bond yield regressions.

Figure 8 presents the results. It compares the average excess returns for banks in the jurisdictions covered by the swap line whose rate changed and who have a significant U.S. presence with two control groups: banks not covered by the swap-line rate change, and banks in the swap lines but without a U.S. presence. Clearly, it is those banks that are connected with the United States and that have access to swap line dollar emergency funding that experience the excess returns following the announced increase in the generosity of the swap line. The shareholders in these banks appear to value the liquidity insurance offered by the swap facility.

Table 5 presents the associated comparison of mean excess returns across different groups of banks calculated by weighing each bank equally or by its relative market value in dollars at the start of November 2011. The associated standard errors are computed by bootstrapping alternative event dates. Here we focus on the cumulative excess returns in the 3 days following the announcement as that is when most of the effect comes through. When weighing banks equally, those that were treated by the swap-line change and have a U.S. presence experience a 2.7% excess return, while those without a U.S. presence, or those not covered by the swap line because they are based in the United States or elsewhere, did not. This supports the prediction of the model, and was already visible in figure 8.

However, once weighted by market size, there are significant excess returns for all but the non-treated, non-U.S. bank returns. The difficulty is that U.S. presence is strongly correlated with bank size, and that around the date of the swap changes, all large banks had positive excess returns. The data do not allow us to separate the effects of size from those of U.S. presence.

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[35]Note that the banks we used in the bond flows regression have a US presence.

[36]The appendix presents also similar estimates (and slightly smaller standard errors) from using an alternative measure of excess returns using the Fama-French factors.

Figure 8: Cumulative bank excess returns averaged across different banks after treatment date
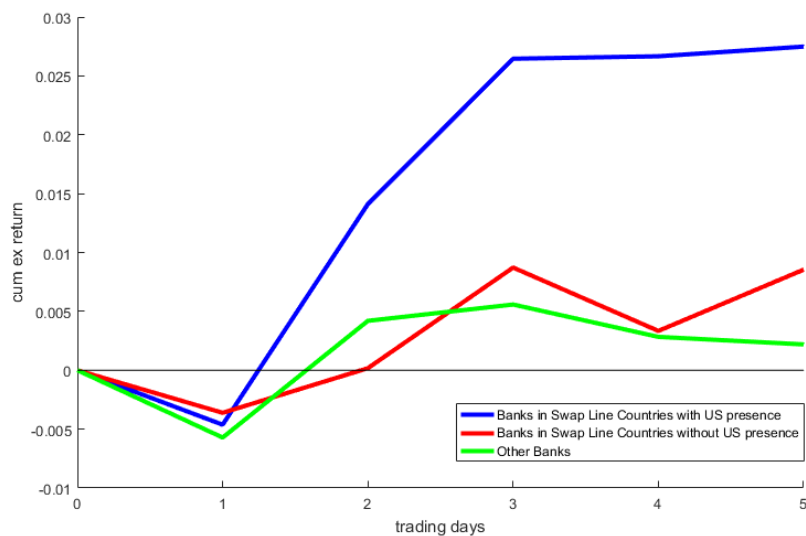
Table 5: Average bank excess returns after swap line rate change

| | Swap Line Banks | | US Banks | Other Banks |
	US Presence	No US Presence		
Average	0.0265*	0.0087	0.0063	-0.0033
	(0.0140)	(0.0068)	(0.0084)	(0.0098)
Size Weighted	0.0251**	0.0281***	0.0290*	0.0047
	(0.0125)	(0.0086)	(0.0154)	(0.0103)
N	36	72	310	24

Notes: Excess returns are computed accumulating over 3 days using a beta-to-local market return that is estimated over the 100 days prior to 01/11/11. Swap line banks are headquartered in Canada, Euro-area, Japan, Switzerland, or the United Kingdom. U.S. presence is taken from "U.S. Agencies and Branches of Foreign Banking Organisations" dataset. Bootstrapped confidence intervals in brackets are constructed by randomly sampling event dates over the window 01/06/10-31/11/11. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.

5   Conclusion

This paper tested the effectiveness of central bank lending programs in general, and of central bank swap lines in particular. Our first contribution was to show that the swap lines were a vehicle for a central bank to provide lending of last resort to foreign banks, using the foreign central bank as an agent in assessing eligibility and bearing the credit risk. While many unconventional monetary policies taken during the crisis can be described as alleviating funding crises, we showed in what concrete ways this particular one worked. This can explain why, unlike many other unconventional policies, central bank swap lines have survived well past the financial crisis in a world that has global banks exposed to cross-country funding imbalances, and why they are today a part of the international financial architecture.

Second, we showed that the particular market price on which this lending program puts a ceiling is one specific measure of CIP deviations, the one-week OIS-based one between countries in the swap line network. That ceiling is equal to the swap-line spread chosen by the source central bank, plus the difference between policy and deposit rates of the recipient country's central bank. In practice, there is variation in this ceiling both from domestic and foreign policy sources that allows us to estimate the effect of this ceiling in the distribution of CIP deviations across currencies with respect to the dollar. Credibly identified estimates suggest that a 1% fall in the ceiling lowered the average CIP deviation across price quotes by 0.56%, and the 90th percentile by 1.17%. In days of swap-line auctions, the ceiling binds tightly across time and currencies, with CIP deviations spiking in quarter ends only for the few days when there is no swap-line auction.

Third, we showed that this lending program encourages financial institutions to invest in foreign assets. Empirically, we found evidence for a significant portfolio tilt towards dollar bonds following a reduction in the cost of the dollar swap line, amounting to 4.8% of absolute flows over one week. This was also visible in an appreciation of the price of the USD bonds that happen to be heavily traded by European banks. Changes in the rate charged by the central bank in the swap line are estimated to have approximately the same effect on the corporate bond yields as an equivalent change in the standard policy rate. Finally, we found some empirical support for the swap line reducing foreign banks' expected funding cost ex ante and preventing banking failures ex post, as reflected in their stock prices.

Many interesting questions are left open for future research. Are the empirical results specific to dollar swap lines or do they extend to other currencies as well? What role would swap lines play in a world in which the euro or the renmibi wanted to compete with the dollar for the status of dominant currency? Does the increase foreign funding by global banks allowed by the swap lines raise or lower welfare in the global macroeconomic equilibrium? Are foreign banks investing too much in domestic assets or relying too much on domestic funding leading to macro-financial fragility, and is this enhanced by the swap lines? By lowering the cost of a financial crisis, do the swap lines make a crisis more likely? How can the two central banks in a swap-line arrangement

coordinate their choices and how does this spill over to conventional monetary policies?

What this paper has shown is that central bank lending policies can be very effective, as hypothesized by Bagehot (1873), but rarely tested. Overall, the swap lines eased funding pressures as reflected in the cost of hedging foreign funding, the choice of investments they fund, the asset prices of these investments, and the stock prices of the investors. Perhaps because of this, the number of central bank swap lines has been growing every year. Already today, any study of liquidity provision or of the international financial system will be incomplete without a discussion of the role of the central bank swap lines.

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Appendix – For Online Publication

Appendix A provides the proof of proposition 3. Appendix B has additional empirical results and robustness results on the regressions discussed in the main text. Appendix C describes in detail how we built the variables used throughout the paper.

A   Proof of proposition 3

In the more general case, consider what happens when: (i) bank a can choose whether to obtain dollars from the swap line or from an "other" source of funding, and their rate-collateral pairs are: (ξ^c, i_t^s) and (ξ^o, i_t^o), respectively; (ii) the unsecured lending rate for bank a is $i_{a,t}^u$; (iii) for every unit of investment in the trade, the bank has to fund the transaction with ω of capital, which has shadow cost $\lambda_{a,t}$, and $1 - \omega$ of debt financing, so that ω can be thought of as the total capital held against the central bank reserves and the forward contract. In that case, the arbitrage argument in equation (1) becomes instead:

$$(1 - \omega)\min\{\xi^c i_t^s + (1 - \xi^c)i_{a,t}^u, \xi^o i_t^o + (1 - \xi^o)i_{a,t}^u\} + \omega\lambda_{a,t} \geq s_t - f_t + (i_t^{v*} + i_t^* - i_t^{p*}). \tag{A1}$$

Using the definition of the CIP deviation in equation (2) and rearranging gives the generalized version of our ceiling result:

$$x_{a,t} \leq (1 - \omega)\min\{\xi^c i_t^s + (1 - \xi^c)i_{a,t}^u, \xi^o i_t^o + (1 - \xi^o)i_{a,t}^u\} - i_t + (i_t^{p*} - i_t^{v*}) + \omega\lambda_{a,t}. \tag{A2}$$

There is still a ceiling, and an exogenous reduction in i_t^s still weakly reduces the right-hand side.

In the text, we argued that during our sample period: (i) the alternative source of funding was borrowing from the recipient-country central bank's recipient-country currency and using the forward market to turn it into synthetic dollars, so $i_t^o = i_t^{p*} + s_t - f_t$, (ii) during this sample period, the policy and OIS rates were almost identical, so $i_t^{p*} = i_t^*$, and (iii) the collateral requirements by recipient-country central banks were identical for their dollar swap line and conventional recipient-currency lending, so $\xi^o = \xi^c$. It then follows that:

$$\min\{\xi i_t^s + (1 - \xi^c)i_{a,t}^u, \xi^o i_t^o + (1 - \xi^o)i_{a,t}^u\} = \xi^c \min\{i_t^s, i_t + x_{a,t}\} + (1 - \xi^c)i_{a,t}^u. \tag{A3}$$

Thus, the bank will not use the swap line, unless $x_t \geq i_t^s - i_t$. Given the reasonable assumptions that: (i) $i_{a,t}^u \geq i_t$, or that unsecured borrowing rates exceed secured borrowing rates, (ii) the interest on reserves puts a floor on the policy rate, $i_t^{p*} \geq i_t^{v*}$, then:

$$i_t^s - i_t \leq \xi^c \min\{i_t^s, i_t + x_{a,t}\} + (1 - \xi^c)i_{a,t}^u - i_t + (i_t^{p*} - i_t^{v*}). \tag{A4}$$

Therefore, we can dispense with the min operator in the ceiling expression.

Table A1: The effect of swap line ceiling on CIP deviations

	EUR	GBP	JPY	CHF	CAD
	x_{jt}	x_{jt}	x_{jt}	x_{jt}	x_{jt}
Ceiling (c_{it})	0.2120**	0.2058	0.1179	0.2828**	0.1533**
	(0.097)	(0.138)	(0.117)	(0.118)	(0.074)
N	1900	1900	1900	1900	1900

Notes: Estimates of equation (7). The dependent variable is the 1-week CIP deviation of the CAD, CHF, EUR, GBP, and JPY vis-a-vis the USD. The sample runs from 19th September 2008 (the date of the first multilateral Federal Reserve swap agreement) through to 31st December 2015. Newey-West standard errors with a ten trading day window in brackets. Columns (1)-(5) present currency specific estimates. *** denotes statistical significance at the 1% level; ** 5% level; * 10% level.

The ceiling result then becomes:

$$x_{a,t} \leq (i_t^s - i_t) + (i_t^{p*} - i_t^{v*}) + (1 - \xi^c)(i_{a,t}^u - i_t^s) + \psi_{a,t}, \tag{A5}$$

as long as we define: $\psi_{a,t} = \omega(\lambda_{a,t} - i_t^s - (1 - \xi^c)(i_{a,t}^u - i_t^s))$, the shadow value of relaxing the regulatory constraint. Note that in principle $\psi_{a,t} \geq 0$ since capital is more costly than the weighted cost of secured and unsecured debt.

B   Additional Results

This section describes further results and robustness checks on our empirical analysis in sections 3 and 4. In addition, it presents estimates of the demand curve for dollars by banks at the swap line and compares it with the demand curve for local currency from standard monetary operations.

B.1   Additional results on CIP and the central bank ceiling

Figure 9 presents the equivalent of figure 2 for other swap line currencies and the DKK. CAD does not experience any ceiling violations. In the case of CHF and JPY, the CIP deviations are also subject to spikes at year end, and at quarter end from 2015 onward for the JPY, but also experience occasional short lived spikes towards during the year. See section 3.8 for discussion regarding why these spikes are not necessarily problematic. In contrast, consider the DKK: on October 30, 2009 the swap line lapsed, and after that the CIP deviation experienced sustained periods above an hypothetical ceiling in mid 2012 and early 2015.

Table A1 presents the equivalent to table 2 broken down by currency. As can be seen, all estimates are positive, with estimate that range between 12bp and 28bp.

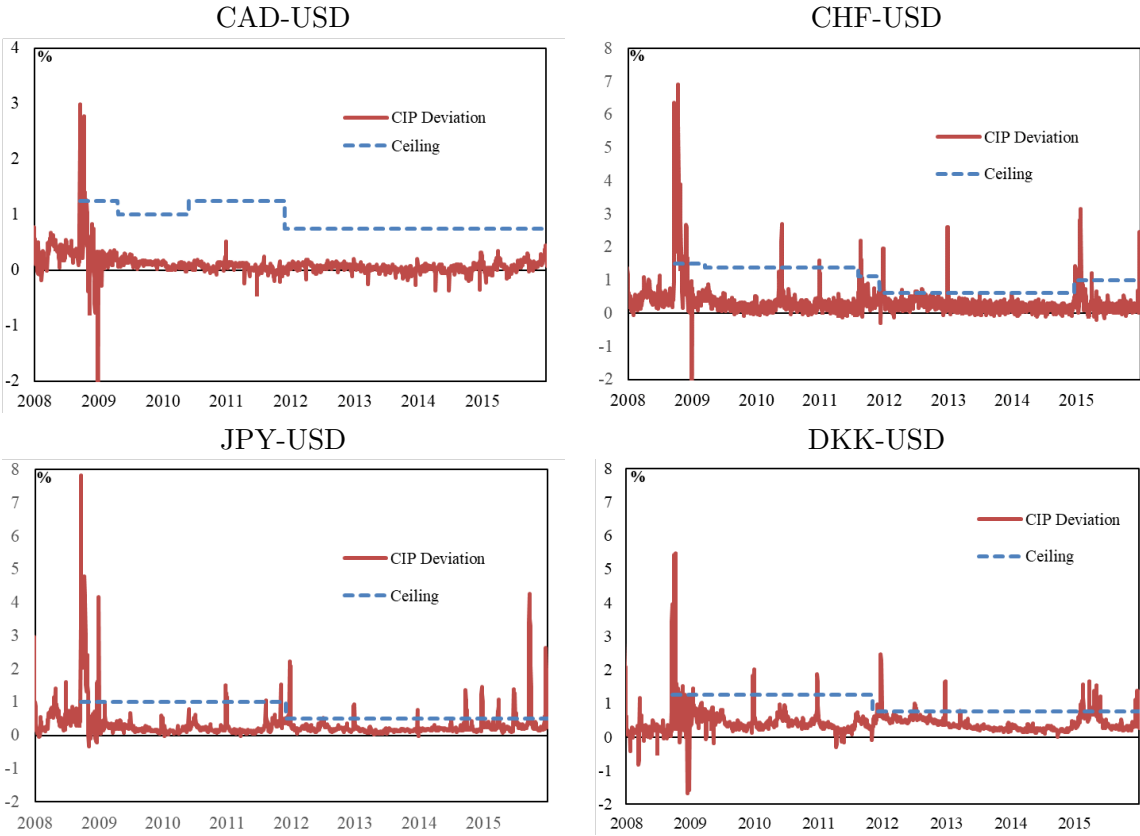Figure 9: CIP deviations and the swap line ceiling: CAD, CHF, JPY and DKK

Figure 10: Pre-trends: one-week Libor CIP deviations versus USD, 01/09/2011-29/11/2011
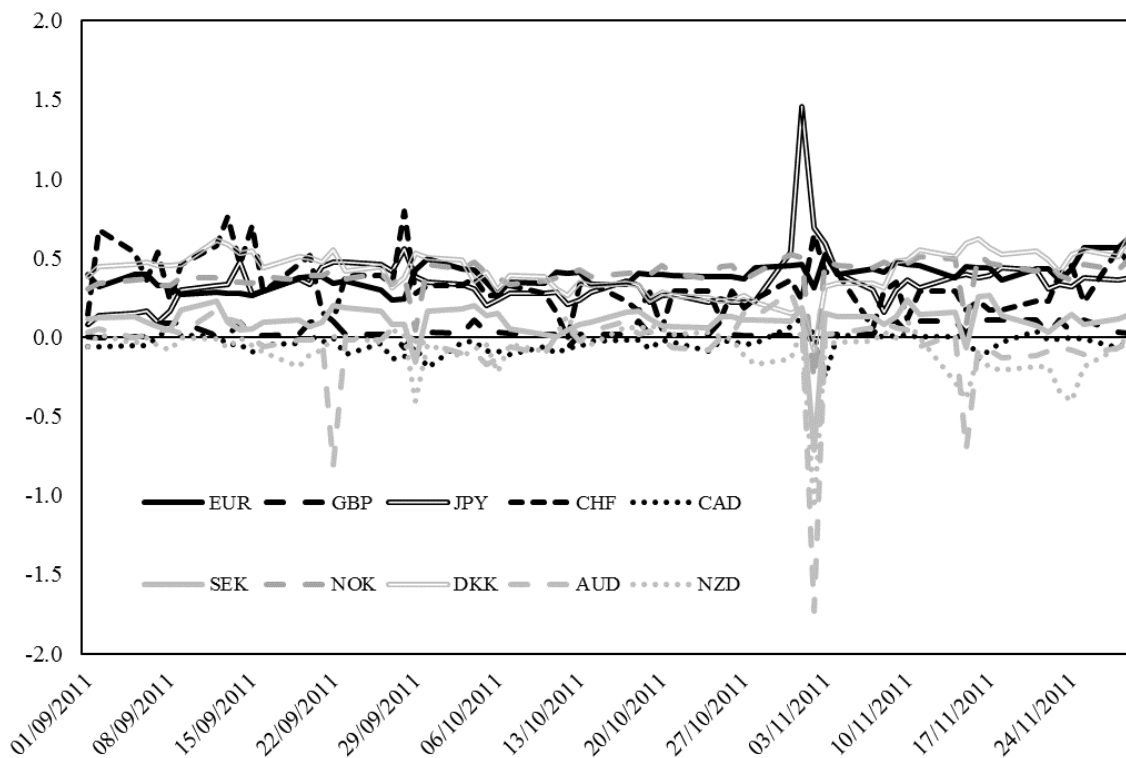
B.2 Difference-in-differences CIP estimates: pre trends

Figure 10 presents daily data on 1-week Libor CIP deviations vis-a-vis the USD for the 10 currencies in our sample in the three months prior to the announced change in the swap line rate on 30th of November 2011. As the picture shows, the deviations are both volatile through time and heterogeneous across currencies. There is no obvious pre-trend among currencies in either group. Nor do the days in the build up to the announcement appear unusual.

B.3 Difference-in-differences CIP estimates: by individual currencies

Table A2 decomposes the distribution CIP deviations before and after the swap line rate change, as presented in table 1 and figure 3, into individual currencies.

B.4 Difference-in-differences CIP estimates: robustness

Table A3 considers the robustness of the results in table 1 in the main text on the difference-in-differences estimates of the effect of the swap line on CIP deviations.

Table A2: The effect of the swap line rate change on CIP deviations: by currency

Non-swapline currencies

	AUD		NZD		NOK		SEK		DKK		Average	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Mean	-0.072	0.074	-0.170	0.106	0.419	0.571	0.103	-0.008	0.503	0.736	0.1566	0.2958
Median	-0.130	-0.034	-0.358	-0.034	0.513	0.652	0.100	-0.083	0.392	0.587	0.1034	0.2176
75th Percentile	-0.094	-0.016	-0.171	-0.022	0.566	0.705	0.115	0.003	0.457	0.667	0.1746	0.2674
90th Percentile	-0.075	0.005	-0.128	-0.005	0.592	0.717	0.127	0.021	0.518	0.714	0.2068	0.2904

Swap line currencies

	EUR		JPY		GBP		CHF		CAD		Average	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Mean	0.767	0.442	-0.020	-0.008	0.069	0.148	0.427	0.181	-0.005	0.029	0.248	0.158
Median	0.747	0.323	-0.016	-0.007	0.071	0.120	0.401	0.302	-0.013	0.030	0.238	0.154
75th Percentile	0.834	0.530	-0.013	-0.004	0.074	0.132	0.543	0.401	0.014	0.046	0.290	0.221
90th Percentile	0.844	0.614	-0.012	0.001	0.078	0.246	0.585	0.528	0.030	0.069	0.305	0.292

Notes: Swap Line Currencies refers to EUR, GBP, CAD, JPY, CHF. Non-swap line currencies refers to AUD, NZD, SEK, NOK, DKK. The statistics cover 1 week Libor CIP deviation versus USD computed from all quotes on FX swaps recorded in Datascope. Before refers to 5 trading days prior to 30th November 2011 and after to 5 trading days from December 8th (the settlement date of the first auction after the rate change). Average refers to the simple mean of each statistic for the five currencies in each group rather than pooling the quote-level data.

The first column shows that our results hold if we weight the quote data to equally weight currencies. Bootstrapped standard errors are complex to compute in weighted quantile regressions, we omit them and note that the point estimates conform to the unweighted baseline where inference is more straightforward.

The second column shows the results on quotes excluding all European currencies. The effects are still present if less dramatic as the CIP deviations for JPY and the CAD were less elevated initially. It is worth emphasizing that this arises due to an increase in the CIP deviations of the control group rather than a fall in the treatment group.

The final five columns are based on daily data: they shows that our results, particularly in the tail of the distribution of CIP deviations, are robust to calculating the deviations using interest on excess reserves rather than LIBOR and to considering two and three month event windows. The sixth column conducts a pre-event falsification test and compares August 2011 to October 2011. We do not obtain statistically significant differences. This suggests that our results are not just a manifestation of a pre-existing trend. The seventh column uses more data to compute standard errors by bootstrapping not just over currencies but also over alternative monthly event windows centered a month sampled from January 2009-October 2010 (excluding December due to year end volatility). This tightens the standard errors for the effect of the swap line change at the center of distribution (i.e. the mean/median) but reduces the significance of the estimated effect on the tail.

B.5 Difference-in-differences CIP estimates: placebos

The change in the swap line rate on November 30th 2011 occurred simultaneously with an extension of the swap arrangements. Our predictions relate to the swap line rate not to the length of the swap line arrangement. To rule out that the extensions explain our results we consider as placebos four other event dates: May 9th 2010; December 21st 2010; June 29th 2011 and December 13th 2013. These all correspond to dates where the swap arrangements were renewed or extended without any change in the swap rate. Figure 11 summarizes the results in the form of histograms of the distribution of daily CIP deviations over relevant months. As can be seen these extensions are not associated with any major shift in the distribution of CIP deviations.

B.6 Difference-in-differences CIP estimates: alternate CIP measures

For swap line currencies, Figure 12 presents the equivalent to Figure 3 when computing the CIP deviation using OIS rates rather than LIBOR rates. The shift in the distribution following the tightening of the swap line rate is clear.

Table A3: Robustness of Difference-in-Differences Results on CIP deviations

| | Quote Data | | Daily Data | | | | |
	(1) Weighted	(2) Non-European Currencies	(3) Nov vs Jan, Interest on Excess Reserves	(4) 2 month window	(5) 3 month window	(6) Falsification (Aug vs Oct)	(7) Bootstrap Alternative Monthly Event Windows
Mean	-.214	-.162***	.035	-.121	-.074	-.065	-.184**
		(0.056)	(.056)	(.079)	(.079)	(.090)	(0.090)
Median	.033	-.182**	-.071	-.113	-.113	-.046	-.146*
		(0.083)	(.149)	(.326)	(.326)	(.084)	(0.087)
75 %tile	-.326	-.116***	-.093	-.163	-.127	.062	-.155
		(0.016)	(.134)	(.123)	(.096)	(.160)	(0.105)
90 %tile	-.607	-.096***	-.284***	-.252***	-.254**	-.179	-.281
		(0.018)	(.102)	(.104)	(.100)	(.267)	(0.211)
N	288374	157257	430	850	1,290	440	430

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table presents the equivalent of the difference in differences estimates 5 in table 1 in the main text for alternative specifications. Column (1): Equivalent to Column (1) in table 1 (baseline) but with quote-level observations reweighted so each currency has equal weight. Column (2): Equivalent to baseline but compares JPY, CAD to AUD, NZD. Column (3): As Column (7) in table 1 but recompute the CIP deviation using the interest rate on excess reserves rather than Libor rates. Column (4): As Column (7) in table 1 but two month event window, Oct-Nov 2011 versus Jan-Feb 2012. Column (5): As Column (7) in table 1 but three month event window, Sep-Nov 2011 versus Jan-March 2012. Column (6): Placebo study, August 2011 2011 versus October 2011; daily CIP data versus USD using Libor rates. Column (7): As Column (7) in table 1 but bootstrapped standard errors computed by randomly selecting event months between January 2009 and November 2011 (excluding windows that overlap year end) and block bootstrapping currencies with replacement. *** denotes significance at the 1% level; ** 5% level; * 10% level. Standard errors, block bootstrapped at the currency level, in brackets (excepting columns(1),(11)).

Figure 11: Daily CIP deviations histograms for treated and non-treated currencies around swap line extensions
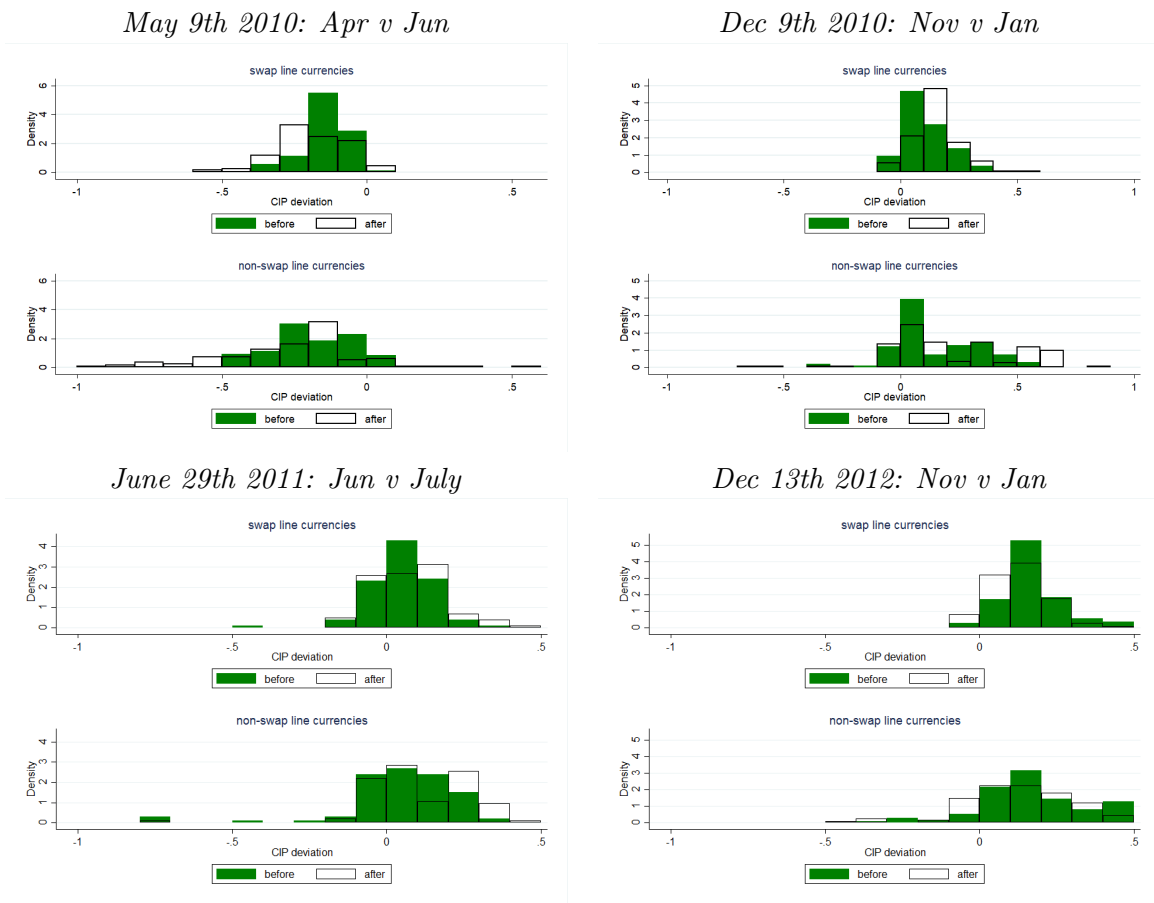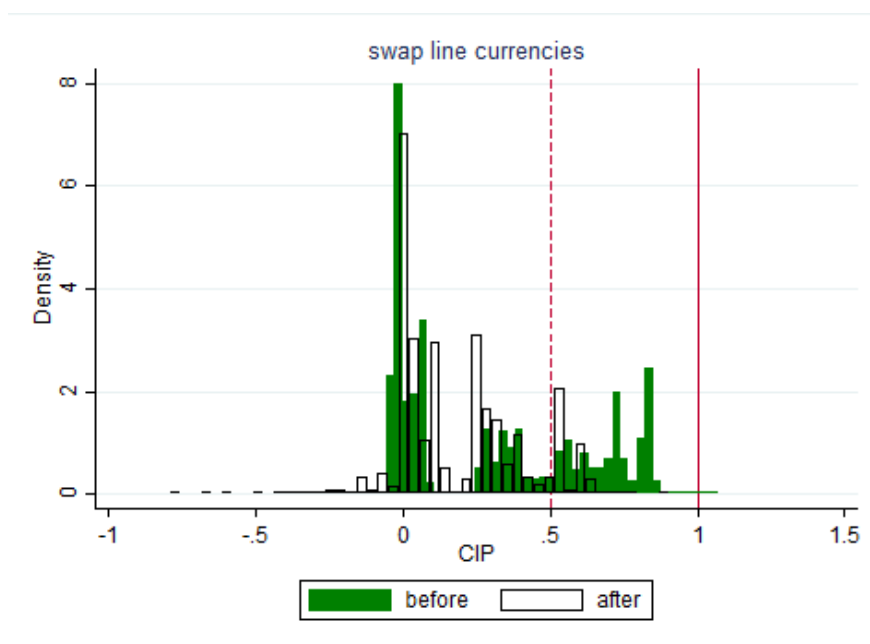
Figure 12: Price quote CIP deviation histograms for swap line currencies using OIS rates: 23-29 of November versus 8-13 December

B.7 Additional results on post-2015 ceiling violations

Figure 9 presents one-week OIS CIP deviations vis-a-vis the USD for the five swap line currencies in the period after 2015. Spikes at quarter end sufficient to breach the swap line ceiling are clearly visible.

Figure 14 presents the equivalent of figure 4 across all quarter ends (excluding year ends) between 2016 and 2018 where there were sustained ceiling violations. Note that 2016Q1, 2018Q2 and 2018Q3 did not see an extended period of ceiling violations across most currencies. As can be seen, ceiling violations are typically bracketed by the swap line operations.

Figure 15 presents the equivalent of panel (a) in figure 5 for the GBP, CHF and JPY. CHF and GBP display similar patterns to the EUR. There is a single Bank of England swap line operation on August 3rd-4th 2016, which had a GBP ceiling violation persisting through the settlement date. Hence, the estimates of $\beta_{j,1}^1$ and $\beta_{j,1}^2$ are not a precise zero for the GBP unlike the CHF and EUR. For the JPY, ceiling violations regularly persist through a BoJ swap line operation (this is also visible inspecting figure 13). This is despite the BoJ, unlike the SNB or BoE, making positive allotments at the USD operation. As described this may reflect a long settlement cycle with the BoJ's operation. Alternatively, there may also be stigma for Japanese banks associated with the swap line.

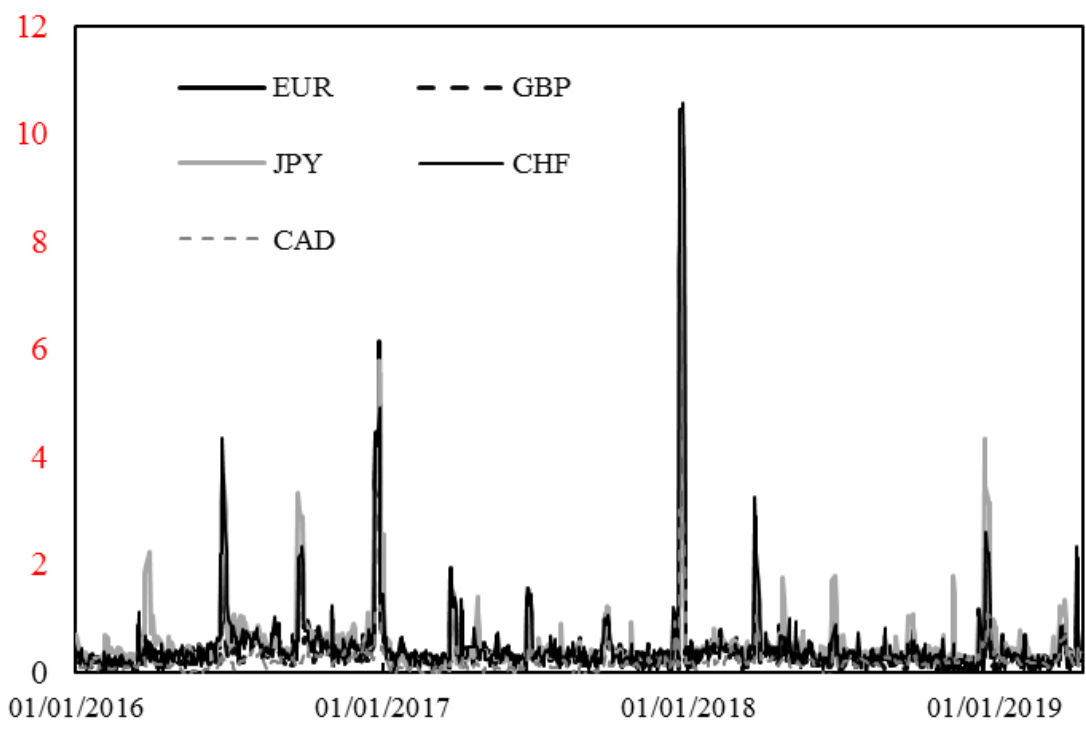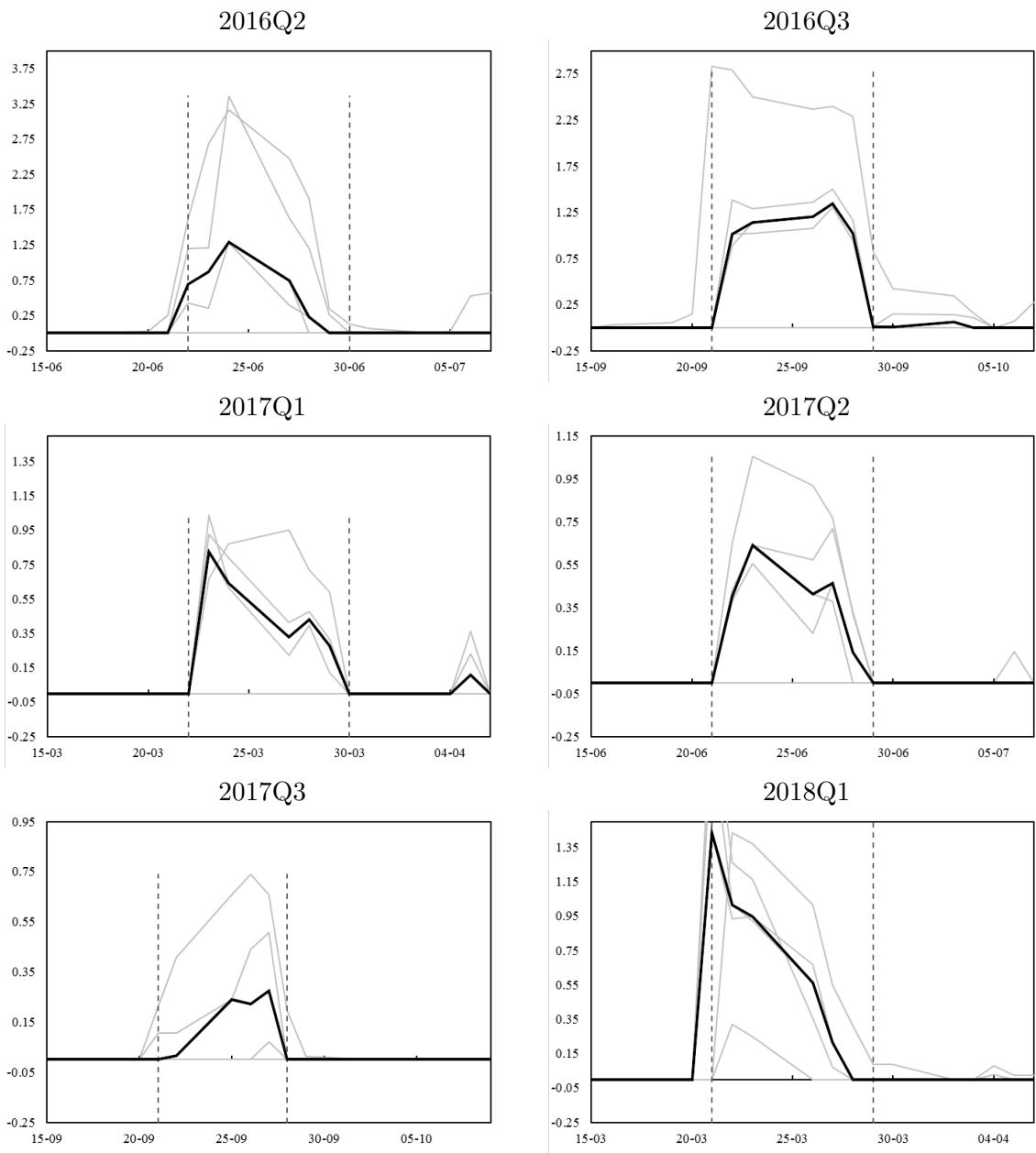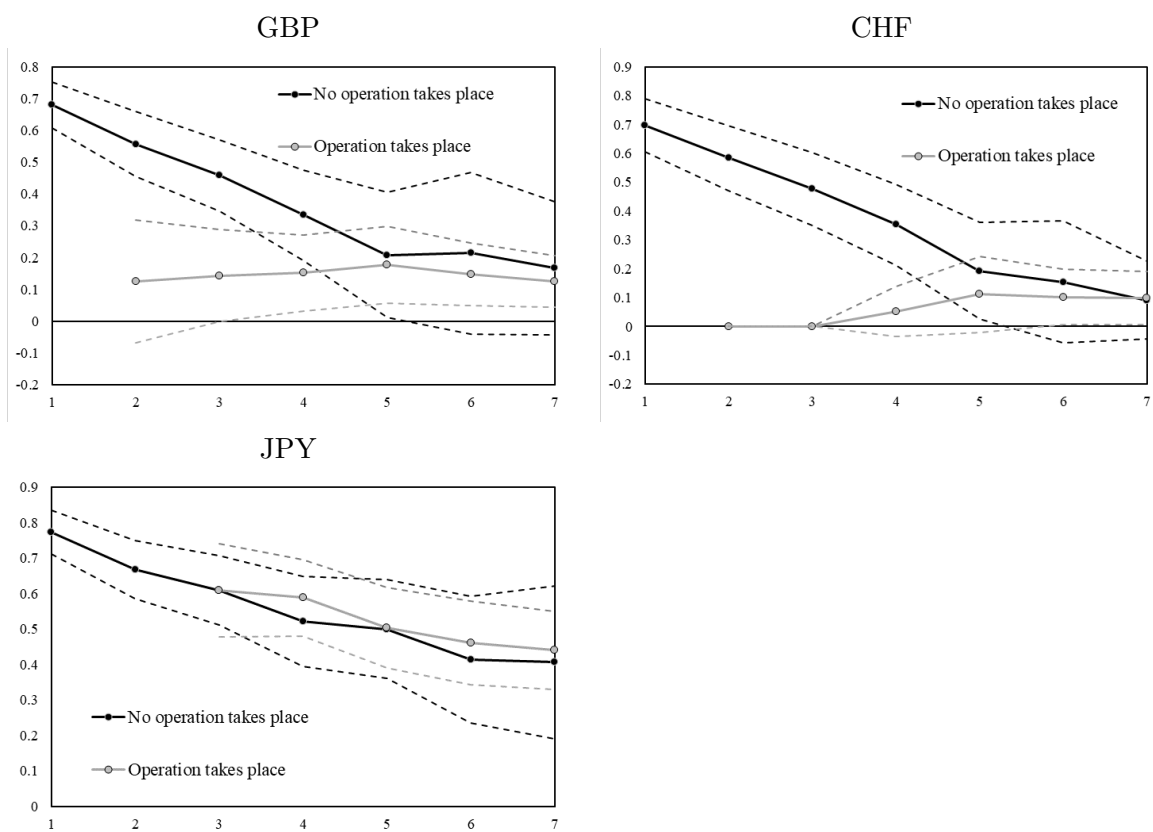Figure 13: CIP deviations after 2015

Figure 14: Daily CIP deviation minus swap line ceiling around quarter ends

Notes: See notes to figure 4.

Figure 15: Linear probability estimates of CIP deviation breaking the ceiling: GBP, CHF, JPY.

Notes: See notes to panel (a) in figure 5.

Table A4: Robustness of fixed-effects panel regression on investment flows

	(1)	(2)	(3)
	falsification, four weeks prior	*include lag*	*collapse window, bootstrap errors*
$Post_t \times Swap_a$	-0.0010	0.0879*	0.0799*
$\times USDBond_b$	(0.023)	(0.050)	(0.045)
$n_{a,b,t-1}$		-0.1200***	
		(0.014)	
N	137850	205074	43362
$bank \times period$ f.e.	Yes	Yes	Yes
$bank \times bond$ f.e.	Yes	Yes	Yes
$period \times bond$ f.e.	Yes	Yes	Yes

Notes: Further estimates of equation (11) as robustness of table 3. Column (1): falsification study using an event window of four weeks before. Column (2): include the flow in the previous day as a further explanatory variable. Column (3): collapse the sample into pre- and post announcement with means and bootstraps errors at the firm level. Otherwise, standard errors clustered at the bank and bond level in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.

B.8   Robustness of triple-diff bond flows estimates

Table 3 presented triple-difference estimates of the effect of the swap line on demand for dollar denominated bonds. Table A4 considers the robustness of these estimates.

The first column shows a falsification test, reestimating the regression on an event window four weeks prior to the swap rate change; we find no evidence of an effect, suggesting again that our results are not a manifestation of a pre-existing trend.

The second column introduces the flow in the previous day to show that possible inertia in portfolio adjustment is not affecting our results.

The third column is more conservative with regards to inference. We collapse the observations into pre- and post-event averages to reduce the autocorrelation in our data. We also block bootstrap the standard errors at the bank level to address the fact the we have a relatively small number of banks in our sample. This has no impact on our results.

B.9   Robustness of bank equity returns estimates

Table A5 presents the equivalent to Table 5 when we compute excess returns additionally controlling for the Fama-French size (SML), book to market (HML), profitability (RMW) and investment (CMA) factors from Fama and French (2015). This makes no meaningful difference to the results.

Table A5: Average bank excess returns after swap line rate change: excess returns relative to 4 Fama-French factors

	Swap Line Banks		US Banks	Other Banks
	US	*No US*		
	Presence	*Presence*		
Average	0.0272**	0.0101	0.0048	-0.0033
	(0.0131)	(0.0067)	(0.0105)	(0.0112)
Size Weighted	0.0241**	0.0298***	0.0206***	0.0029
	(0.0122)	(0.0084)	(0.0054)	(0.0106)
N	36	72	309	24

*Notes: Excess returns computed over 3 days using a beta to local market return and the SMB, HML, RMF and CMA Fama-French factors estimated over the 100 days prior to 01/11/11. Swap line countries: Canada, Euro-Area, Switzerland, Japan, United Kingdom. Non swap line: Australia, Norway, Denmark, Sweden, US. Bank returns and resident country sourced from Datastream. US presence taken from "U.S. Agencies and Branches of Foreign Banking Organisations" dataset. Bootstrapped confidence intervals constructed by randomly sampling event dates over the window 01/06/10-31/11/11. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.*

B.10 CIP deviations and the allotments at swap line operations

Do higher CIP deviations result in higher drawings from the swap line? Figure 16 shows the allotment at 1-week operations of the ECB and Bank of Japan, the two central banks that had significant drawings even after the intense phase of the crisis, until end 2015.[37]

Let $q_{j,t}$ be the flow of dollars allocated by a central bank in swap-line country j at a one-week operation at date t. We estimate the following regression over time for each country j:

$$\log(q_{j,t}) = \alpha_j + \beta_j x_{j,t-1} + \varepsilon_{j,t}. \tag{A6}$$

The terms of these dollar operations were announced in advance and were well known at most operation dates. Moreover, these were full allotment auctions, where banks could obtain as much funding as they wanted at this rate. Thus, the supply of dollars was horizontal and known. Therefore, this regression identifies the demand curve for central bank liquidity.

Table A6 shows the results. The elasticity of demand for dollars by European banks is 2.2%, while that by Japanese banks is 2.4%. Both elasticities are positive, as the theory predicts, and surprisingly close to each other.[38] The last column of the table presents a different estimate, of the elasticity of euros lent out by the ECB in its 1 week operations with respect to the marginal cost of funds, the 1 week euro LIBOR-OIS spread. The elasticity is 1.6%, not statistically significantly different from the elasticity of demand for dollars from the ECB by the same set of banks. This confirms the tight link between conventional lending facilities and the unconventional swap lines

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[37]The BoJ commenced 1 week auctions on the 29th of March 2011.

[38]We have also estimated a Heckman model to adjust for any potential selection effect from the operations where no amount was allotted. This yielded very similar results.

Figure 16: Allotment at USD operations by ECB and BoJ, and CIP deviations

ECB   **BoJ**
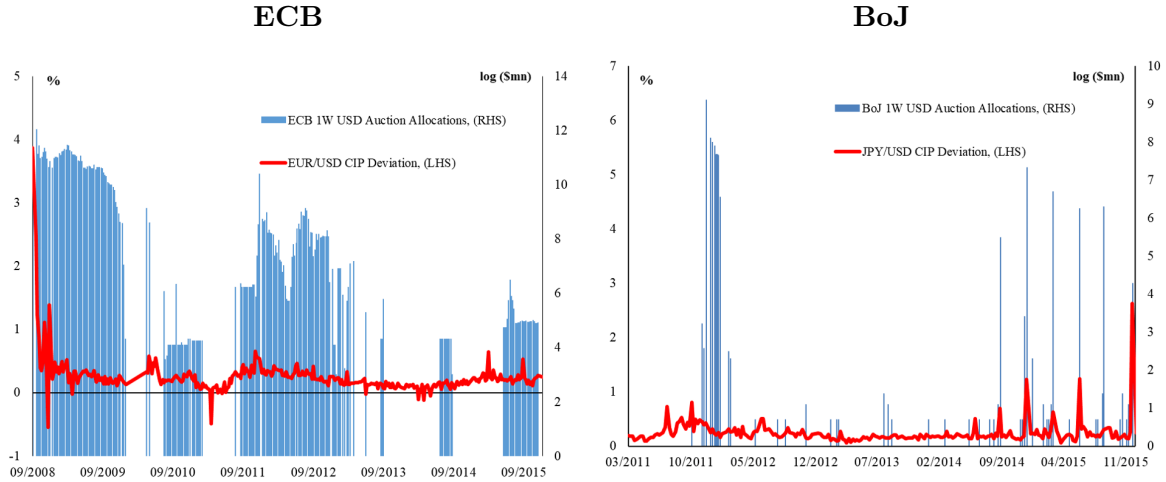
Table A6: Auction allotments and funding costs

	ECB: USD Auctions $\log(q_{j,t})$	BoJ: USD Auctions $\log(q_{j,t})$	ECB: EUR Auctions $\log(q_{j,t})$
$x_{j,t-1}$: CIP Deviation	2.2353***	2.4262***	
	(0.527)	(0.9891)	
$x_{j,t-1}$: 1-week Libor-OIS			1.5804***
			(0.587)
N	217	90	388
Adjusted R^2	0.08	0.14	0.14

*Notes: Estimates of equation (A6). CIP deviation is the 1-week EUR or JPY vis-a-vis the USD on the day prior to the auctions. We consider auctions where a positive amount is alloted between the 19th September 2008 (the date of the first multilateral Federal Reserve swap agreement) through to 31st December 2015. Robust standard errors are in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.*

that was the main result of section 2.[39]

C Data Appendix

Appendix C.1 describes the data used to measure CIP deviations and the ceiling in section 3. Appendix C.2 the data on bond flows, and appendix C.3 the data on bank equity returns, used in section 4. Appendix C.4 describes the data on central-bank auctions used in appendix B.10.

C.1 Financial market data used to construct CIP deviations and ceilings

We obtain the data on interest rates, spot and forward exchange rates primarily from Refinitiv Datastream at a daily frequency. Exceptions include some OIS rates, which are taken from Bloomberg and some central bank policy rates, which are taken directly from the institution's website. Quote data on FX swaps and spot exchange rates are taken from Refinitiv Datascope. Here we list specific data series along with the source used to construct CIP deviations $x_{j,t}$, and swap line ceilings $c_{j,t}$.

Table A7 presents summary statistics by currency vis-a-vis the USD for two alternative measures and samples of daily CIP deviations: (i) where i and i^* are defined as 1-week OIS rates over the period following 19th September 2008 for swap line currencies as used in sections 3.7 and 3.8, and appendix B.10; and (ii) where i and i^* are defined as 1-week LIBOR rates over the period 1st January 2010 to 31st of October 2011 for the treatment and control group so as to summarise deviations in the build up to the change in the swap line rate on the 30th November 2011 as analysed in section 3.6.

Swap Line Currencies data:

USD: The 1-week OIS rate is Datastream ticker OIUSDSW. The 1-week LIBOR rate is Datastream ticker BBUSD1W.

EUR: The 1-week OIS rate is Datastream ticker OIEURSW. The 1-week LIBOR rate is Datastream ticker BBEUR1W. The spot price of a USD in EUR is Datastream ticker EUDOLLR. The 1-week forward price of USD in EUR is Datastream ticker EUDOL1W. The ECB deposit facility rate is Datastream ticker EURODEP. The ECB main policy rate is the rate on the short term repo facility, Datastream ticker EURORPS. For the quote data: the 1 week EUR FX swap versus USD has Datascope RIC EURSW=, the spot exchange rate is EUR=.

GBP: The 1-week OIS rate is Datastream ticker OIGBPSW. The 1-week LIBOR rate is Datastream ticker BBGBP1W. The spot price of a USD in GBP is Datastream ticker UKDOLLR. The 1-week

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[39]From the perspective of the recipients, Rose and Spiegel (2012) find a cross-sectional relation between the amount of dollars lent out by the Fed, and the CDS rates of the recipient countries.

forward price of USD in GBP is Datastream ticker UKUSDWF. The BoE main policy rate is the Bank rate, Datastream ticker LCBBASE. The BoE deposit facility rate is Datastream ticker BOESTOD, with policy rate -25bp prior to 20th October 2008. From 5th March 2009 the Bank of England switched to a floor system and we set the deposit facility rate equal to the policy rate. For the quote data: the 1 week GBP FX swap versus USD has Datascope RIC GBPSW=, the spot exchange rate is GBP=.

JPY: The 1-week OIS rate is Bloomberg ticker JYSO1Z Curncy. The 1-week LIBOR rate is Datastream ticker BBJPY1W. The spot price of a USD in JPY is Datastream ticker JAPAYE$. The 1-week forward price of USD in JPY is Datastream ticker: USJPYWF. The BoJ main policy rate is Datastream ticker JPCALLT; the BoJ opened its complementary deposit facility on 31/10/2008, the deposit interest rate has been equal to policy rate since its introduction, hence we always treat the deposit facility rate as the policy rate (see weblink). For the quote data: the 1 week JPY FX swap versus USD has Datascope RIC JPYSW=, the spot exchange rate is JPY=.

CAD: The 1-week OIS rate is Bloomberg ticker CDSO1Z Curncy. The 1-week LIBOR rate is Datastream ticker BBCAD1W. The spot price of a USD in CAD is Datastream ticker CNDOLL$. The 1-week forward price of USD in CAD is Datastream ticker USCADWF. The BoC main policy rate comes directly from the BoC website and the series code is V39078 (Bank Rate). The deposit facility rate is the lower corridor rate, series code V39076. For the quote data: the 1 week CAD FX swap versus USD has Datascope RIC CADSW=, the spot exchange rate is CAD=.

CHF: The 1-week OIS rate is Bloomberg ticker BBCHF1W. The spot price of a USD in CHF is Datastream ticker SWISSF$. The 1-week forward price of USD in CHF is Datastream ticker USCHFWF. For technical reasons, the CHF TOIS fixing in not an effective gauge of risk free interest rates in CHF (and has recently been replaced with SARON). Since the SNB directly targets CHF LIBOR rates, and the CHF 1-week LIBOR adheres closely to that target (subject to a corridor system) we prefer to use always LIBOR rates for our CHF basis. Our regression results in section 3.7 are robust to using the TOIS fixing as an alternative, but with a CHF/USD basis based on TOIS there are persistent and large ceiling violations in 2015. The SNB main policy rate is Datastream ticker SWSNBTI (3 month LIBOR Target). The deposit facility rate is the lower bound on the 3 month LIBOR target, Datastream ticker SWSNBTL. For the quote data: the 1 week CHF FX swap versus USD has Datascope RIC CHFSW=, the spot exchange rate is CHF=.

Non-Swap Line Currencies data: 1-week OIS rates are not always available for all the currencies that are not part of the swap line network. Hence we exclusively compute bases using LIBOR and the central bank interest on excess reserves (this also applies to the equivalent USD interest rates).

AUD: The 1-week LIBOR rate is Datastream ticker GSAUD1W. The spot price of a USD in AUD is the inverse of Datastream ticker AUSTDOI. The 1-week forward price of USD in AUD is Datastream

ticker USAUDWF. The interest rate on excess reserves is the RBA cash rate, Datastream ticker RBACASH, less 25 basis points. For the quote data: the 1 week AUD FX swap versus USD has Datascope RIC AUDSW=, the spot exchange rate is AUD=.

DKK: The 1-week LIBOR rate is Datastream ticker CIBOR1W. The spot price of a USD in DKK is Datastream ticker DANISH$. The 1-week forward price of USD in DKK is Datastream ticker USDKKWF. The interest rate on excess reserves is the daily minimum of the Danmarks National-bank's official certificates of deposit rate sourced directly from DNB statbank table DNRENTD and the Danmarks Nationalbank's Current Account Rate, Datastream ticker DKFOLIO. For the quote data: the 1 week DKK FX sawp versus USD has Datascope RIC DKKSW=, the spot exchange rate is DKK=.

NOK: The 1-week LIBOR rate is Datastream ticker NWIBK1W. The spot price of a USD in NOK is Datastream ticker NORKRO$. The 1-week forward price of USD in NOK is Datastream ticker USNOKWF. Norway operates a floor system, so the interest rate on excess reserves is the Norges Bank's reserve rate, Datastream ticker NWRESVR. For the quote data: the 1 week NOK FX swap versus USD has Datascope RIC NOKSW=, the spot exchange rate is NOK=.

NZD: The 1-week LIBOR rate is Datastream ticker GSNZD1W. The spot price of a USD in NZD is Datastream ticker NZDOLL$. The 1-week forward price of USD in NZD is Datastream ticker USNZDWF. The interest rate on excess reserves is the RBNZ official cash rate, Datastream ticker: NZRBCSH. For the quote data: the 1 week NZD FX swap versus USD has Datascope RIC NZDSW=, the spot exchange rate is NZD=.

SEK: The 1-week LIBOR rate is Datastream ticker SIBOR1W. The spot price of a USD in SEK is Datastream ticker SWEKRO$. The 1-week forward price of USD in SEK is Datastream ticker USSEKWF. The interest rate on excess reserves is the Riksbank's deposit facility rate, Datastream ticker SDDEPOS. For the quote data: the 1 week SEK FX swap versus USD has Datascope RIC SEKSW=, the spot exchange rate is SEK=.

Computing CIP deviations from FX swap quotes: We download all available quotes for 1 week FX swaps versus USD for the ten currencies in our sample on Thomson Reuters Datascope over the period November 2011 to 31st January 2012. We then drop quotes that occur over the weekend, on holidays or between 21:40-06:50 London time. This leaves us with 1,763,608 unique quotes across 10 currencies in November 2011 (671,388), December 2011 (534,971) and January 2012 (557,249). We take the mid swap price in swap points and match each quote to the mid-spot exchange rate in the minute that the quote was taken. The mid spot is calculated as the average of the mid open and mid close in the minute interval; these are computed directly by Datascope using the intraday summary feature. This enables us to calculate the implicit outright forward

price in the swap and hence the log forward premium. Note that GBP, AUD and NZD swaps and spot exchange rates are quoted in USD per local currency unit and hence we transform the quotes accordingly. We then use the relevant daily interest rate fixing (OIS/LIBOR) to compute the CIP deviation.

Ceiling violations: Daily ceiling violations are defined as the indicator $\mathbf{1}(viol_{j,t}) = \mathbf{1}(x_{j,t} > (i_t^s - i_t) + (i_{j,t}^{p*} - i_{j,t}^{v*}))$ where $x_{j,t}$ is the 1 week OIS CIP deviation vis-a-vis the USD on day t for currency j. In addition, we allow for 2bp of grace before defining the ceiling as violated.

Table A7: CIP deviations summary statistics (1 week vs USD)

	mean	std. dev.	median	25th %-ile	75th %-ile	N
OIS based CIP Deviations: 19 Sep 2008 - 31 Dec 2015						
EUR	.27	.43	.21	.14	.29	1900
GBP	.12	.32	.08	.03	.11	1900
JPY	.29	.44	.19	.14	.27	1900
CHF	.34	.55	.24	.13	.37	1900
CAD	.09	.23	.07	.02	.12	1900
LIBOR based CIP Deviations: Jan-2010 to October-2011						
EUR	.2	.2	.17	.11	.25	767
GBP	.085	.087	.078	.013	.14	767
JPY	.2	.21	.16	.099	.23	767
CHF	.24	.28	.2	.093	.33	767
CAD	.033	.067	.037	-.001	.076	767
SEK	.11	.15	.12	.043	.18	767
DKK	.46	.23	.45	.34	.55	767
NOK	.26	.18	.25	.21	.32	767
AUD	-.0083	.26	.033	-.016	.086	767
NZD	.014	.15	.039	-.019	.09	767

Notes: Sample covers trading days from 19th September 2008 (date of the first multilateral Federal Reserve swap agreement) through to 31st December 2015.

C.2 Bond flow data

C.2.1 Data Sources and Coverage

The starting point is to establish a universe of potentially-traded corporate bonds in November 2011. We do this by breaking out the securities used in any of the following Bank of America/Merrill Lynch Corporate Bond Indices (BAML) as of 30th January 2012[40]: *Global Broad Market Corporate Index;*

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[40]This is the earliest observation we have, but the index composition is unlikely to change dramatically in the two months since the event. Note that this omits bonds that mature before 30 January 2012 so bonds with only a couple of months of residual maturity are excluded from our sample.

Global Emerging Market Credit Index; Global High Yield Index; U.S. Corporate Master Index; U.S. High Yield Master II Index; Sterling Corporate Securities Index; Sterling High Yield Index; EMU Corporate Index; Euro High Yield Index. This provides a list of corporate bonds (by ISIN) and their relevant charactistics (Issuer, Rating, Face Value, Currency etc.). From this list we then exclude bonds issued by financials and banks (industries "CASH" and "FNCL" in the BAML data). This leaves us with 8512 unique bonds.

Our data on bond transcations comes from the UK financial conduct authority's (FCA) ZEN dataset. This data is confidential regulatory data collected under the EU Markets in Financial Instruments Directive (better known as MIFID I). The coverage is as follows. (A) All trades by UK-regulated firms in bonds admitted to trading on regulated markets. (B) All trades by EEA-regulated firms in bonds that are (i) admitted to trading on regulated markets, and (ii) issued by entities where the registered office is in the UK. It is useful to breakdown this definition. The term admitted to "admitted to trading on regulated markets" means that the bond is listed on an exchange somewhere worldwide (not necessarily in the UK or EEA). This requirement is also bond specific, not trade specific, so as long as the bond is traded on a regulated market somewhere, OTC transactions in the bond still need to be reported. UK-regulated firms includes the subsidiaries of foreign banks (including EEA banks) that operate in the UK and hence are regulated by the FCA. In the data, the large majority of trades occur in bonds where the issuer is not based in the UK. Hence the second requirement that EEA regulated entities report their trading in UK bonds is less relevant for determining the sample.

If the firms on either side of the trade are covered by the data then we will see both legs of a trade, in that sense there is double counting in our analysis. However, we sum across trades to generate daily flows and since the bonds can be supplied by firms outside the sample it is not the case that the net flow needs to equal zero.

C.2.2 Sample selection

We take the intersection between the bonds in the BAML indices and trades recorded in the ZEN data for trading days between 14th November and the 15th of December 2011 (we exclude bonds issued after 14th November). The sample period consists of the five weeks centred around the swap line rate change on the 30th of November and contains 98,252 individual trades.

Banks: We use a pre-existing Bank of England algorithm to identify most of the firms trading in the dataset; the remainder we identify via web searches on the firm's name. There may be multiple legal entities trading under the umbrella of a given bank or securities firm and we merge these accounts at the group level. One consequence of this is that we cannot distinguish between trades that a bank makes on behalf of clients versus their own books. This is a weakness in the data. We focus solely on the firm that reports the transaction rather than the counterparty. This means that we do not attempt to discern trades that, for whatever reason, are not reported by a firm by

looking at trades where that firm is the counterparty. This is for simplicity and to limit mistaken double counting.

159 firms report trades in securities at the intersection between the BAML and ZEN data. To ensure similarities between treatment and control groups we drop firms who are not banks (53 firms). Many banks in the data only trade once or twice over the sample period. Our regression design, as articulated in the main text, uses a balanced panel of net daily flows by trading banks into specific bonds. Therefore we exclude infrequently trading banks to avoid adding large numbers of zeros into the sample. We drop banks who transact in fewer than 4 bonds a day on average and trade less than 80% of trading days. Adding inactive banks does not meaningfully affect our point estimates but raises the standard errors substantially. This leaves us with 26 banks, 19 of which are headquartered in countries where the central bank had acccess to a swapline.

Bonds: The intersecton between the ZEN and BAML datasets covers 1703 unique bonds. Many of these bonds are infrequently traded and only appear a few times in the dataset: the median bond is traded 30 times and the bond in the 25th percentile traded just 7 times. Furthermore, some bonds have trades that are heavily concentrated in only a couple of days within our sample. Again to avoid a sparse panel, we exclude any bond where it is not the case that at least one trading firm has non-zero net flows into the bond in at least 50% of trading days. This leaves us with 77,086 trades covering 790 unique bonds, issued by 167 unique entities, of which 69 are USD denominated.

C.2.3 Data handling

For each bank we calculate the net flow into a particular bond each trading day. As a measure of bank activity we take the sum of the absolute value of these net flows across all 790 bonds in our sample averaged across the 25 trading days. We then scale the net flow into each bond by each bank by this activity measure. This is the dependent variable in our regression. We set up our dataset as a balanced panel such that when no trades are recorded in a day between a particular bank-bond pair a zero entry for the net flow is added.

The ZEN data can contain erroneous entries. These can substantially distort the results if the trade is recorded at the wrong order of magnitude: e.g. if the return is for 10 million units rather than the 10,000 actually traded. This is apparent in the data: some trades are for many multiples of the outstanding market value of the bond. To circumvent this issue we trim the daily flow data at +/-1%, dropping observations that are very large in absolute magnitude.

We convert all currencies into USD using the prevailing exchange rates on the 1st of November 2011.

Table A8: Summary statistics for the bond flows data

	mean	std. dev.	median	25th %-ile	75th %-ile	N
By Bond						
All bonds						
Trades per day	3.9	3.3	2.8	1.8	4.8	790
Daily volume ($ '000s)	2496	2083	1950	1095	3191	790
Average net daily flow ($ '000s)	15	404	15	-195	234	790
Residual Maturity (years)	6.3	6.1	4.6	2.7	7.2	790
High Rating (A- or greater = 1)	0.5	0.5	1	0	1	790
Face Value ($ mn)	1116	643	1024	683	1365	790
USD bonds						
Trades per day	3.6	2.3	3.1	2.1	4.8	69
Daily volume ($ '000s)	1832	2018	1075	419	2007	69
Average net flow ($ '000s)	-35	278	-18	-146	108	69
Residual Maturity (years)	7.2	7.9	4.3	2.5	7.8	69
High Rating (A- or greater = 1)	.61	.49	1	0	1	69
Face Value ($ mn)	1271	734	1000	750	1750	69
By Bank						
Trades per day	119	99	98	30	190	26
Daily volume ($ '000s)	75833	69965	59441	10099	122618	26
Average trade size ($ '000s)	616	314	618	421	793	26
Average net flow ($ '000s)	447	11882	21	-3723	5359	26
Activity measure ($ '000s)	44906	39253	38174	6090	78302	26

C.2.4 Summary Statistics

Table A8 presents summary statistics for the different bonds and banks in our sample. The average bond trades 3.9 times a day with an average trade size of $616,000 and a volume of $2.5mn. The dollar denominated bonds have similar characteristics, both in terms of trading behaviour and residual maturity, face value, etc. If we observed the universe of trades, every bond would be in zero net supply and there would be no net daily flow into any bonds. This is not exactly the case in our data but average net daily flows are typically relatively small. The average bank in our sample trades 119 times per day with an average volume of $76mn. The sum of absolute net flows into all bonds, our activity measure, averages about $45mn per day across our 26 banks.

C.3 Bank equity returns

We obtain returns on bank equity from Datastream. We extract return indices for all banks listed in datastream in the following markets: U.K., Switzerland, Canada, Japan (non-Euro Area swapline banks); Germany, France, Spain, Italy, Belgium, Portugal, Netherlands, Ireland, Austria (Euro-area

swap line banks); Australia, Norway, Denmark, Sweden (banks in countries without a swap line); and the U.S. We extract the total market return for each country to serve as the benchmark for computing excess returns. We exclude banks for where there are gaps in coverage anytime between 1st July 2010 and the 31st of December 2012. We exclude banks with very illiquid stocks where the the price changes in less than 50% of trading days. This leaves us with the sample described in the main text.

The market capitalization of the banks is calculated as of 1st November 2011 and converted into USD using the prevailing exchange rate.

In the robustness section we additionally use the Fama-French size (SML), book to market (HML), profitability (RMW) and investment (CMA) factors to compute excess returns. These are downloaded directly from Ken French's website.

C.4   Data on Central Bank Operations

In appendix B.10 we use data on operations by the ECB and the Bank of Japan. Summary statistics are presented in table A9. The data description for each central bank is below.

ECB: The operation data was downloaded from the ECB's history of open market operations website. Dollar Operations are those where the operation currency is listed as USD. We define a one week operation to include any duration between 5 and 16 days. This maximum is to capture that the regular one week auction is substituted by a two week auction around year end. We focus solely on reverse transactions. This leaves us with 352 auctions of which 217 have a positive amount alloted between 19th September 2009 and 31st December 2015. All bar one operation (26th September 2009) have unlimited allotments at a fixed rate (dropping this observation does not affect the results).

Euro operations are all liquidity providing auctions where the operation is denominated in EUR with a duration greater than our equal to 5 days and less than or equal to 13 days. This largely captures the ECB's main refinancing operation. We consider auctions between 1st September 2009 and 31st December 2015: this provides 388 operations all of which have a positive amount allotted.

BoJ: The data was downloaded from Market Operations by the Bank of Japan section of the BoJ's website. We combine details of the BoJ's U.S. Dollar Funds-Supplying Operations against Pooled Collateral from the monthly tables to draw together a database of all USD operations by the BoJ. We then focus on the operations where the duration is between 6 and 21 days (as with the ECB the 21 day operation replaces the weekly operation over the year end of 2012). The first operation took place in 29th of March 2011 and there were 238 in total by the time our sample ends at the 31st December 2015. Of those operation, 90 had a positive amount allotted.

Table A9: Operation summary statistics

	mean	std. dev.	median	25th %-ile	75th %-ile	N
ECB USD Operation						
Amounts Alloted ($mn)	16393	27251	1580	140	24192	217
Number of Bidders	8.5	13	3	1	9	217
ECB EUR Operations						
Amounts Alloted (Eur mn)	126709	61089	110732	87396	156731	388
Number of Bidders	186	163	134	86	180	388
BoJ USD Operations						
Amounts Lent ($mn)	291	1120	2	1	3	90

Notes: 1 week operations over from 19th September 2008 (date of the first multilateral Federal Reserve Swap Agreement) through to 31st December 2015. Operations where no amount is alloted are excluded.