Central Bank Swap Lines*

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Abstract

Swap lines between advanced-economy central banks are a new important part of the global financial architecture. This paper analyses their monetary policy effects from three perspectives. First, from the perspective of the central banks, it shows that the swap line mimics discount-window credit from the source central bank to the recipient-country banks using the recipient central bank as the bearer of the credit risk. Second, from the perspective of the transmission of monetary policy, it shows that the swap-line rate puts a ceiling on deviations from covered interest parity, and finds evidence for it in the data. Third, from the perspective of the macroeconomic effects of policy, it shows that the swap line ex ante encourages inflows from recipient-country banks into assets denominated in the source-country's currency by reducing the ex post funding risk. We find support for these predictions using difference-in-difference empirical strategies that exploit the fact that only some currencies saw changes in the terms of their dollar swap line, only some bonds in banks' investments are exposed to dollar funding risk, only some dollar bonds are significantly traded by foreign banks, and only some banks have a significant U.S. presence.

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1 Introduction

On September 11th 2001, U.S. money markets unexpectedly closed. A few foreign banks with significant dollar investments that were funded by rolling over financing from U.S. money markets found themselves in a crisis. The Federal Reserve resolved the problem with a novel emergency liquidity facility: the Fed would lend the Bank of Canada, the Bank of England, and the ECB up to $90 billion through a swap line against their local currency, which these central banks would then lend out to banks in their own jurisdictions. One month later, when money markets had reopened, the swap line was closed and a liquidity crisis was averted.

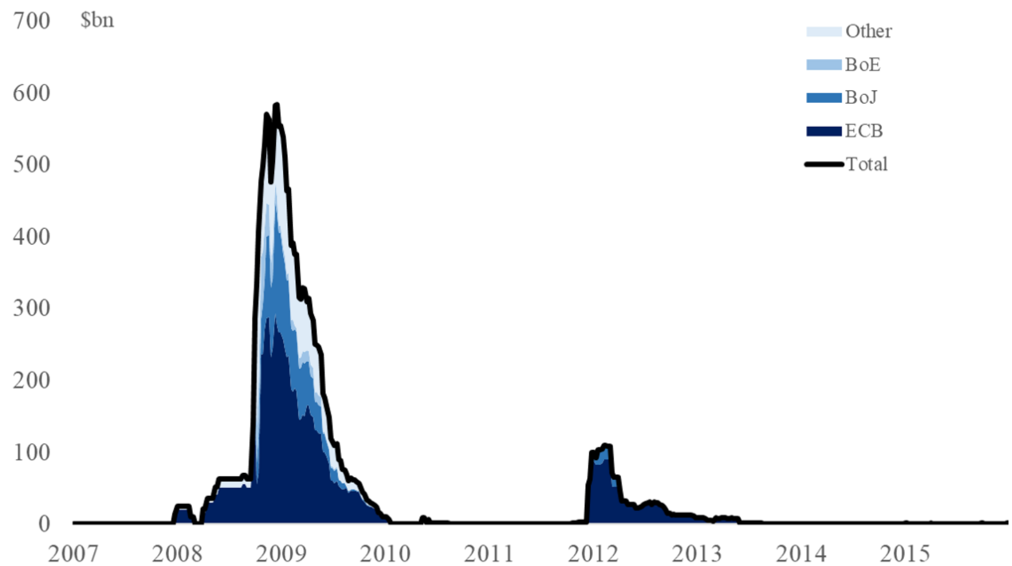
When the great financial crisis erupted, central banks revived this tool. In 2007, European banks, that over the preceding decade had become reliant on U.S. money markets, needed liquidity assistance. In December, a $20bn swap line was arranged with the ECB, and within one year a dozen other central banks. The lines came into use between September of 2008 and January of 2009, with the amount drawn peaking at $586bn; see figure 1. The swap lines were formally reintroduced in May of 2010 and made into permanent standing arrangements in October of 2013 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]

Swap lines are not limited to providing US dollars. For example, the Swiss National Bank established swap lines with the Polish and Hungarian central banks as these country's financial systems had extensively issued Swiss franc mortgages. In the last few years, the People's Bank of China established an alternative network of more than 100 active swap lines involving more than 40 other countries and a formal limit that exceeds $1 trillion. Today, there are an estimated 160 bilateral swap lines between central banks around the world, so many that the Wall Street Journal (2017) reported that: "The governor of the Reserve Bank of India on Sunday called on major central banks to extend their network of currency swap lines deep into emerging markets, saying a type of "virtual apartheid" in the provision of foreign currencies hampers efforts to fight financial instability." From exceptional, these swap lines have become permanent and large in the amounts allowed for, so that what is exceptional today is for a central bank to not have them. Discussions of the global financial architecture devote significant attention to them (e.g., di Mauro and Zettelmeyer, 2017).

This paper provides a first analysis of the role played by these new central bank swap lines

[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.

Figure 1: Federal Reserve dollar lending through its swap lines



in monetary policy and on the macroeconomy. It is composed of three parts studying the effect of the swap lines: on central bank balance sheets and operations; on financial markets and the transmission of policies; and on the macroeconomy through investment decisions.

We start by describing the terms and operation of the swap contracts. This clarifies that the swap lines provide a substitute for discount-window 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 were needed as a supplement to the traditional discount window, or to using private funding markets.

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 policy and deposit central bank rates in the recipient country, provides a hard ceiling on the deviations of covered interest parity (CIP) between the two currencies. Breaking this ceiling would give rise to an arbitrage opportunity. We turn to the data on CIP deviations since 2008 to confirm these results using three complementary empirical strategies: a difference-in-differences regression that uses a change in the Fed's swap rate, a time-series regression that exploits variation in domestic interest rates, and the estimation of the demand curve for liquidity, both domestic and foreign.

Then, we turn to the macroeconomic effects of the swap lines. A simple model of global banks and cross-border funding shocks predicts that the swap line reduces funding risk. A fall in the swap-line rate increases investment by recipient-country banks in origin-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 firms under the jurisdiction of a central bank with access to these swap lines and on U.S. dollar denominated corporate bonds, relative to banks not covered and to non-dollar bonds. This 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, finds 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 the price of the dollar corporate bonds held by European firms relative to other dollar bonds. This is consistent with the swap line being a lending facility of last resort that can prevent 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.

All combined, the theory and evidence support an important role for the swap lines in the global economy: (i) they perform a basic 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; and (iii) they incentivize cross-border gross capital flows, and they potentially prevent financial crises in source-country financial prices and in recipient-country financial institutions.

With regards to the literature, the role that lending facilities and their rates play in determining market rates, and the reaction of economic agents to funding shocks and liquidity insurance, have all occupied an enormous literature in macroeconomics, dating back at least to Bagehot (1873). Empirically testing these effects is typically hard because these policies have been around for a long time, and any changes to their operation arise in response to the state of the economy. Using a new facility, whose terms were experimented with, we are able to provide evidence that lending facilities have large effects on financial prices and investment decisions. Moreover, our evidence and simple model point to the need to incorporate global banks and multiple central banks into models of liquidity shocks and management in the tradition of Holmström and Tirole (2011) and Poole (1968).

Ivashina, Scharfstein and Stein (2015) show that, during the Euro-crisis, money market funds lent less to European banks. In turn, they participated less in dollar 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 bank lending, our focus is on asset markets, in particular the markets for currency, corporate bonds, and stocks of European banks. Moreover, we study a policy tool that can affect these. Brauning and Ivashina (2017) and Buch et al. (2018) also complement our study by finding a transmission of conventional interest-rate policy on global banks' foreign reserves and lending. We find instead a transmission for a new unconventional liquidity policy.

Over the past decade, a small but growing literature documented deviations from CIP (Du, Tepper and Verdelhan, 2018) and proposed explanations for them, tied to regulation (Borio et al., 2016; Avdjiev et al., 2016; Cenedese, Corte and Wang, 2017) or to debt overhang (Andersen, Duffie and Song, 2018). Our paper takes from this literature the existence of CIP deviations and a simple model to describe them, but adds to it the result that central bank swap lines put a ceiling on them and affect their average size and distribution, as well as affecting investment choices with macroeconomic consequences. Goldberg, Kennedy and Miu (2010) linked the swap lines to CIP deviations, while Baba and Packer (2009) documented a partial correlation between the quantity of dollars lent out under the swap lines and one particular measure of CIP deviations. We instead argue for an equivalence between swap lines and standard domestic liquidity facilities so that the former can be used to understand the latter; we use theory to prove a tight link between one particular measure of CIP deviations and the swap line price rather than quantity; we use identification strategies to assess causal effects; and we study the effect of the swap line 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; Rose and Spiegel, 2012, for recent examples). 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 the other central banks. These accounted for the bulk of activity during and after the financial crisis, and it helps 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 its policy rate, paid at the fixed term later, and settled in dollars. This is a standing facility, 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 has charged it. It asks for the same high-quality liquid assets as collateral that it asks for in other emergency 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 currency that was being held at the Fed.

From the perspective of the Fed, the end result is a standing lending facility of dollars to recipient-country 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 standard lending facilities. What is novel is the presence of the recipient central bank doing the monitoring, picking the collateral, and enforcing repayment. The swap lines therefore complement the array of liquidity facilities used by central banks by being geared towards foreign banks.

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 into circulation, being held and returned by the source central bank, and none of its policy rates change, so again 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, since terms are set today when the contract is signed. There is also no interest-rate risk, since the interest rate is set today as a spread over the policy rate. 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, but this is 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.[2] 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 needed to sustain a peg. Yet, with the modern swap lines, the source-country currency is not used right away to buy recipient-country currency and prop up 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 had no explicit target 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 by source-currency funding. 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

[2] There are many examples of confusion about the swap line in policy and general discussions, too many to mention. An exception is the lucid discussion in Kohn (2014).

conditionality.

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 only have their funding needs met, not their risk nationalized. Similarly, the swap lines do not emerge because of some general scarcity of dollars, but rather because solvent but source-currency illiquid recipient-country banks need them.

Finally, the swap line is not a subsidy from the source central bank to foreigners. It is a liquidity program, where insofar as the interest rate charged is the same as that charged in the discount window, all banks, domestic or foreign, face similar terms.[3]

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 is justified because this liquidity operation involves the source-country monetary base, but the banks that are borrowing are regulated by the recipient central bank, which will have superior information on their solvency, the quality of their collateral, and the potential for moral hazard in ex ante bank risk-taking.

Yet, insofar as most major foreign banks have a U.S. branch or subsidiary, they can go to the discount window instead of using their central banks and the swap line. Why was the swap line then needed? There are a few important differences between the two programs. First, 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 can be avoided, since the recipient central bank can keep the anonymity of the borrower for a period of time. Even today, the ECB does not make public the identity of the financial institutions that borrowed dollars from it. Second, the amounts lent were very large relative to the size of the U.S. branches or subsidiaries of foreign banks. Given the Fed's limited monitoring ability over foreign banks outside its jurisdiction, the swap lines allowed the use of the recipient central bank's monitoring. Third, the recipient bank's assets in the source country were often held at the level of the recipient's parent. Hence, the required funding needs were large

[3] Actually, insofar as the source central bank is charging the same rate as it does on the discount window, but the recipient central bank bears the credit risk that it would have in the discount window, then the source central bank is actually receiving a transfer from foreigners in risk-adjusted terms.

relative to the branch/subsidiary's balance sheet and would require collateral transfers from the parent, which recipient-country regulators would be uneasy with.[4]

A 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. This is, in principle, inferior to the central bank swap lines on three accounts. First, because it would not increase the dollars in circulation, so the increase in demand would, all else equal, lead to dollar deflation. Second, because it requires private banks to serve as the intermediaries in a crisis, just as they are under stress and refusing to fund the foreign banks directly. Third, and more speculatively, insofar as the recipient central bank is less likely to default on the origin central bank than on financial intermediaries, the terms of the swap contract might be worse.

A third and final alternative is for recipient-country banks to get their own currency from the recipient central bank, exchange it for dollars in the swap market, and at the same time buy a forward contract that removes the exchange-rate risk. Even at the height of the financial crisis, the foreign exchange market for dollars never closed. The seller of the 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 were not needed before 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 the foreign-oriented twin of central bank lending facilities, we now show how this monetary policy tool transmits through financial markets by looking at its effect on a key asset return.

3.1 Theory

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

[4]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, and especially after TAF was discontinued, the swap lines are preferred to the discount window.

currency at a locked exchange rate of f_t for the same duration as the swap line. It deposits this domestic currency at its central bank's deposit facility, earning the interest on reserves i_t^{v*}. Because reserves are usually overnight, while the swap-line loan is for a fixed term, to match the maturity of the funding and the investment the bank buys an overnight indexed swap that converts the interest on reserves into a fixed rate for the fixed term. 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 swap contract, which is usually a policy rate targeted by the central bank. Because all the lending and borrowing involves the recipient central bank, this trade involves no risk beyond the negligible counterparty risk in the forward and swap contracts. While the OIS index rate is used, there is no lending or borrowing between banks in this trade.

The principle of no arbitrage opportunities implies that:[5]

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

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, given the conclusion from the previous section that the central bank swap lines work just like a lending facility to foreigners. Moreover, any bank that has access to the central bank can undertake the trade underlying the proposition, so that even if some banks face worse prices for forward contracts,

[5] These are all expressed as the logs of gross returns.

the ceiling would apply to them as well.[6] The proposition is sharp in the sense of indicating what is 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 match the pricing of the central bank swap lines.[7]

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 use for a central bank swap line. However, following the collapse of Lehman Brothers, there was a large spike in x_t. This created the need for a ceiling as banks have found it expensive to respond to funding shocks in other currencies.

The two interest-rate spreads in the two parentheses 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, and positive otherwise. The empirical work exploits these two potentially independent sources of variation to test the proposition.

3.1.1 Collateral and regulation

Proposition 1, and the central bank trade behind it, ignored bank regulation and the collateral involved. We now discuss their possible role.

The loans to banks from the central bank through the swap line are secured and a haircut applies to the collateral. Letting ξ denote the cash coefficient applied to the collateral offered by the bank, the cost of borrowing from the central bank is $\xi i_t^s + (1-\xi) i_{a,t}$ where $i_{a,t}$ is the unsecured financing rate in dollars facing bank a; if $\xi = 1$, 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 proposition, the i_t^s term would be replaced by $\min\{\xi i_t^s + (1-\xi) i_{a,t}, \xi^o i_t^o + (1-\xi^o) i_{a,t}\}$. 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.

[6] Rime, Schrimpf and Syrstad (2017) and Cenedese, Corte and Wang (2017) find a wide dispersion in the f_t offered to different banks, making actual CIP deviations bank-specific: our ceiling result applies to all of them.

[7] 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 sharp ceiling.

Central bank swap lines arose 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 in the FX market. 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: $i_t^o = i_t^* + s_t - f_t$. Moreover, in all of the central banks we are aware of, the collateral requirements for borrowing from the central bank, either domestic currency or foreign currency through the swap lines, are identical, so $\xi^o = \xi$. 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 $x_t \leq i_t^s - i_t$. This is, of course, consistent with our ceiling result.

When banks borrow from their central bank, in some jurisdictions these loans are not included in the calculation of leverage ratios for banking regulation. Likewise, deposits at the central bank get a risk-weight of zero in the calculation of risk-based capital requirements. Therefore, the trade that is behind the result in the proposition will be subject to little regulatory constraint for some banks. At the same time, the Basel III leverage ratio requirements that became binding at different dates starting in 2016, and the evaluation of stress tests, may interact with the trade that we describe. In this case using the swap line would add an extra cost term, say $\zeta_{a,t}$, which is bank-specific depending on the shadow value of relaxing the relevant regulatory constraint. There is still a ceiling, and lowering the swap-line rate still tightens it, but there is an extra term in the expression for the ceiling.

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

Proposition 2. *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, 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:*

$$x_t \leq (i_t^s - i_t) + (i_t^{p*} - i_t^{v*}) + (1 - \xi)(i_{a,t} - i_t^s) + \zeta_{a,t} \tag{4}$$

Collateral and regulation considerations add a third possible source of variation to the ceiling, one that is bank-specific. At the same time, note that in a competitive market the ceiling would be the minimum of the right hand side of the inequality in the proposition across all firms a. Some large investors, notably the safest banks, will have enough safe assets that their unsecured and secured funding rates are the same, so $i_{a,t} = i_t^o$. Likewise, for banks in at least some jurisdictions, there are no regulations involved in borrowing and lending from the central bank, so for them $\zeta_{a,t} = 0$. Thus, if funding markets are reasonably close to competitive, the market ceiling will be the one given by proposition 1.

3.2 Data

We focus on dollar swap lines with the Fed because they accounted for most of the volume of transactions through the swap lines. Our sample starts in September of 2008 when formal swap lines were put in place between dollars and British pounds, Canadian dollars, European euros, Japanese yen, and Swiss francs to form a multilateral swap-line network.[8] We complement data on these swap-line network currencies with a series of currencies for which swap lines lapsed after 2009: Australian dollar, Danish krona, New Zealand dollar, Norwegian krona, and Swedish krona.

The five central banks (excluding the Fed) within the swap line network carried out regular USD auctions from September 2008 until present day. There has been some coordination on the timing and maturity of each auction. So, for example, the Bank of England and the European Central Bank carry out a one-week dollar auction every week at the same time. There are auctions at other maturities beyond one week: for instance, at certain points, auctions at a three month maturity also occurred at a monthly frequency (these were discontinued in 2014). However, for the purpose of our empirical analysis, we will focus on one-week maturities as these auctions were the most commonly tapped, they were conducted throughout our sample, and they have 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 to measure $f_{j,t}$. For almost all of what follows we use OIS 1-week rates to compute the CIP deviations; the exception is when we consider the currencies outside the swap network where we rely on LIBOR rates due to data limitations. Because OIS are fixed rates built as swaps on central bank rates, they replicate our no-arbitrage argument, and are the right measures to use for our application. Moreover, the Fed sets its swap rate as a spread from the 1-week OIS rate.

[8]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) as opposed to standing facilities, and in the case of the ECB there was no volume until September of 2018.

Figure 2: CIP deviations and the swap line ceiling

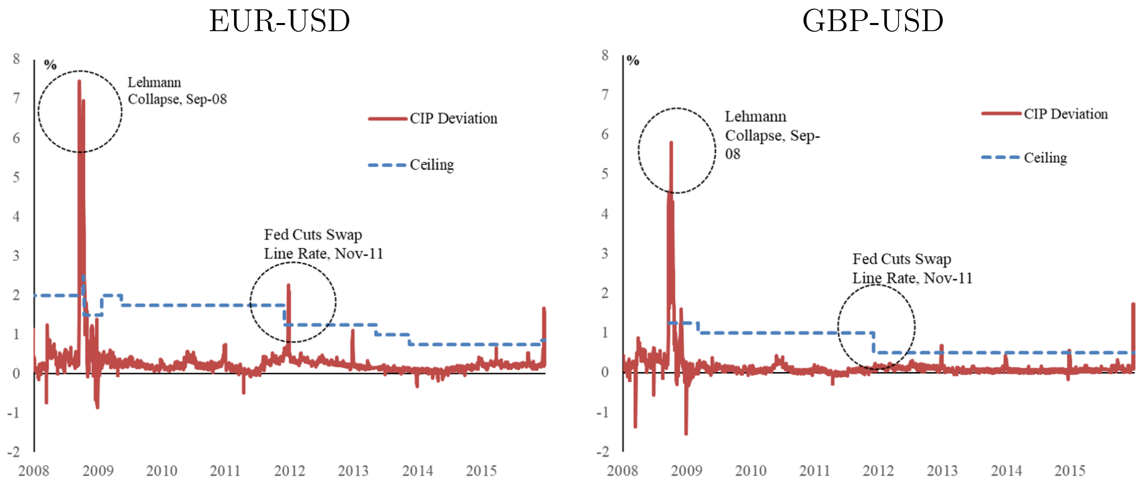


Figure 2 plots the one-week OIS euro-dollar and sterling-dollar CIP deviations together with the ceiling stated in proposition 1. The shock to the CIP deviations from the Lehman failure in September of 2008 is clearly visible, as well as the persistent deviations over the sample period. The ceiling has held well, with only exceptions around year end in 2011 for euro-dollar and in year end 2012 and 2014 in sterling-dollar.[9] The time-series variation in the ceiling for the sterling-dollar since March of 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 December of 2007 and November of 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.

3.3 A difference-in-differences test

On November 30th of 2011, the Fed unexpectedly announced that 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

[9]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 auctions for one week at the end of the year.

became associated with the previously high rate. The minutes show concern over the funding difficulties of foreign banks over the past many months, but there is no mention of responding to one-week CIP deviations. Our measures of $x_{j,t}$ were not particularly elevated the days or weeks before the change. The timing of the change seems to have been partly determined by the outcome of discussions with foreign central banks. The size of the change seems to have been partly random, as there was 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 governors of the Fed. Judging by news reports in the Financial Times, this change came as a surprise to markets.

Using this exogenous change in the ceiling, our empirical strategy is to compare the values of $x_{j,t}$ in a window of one month before and after December (so January versus November) in currencies covered by dollar swap lines and currencies not covered by these swap lines. We choose this wide window because the ceiling should have a permanent effect on the equilibrium rates, and we choose the monthly interval so that we have enough market days to look at the effect on the distribution of the $x_{j,t}$. Moreover, CIP deviations are usually volatile around year end, so leaving the very end of December out avoids this biasing the results.[10]

Figure 3 shows the results. The effects are clear. After the swap rate change, the CIP deviations 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. The figure also shows that there was no differential trend in the prior three months between the two sets of currencies.

Figure 4 presents the comparison differently, by plotting the histograms of $x_{j,t}$ pooled across currencies and days in the 30-day windows before and after the policy change, split between the affected and not-affected currencies. The figure shows that the effect of lowering the ceiling mainly came by reducing the frequency of observations on the right-tail of the distribution. This is where the ceiling is likely to bind, and the shift in mass of the distribution is visible.

Table 1 displays the numerical estimates and their associated standard errors. The first line of results shows that the fall in the ceiling by 0.5% lowered the average CIP deviation

[10] 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 2 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 2.

Figure 3: CIP deviations averaged over treated and non-treated currencies

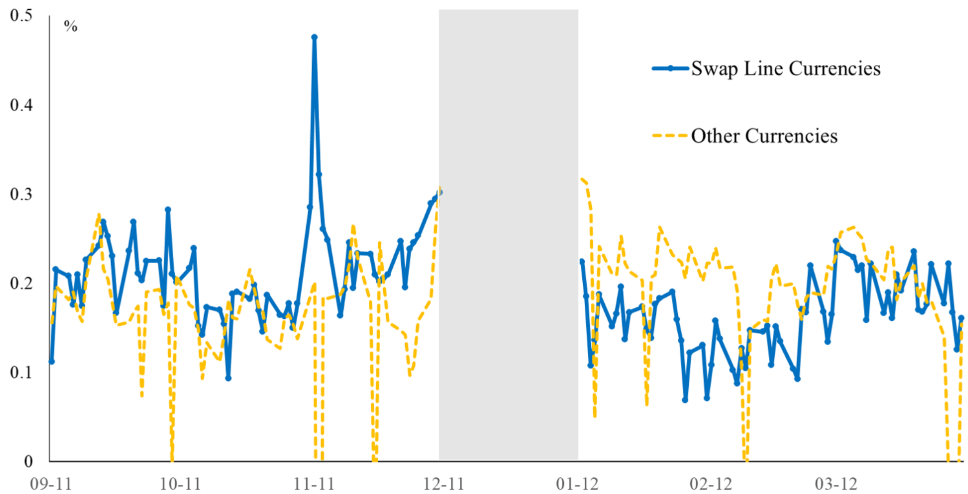


Figure 4: CIP deviations histograms for treated and non-treated currencies

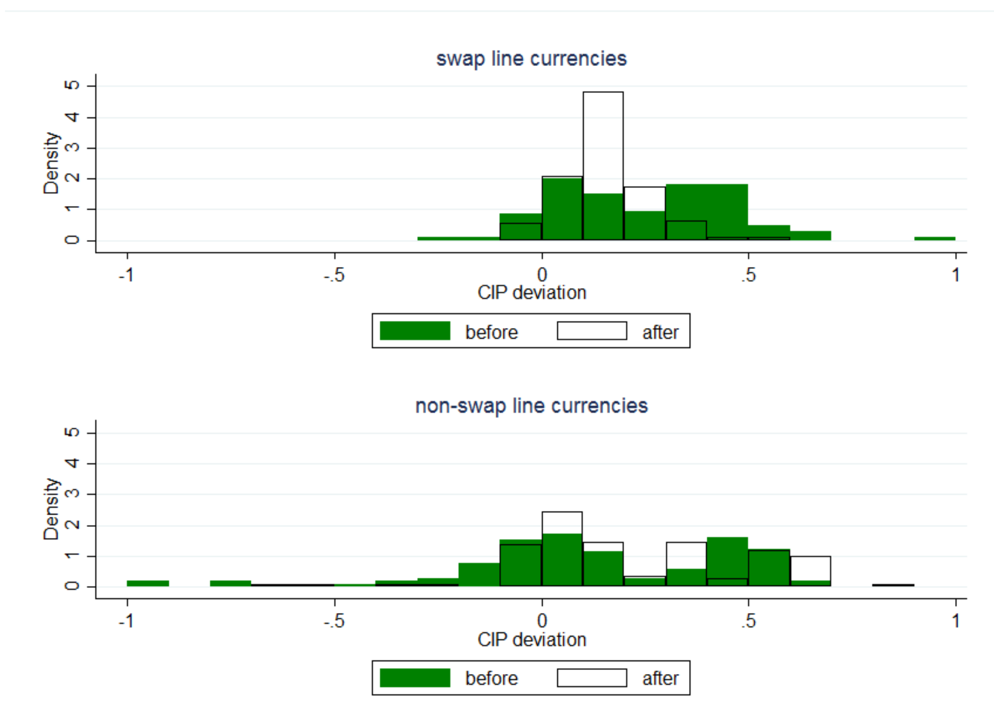


Table 1: Difference-in-differences estimates of the effect of the swap line rate change on CIP deviations

$x_{j,t}$	Swap Line Currencies		Non-Swap-Line Currencies		D-in-D
	Before	After	Before	After	
Mean	.248	.153	.136	.219	-.178*
					(.092)
Median	.261	.117	.120	.144	-.134
					(.147)
25th Percentile	.411	.209	.456	.407	-.154
					(.108)
10th Percentile	.471	.279	.523	.613	-.269**
					(.012)

*Notes: Swap line currencies refers to the EUR, GBP, CAD, JPY, and CHF. Non-swap line currencies refers to the AUD, NZD, SEK, NOK, and DKK. The dependent variable is the 1-week CIP deviation vis-a-vis the USD. Before refers to the days in November 2011 and after to the days in January 2012. Standard errors, block-bootstrapped at the currency level, are in brackets. The quantile difference-in-differences estimators are estimated simultaneously with the cross equation covariance matrix is estimated using bootstrapping. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.*

by 0.18 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 on the median is small (and not statistically significant at conventional levels), but the higher the percentile in the distribution, the larger the effects of the change in the ceiling. In the top decile of the distribution, the 0.5% fall in the swap-line ceiling lowered the average CIP deviation by 0.27 percentage points. The appendix shows that these estimates are robust to: measuring CIP deviations using the interest on excess reserves at the central bank, enlarging the window to 2 or 3 months, and conducting a placebo test by comparing August to October.

3.4 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

Table 2: Regression estimates of the effect of swap line ceiling changes on CIP deviations

	Baseline	Censored	Time fixed effect	Shorter sample
	x_{jt}	x_{jt}	x_{jt}	x_{jt}
Ceiling ($c_{j,t}$)	0.1996***	0.6578*	0.1675**	0.248***
	(0.037)	(0.249)	(0.057)	(0.039)
N	9500	9500	950	8195
Adjusted R^2	0.08	0.16	0.67	0.08

*Notes: Estimates of equation (5). 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): panel least squares estimator including time fixed effects. Column (4): Removes 2015 observations so the sample ends on the 31st of December of 2014. Standard errors, clustered by currency and date, are in brackets. *** denotes statistical significance at the 1% level; ** 5% level; * 10% level.*

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:

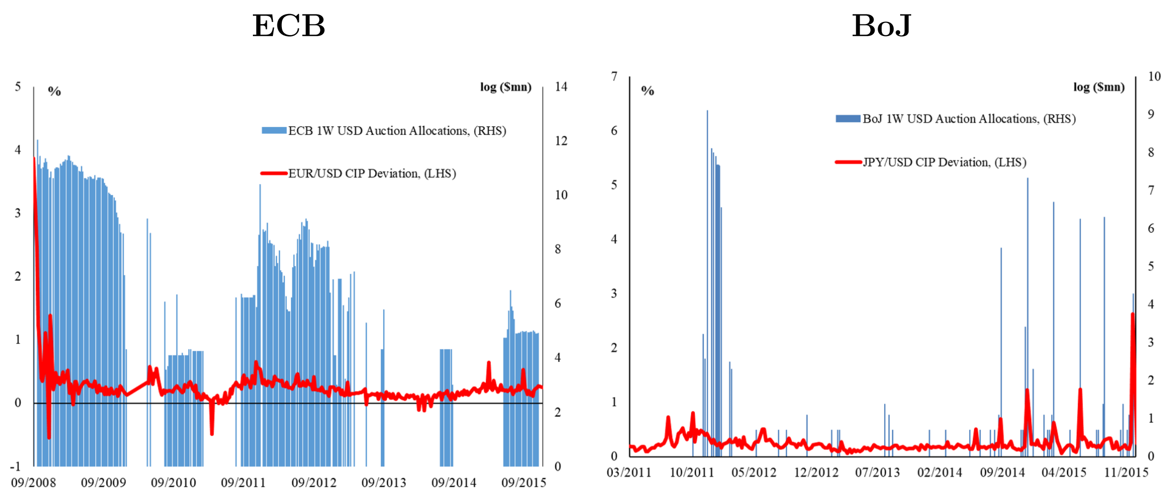
$$x_{j,t} = \alpha_j + \beta c_{j,t} + \varepsilon_{j,t} \tag{5}$$

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 daily data from September 19th 2009 to 31st December 2015, clustering standard errors at the currency level.[11]

The first column of table 2 shows an estimated effect of a 1% reduction in the ceiling of 20bp 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 66bp. 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 slightly to 17bp, consistent with a downward bias due to reverse causality. Finally, the fourth column stops the sample at the end of 2014 instead of 2015, in case banks started anticipating the regulation that followed and inferring signals about it from changes in the the recipient-country policy

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

Figure 5: Allotment at USD auctions by ECB and BoJ, and CIP deviations



rates. The estimate slightly rises.

3.5 Estimating the demand for funding liquidity by foreign banks

Let $q_{j,t}$ be the flow of dollars allocated by a central bank in swap-line country j at an auction at date t. If the ceiling was never met for any bank, then $q_{j,t}$ should always be zero. However, there is considerable bank variation in quoted forward rates (Cenedese, Corte and Wang, 2017), leading a few banks to hit the ceiling and therefore ask for dollars from their national central bank. Figure 5 shows the allotment for the ECB and Bank of Japan 1-week auctions, which had significant amounts outstanding throughout the sample.[12]

Our next empirical test is to estimate the following regression for one-week dollar auctions:

$$\log(q_{j,t}) = \alpha_j + \beta_j x_{j,t-1} + \varepsilon_{j,t}. \tag{6}$$

The terms of these dollar auctions were announced in advance and were well known at most auction 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 3 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

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

Table 3: 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 (6). 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.*

predicts, and surprisingly close to each other. The last column of the table presents a different estimate, of the elasticity of euros lent out by the ECB in its 1 week auctions 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 that was the main result of section 2.

4 The macroeconomic effects of the swap lines

We have so far established that the central bank swap lines are a lending facility, similar to the conventional discount window, but used by 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, in theory and in the data, that this has macroeconomic effects in the investment decisions of firms and the risks they face.

4.1 A simple model of global banks' investment decisions

Consider a simple model of funding risk affecting banks that live for three periods. 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.

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 the source-country banks may only be able to attract funding subject to an upper bound, for instance on account of limited net worth and limited ability to commit.

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 hire 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 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: $\hat{k}_0^*, \hat{k}^*$.

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.

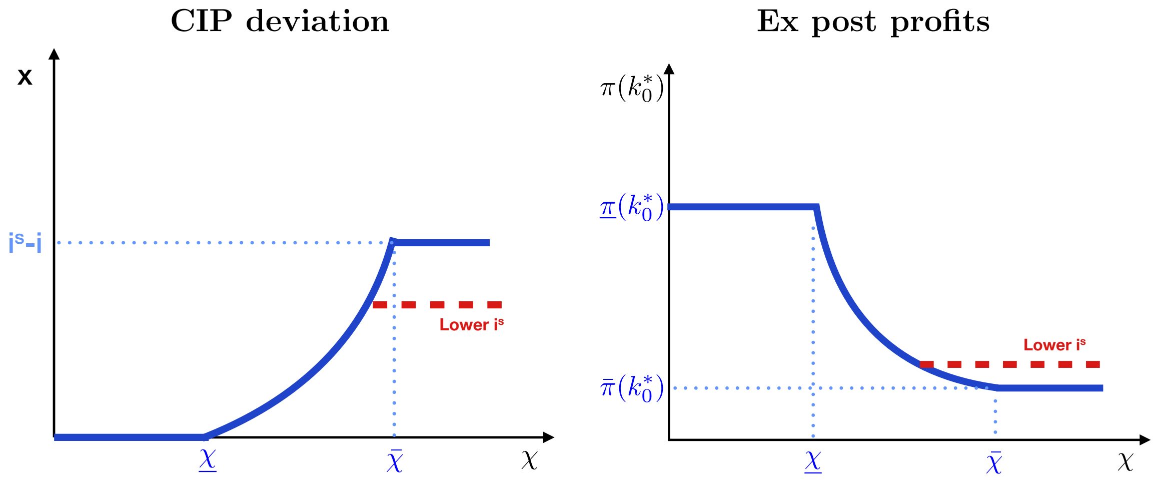
As an alternative source of funding, the recipient-country bank can borrow in recipient-country currency at rate i^*. The exchange rate at the time of the loan is normalized to one, but by the time the output is produced and returns are delivered in source currency to the bank, the exchange rate could be different 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, it must get rid of the exchange-rate risk in a forward contract. Namely, it will buy foreign currency for the investment now, and a forward contract allowing it to lock the exchange rate for one period from now. Therefore, the cost of funding in the recipient-currency market in units of source currency is in logs: $i^* + s - f$ where s is the spot exchange rate (which is zero given our normalization) and f is the price of the forward contract. Replacing this funding would be frictionless if CIP held. However, the forward contract must be provided by intermediaries, which produce them at a cost so that $i^* + s - f - i > 0$. This cost could be due to intermediaries needing to post margin, as in Gârleanu and Pedersen (2011). Referring to their work for the micro-foundations, we capture it in a reduced form as $h(.)$ being an increasing, convex, function of the amount of forward contracts signed, with $h(0) = 0$, so that there is an increasing marginal cost of hedging.

Consider then 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 costs of funding. This cost function has different ranges. If the funding needs are small relative to the source-currency liquidity for recipient-country banks, or $\chi \leq \bar{l} - \hat{k}^* \equiv \bar{\chi}$ 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 bank must turn to recipient-currency funding, so the marginal cost is now: $i + h'(k^* - \chi)$. The bank takes this as given, but it increases with the amount of investment done, because the cost of hedging away the exchange rate risk is rising. If the funding crisis is too extreme, say for $\chi > \bar{\chi}$, the cost of forward contracts becomes too high, and banks prefer to use the swap line, so $MC = i^s$. This ensures a minimum amount of investment that solves $\partial F(.)/\partial k^* = i^s$ and is independent of the funding shock.

Figure 6 represents this equilibrium in short-term investment. The left-side panel shows the CIP deviations as a function of the funding shock. When there is plentiful funding, CIP

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



holds, but as funding becomes scarcer, the limits to arbitrage due to the the cost of providing forward contracts leads to higher CIP deviations. The swap-line rate, as in proposition 1, puts a ceiling on x. The right-side panel shows how profits in the second period depend on the funding shock.[13] 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 other funding market frictions, so that CIP does not hold and the swap-line ceiling has a significant effect.

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:

$$G(\underline{\chi})\underline{\pi}'(k_0^*) + (1 - G(\bar{\chi}))\bar{\pi}'(k_0^*) + \int_{\underline{\chi}}^{\bar{\chi}} \pi'(k_0^*, \chi) dG(\chi) = \rho \tag{7}$$

[13]So, $\pi(k_0) = \max_{k^*} \left\{ F(k_0^*, k^*) - ik^* - \tilde{h} \max\{k^* - \bar{l} + \chi, 0\} - (i^s - i) \max\{k^* - \bar{k}^*, 0\} \right\}$ and where $\tilde{h} = h'(k^* - \chi)$ is taken as given by the firm.

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.

More interesting, a lower rate charged on the swap line will lower $\bar{\chi}$ and raise $\bar{\pi}$, as shown in figure 6. The lower the swap-line rate, the lower the expected costs from ex post having to respond to a funding crisis. Thus, the higher the profits from investing abroad. 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 3. *An exogenous decrease in the swap-line rate* i^s*:*

1. *Lowers the ceiling on CIP deviations, and so lowers the average* x *across realizations of the funding shock;*

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

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

We have already tested the first result. We now turn to the data to test the other two.[14]

4.2 Data and empirical strategy

Turning to the data, 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.

[14]While this proposition was derived in a Holmstrom-Tirole model of banks and central bank lending facilities, we conjecture that similar results would follow in a Diamond-Dybvig setup following the exposition in Rochet and Vives (2010).

The start of our identification strategy to assess this prediction is again the Fed's exogenous decision to lower the interest rate on the swap line from a 1% to 0.5% spread over the OIS 1-week rate on November 30th of 2011. Using data on the daily investment by banks operating in Europe in corporate bonds, we ask: 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? This is 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 investments, between corporate bonds that are denominated in dollars versus other currencies.

We use the ZEN database compiled by the UK Financial Conduct Authority. It covers the universe of all trades by EEA-regulated financial firms 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 firms 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 firms 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. Together these form our control group.

From these millions of observations on individual transactions, we aggregate to measure the net daily flow from *firm* 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 firm 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 firm a for bond b at day t, relative to the typical activity of the firm.[15]

We impose the following restrictions for a firm or bond to be included in the sample: (i) 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; (ii) the firm 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

[15]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 $n_{a,b,t} = \frac{\tilde{n}_{a,b,t}}{\frac{1}{25}\sum_{t=1}^{25}\sum_b |\tilde{n}_{a,b,t}|}$.

consider active traders. These sample selection criteria ensure that our sparse data is not dominated by zero 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. 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.[16]

4.3 Results on bond flows

Figure 7 shows a simple graphical illustration of our triple-difference strategy. The blue solid line shows the average flow into dollar-denominated corporate bonds, less the average flow into bonds of other denominations by banks in countries affected by the swap-line rate change during the 25 trading days surrounding the rate change. The red dashed line shows also relative flows, but now averaged for banks unaffected by the rate change. The comparison shows that flows into USD-denominated corporate bonds by day by swap-line banks substantially increased versus the flows of banks outside the swap network. 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.

Figure 8 plots instead the coefficient estimates of β_t from the following regression:[17]

$$n_{a,b,t} = \beta_t \times SwapLine_a \times USDBond_b + \alpha_{a,t} + \gamma_{b,t} + \varepsilon_{a,b,t} \tag{8}$$

where $SwapLine_a$ is a dummy for whether institution a is a bank 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. Prior to the announcement date, there was no meaningful difference in demand for dollar-denominated corporate bonds by banks headquartered in swap line countries. This validates a parallel-trends assumption. Once the rate change was announced there were a few days of volatility, with excess demand for dollar bonds peaking at 0.15% of gross flows on the 6th of December 2011. This effect dies out by the 9th December.

[16] The data appendix contains more information on the ZEN dataset and our measure, including descriptive statistics. Note that there are not meaningful differences between dollar and non-dollar denominated bonds in our sample in terms of liquidity, face-value, maturity, or rating.

[17] Dashed lines represent 90% confidence derived from standard errors clustered at the issuer and firm level.

Figure 7: Excess flows into USD bonds averaged across banks and bonds around the treatment date

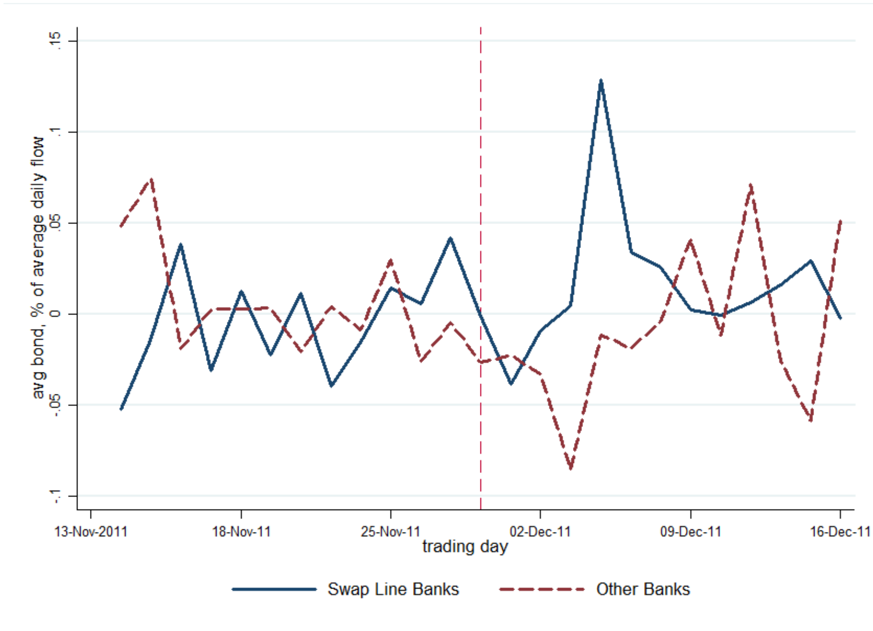
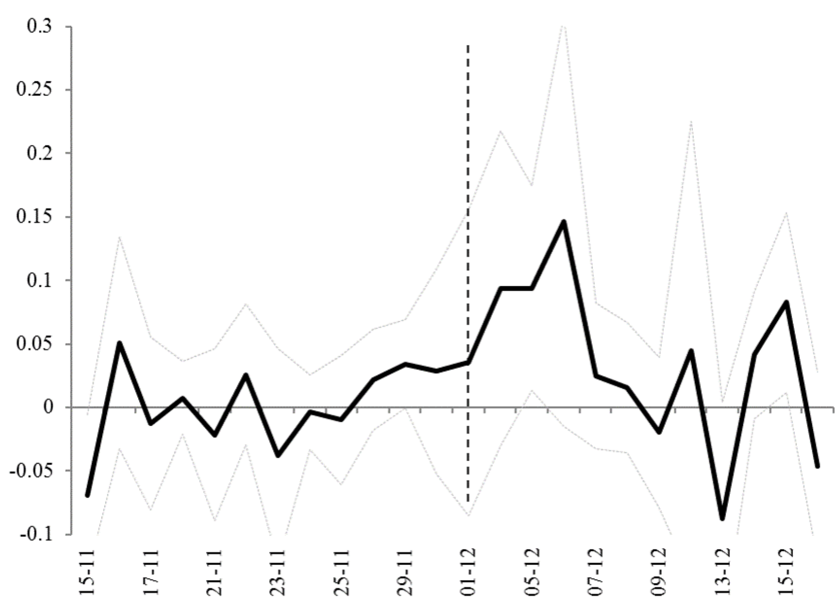


Figure 8: Excess demand for USD bonds by treated banks around the announcement of the swap-line rate change



The first column of Table 4 presents the statistical estimates of β in the regression:

$$n_{a,b,t} = \beta \times Post_t \times SwapLine_a \times USDBond_b + \alpha_{.,t} + \varepsilon_{k,j,t} \quad (9)$$

where $Post_t$ is a dummy variable for after the 30th November 2011, and $\alpha_{.,t}$ is a vector of fixed effects. Therefore, relative to the estimates in figure 8, this now averages the effects over the 5 days before and after the announcement date (excluding the date itself), allows for different combinations of fixed effects, and calculates the associated standard errors, which are multiway clustered at firm and issuer level. According to the estimates, 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 financial firms in different jurisdictions. Moreover, it adds firm fixed effects, interacted with both period and currency, in case some firm characteristics like firm leverage or risk appetite may be correlated with jurisdiction or period in time. Likewise, different firms 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 firm and time. This deals with possibly unobserved differences between dollar bonds and the other bonds. One particular example would be if different bonds would differ in their acceptance 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 firms 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 dollar bonds occurs mostly though lower rated bonds. This could be a sign of either the swap line encouraging firms to take on more risk, or of benefitting from the central bank being more willing to accept lower-

Table 4: 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*
$Post_t \times Swap_a \times USDBond_b$	0.0770*	0.0770*	0.0772*	0.0788*	0.1033	0.0759	0.0756*
	(0.042)	(0.041)	(0.041)	(0.042)	(0.062)	(0.064)	(0.042)
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 (9). 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 and bond level, are in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.*

rated bonds as collateral. It is consistent with these lower-rated bonds being the marginal investment of the firms that are subject to funding risks.

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 firm level. These have no material impact on the results.

These are consistently large effects. Independently of the swap line, they provide strong evidence that liquidity policies affect investment decisions. To get a sense of the magnitudes just within the sample, a back of the envelope calculation may be handy. The average absolute flow from a firm in our sample is $45 million, and there are 69 USD-denominated bonds in the sample. Given the baseline estimate of 0.077%, this implies an increase in $2.4 million per day, per bank, flows into dollar bonds, which summed over 19 banks across 5 days is $230 million. That is a sizable number in the sample, especially considering that in the population there are many more financial instituions trading these bonds, and that the stock of the bonds in our sample outstanding in markets is $89bn.

4.4 Price effects

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.

To look for these in the data, we employ a difference-in-difference strategy. As before, 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 5474 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. This 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 average in the yield of the bonds in the 5 days after the announcement relative to the 5 days prior. 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 5. 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 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.[18] 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 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 investment flows. The estimate rises by one standard error to a 12.2bp price effect. Finally, the third column drops bonds from Euro-area issuers from the sample altogether. The estimates are nearly identical, showing that the results are not being driven by potential confounding aggregate shocks in the Euro-area.

Such large effects may perhaps not be surprising from a financial-markets perspective given the large portfolio flows we already found. Yet, from the perspective of the effectiveness of monetary policy lending facilities and the influence of the lender of last resort activities ex ante, before crises, they are striking and novel to the literature.

4.5 The effect of swap lines on bank valuations

Proposition 3 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

[18] 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 5: Impact of swap line rate change on the yield of frequently-traded USD-denominated bonds

	Nearest Neighbor	Exact Match on Euro Issuers	Dropping Euro-area Issuers
$foreignheld_b$	-0.0860**	-0.1221***	-0.1264***
	(0.036)	(0.036)	(0.038)
N	5474	5474	5257

*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): exact matching estimators that requires the bond issuer to be located in a Euro-area country. Column (3): Drops bonds issued by Euro-area firms. Robust standard errors are in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.*

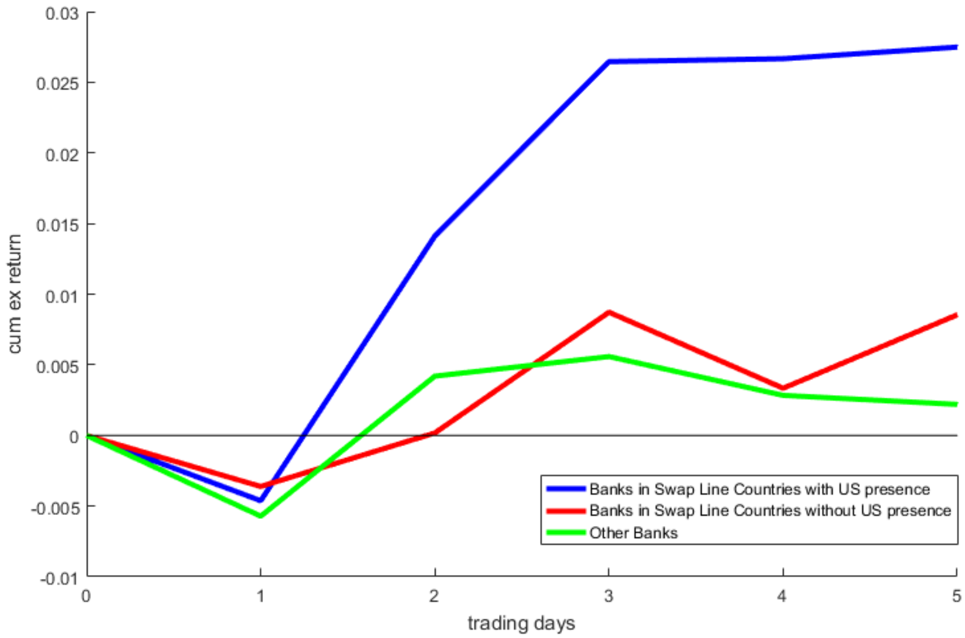
excess returns around the swap-rate change dates. Again, this is a triple-difference exercise, that compares: (i) the days before and after the swap-line rate change by the Fed, (ii) foreign banks in countries covered by the dollar swap lines and so affected by the rate change, and (iii) foreign banks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

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. The window after the announcement over which the excess returns are cumulated is five days.

Figure 9 presents the results. It compares the average excess returns for banks in the

Figure 9: Cumulative bank excess returns averaged across different banks after treatment date



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 6 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 9. However, once weighted by market size, there are significant excess returns for all but the non-treated, non-U.S. bank

Table 6: 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.*

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.

5 Conclusion

This paper studied the role of central bank swap lines in a world that has global banks that are subject to cross-currency funding imbalances. We made three points. First, that the swap line is the twin of conventional central bank domestic lending facilities that arises when a central bank must face foreign banks and wants to use the foreign central bank as its agent in assessing eligibility and bearing the credit risk. Second, that 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, puts a ceiling on CIP deviations between the two currencies in theory. In practice, there is variation in this ceiling both from domestic and foreign policy sources that allow us to estimate the effect of this ceiling in the distribution of CIP deviations across currencies with respect to the dollar. Third, that the swap line encourages investment in dollar assets ex ante by making funding crises less costly. Empirically, we found evidence for a significant portfolio tilt towards dollar bonds following a reduction in the cost of the dollar swap line. This was also visible in an appreciation of the price of the USD bonds that happen to be heavily traded by European banks. Finally, we found 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. 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.

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 remnibi wanted to compete with the dollar for the status of dominant currency? Are the increased foreign funds to U.S. markets allowed by the swap lines welfare enhancing or reducing? Are European banks investing too much in U.S. assets or relying too much on U.S. funding leading to financial fragility in Europe, and is this enhanced by the swap lines? How can the two central banks in a swap-line arrangement coordinate their choices and in which circumstances are their interests not aligned?

What is certain is that the number of central bank swap lines has been growing every year. At this rate, soon, 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

Appendix A provides the proof of proposition 2. Appendix B describes in detail how we built the variables throughout the paper. Appendix C presents robustness results to the regressions.

A Proof of proposition 2

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^s_t, i^s_t) and (ξ^o_t, i^o_t), respectively; (ii) the unsecured lending rate for bank a is $i_{a,t}$; (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:

$$(1-\omega)\min\{\xi i^s_t + (1-\xi)i_{a,t}, \xi^o i^o_t + (1-\xi^o)i_{a,t}\} + \omega\lambda_{a,t} \geq s_t - f_t + (i^{v*}_t + i^*_t - i^{p*}_t). \quad \text{(A1)}$$

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

$$x_t \leq (1-\omega)\min\{\xi i^s_t + (1-\xi)i_{a,t}, \xi^o i^o_t + (1-\xi^o)i_{a,t}\} - i_t + (i^{p*}_t - i^{v*}_t) + \omega\lambda_{a,t}. \quad \text{(A2)}$$

There is still a ceiling, and an exogenous reduction in i^s_t 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 $i^o_t = i^{p*}_t + s_t - f_t$, (ii) during this sample period, the policy and OIS rates were almost identical, so $i^{p*}_t = i^*_t$, and (iii) the collateral requirements by recipient-country central banks were identical for their dollar swap line and conventional recipient-currency lending, so $\xi^o = \xi$. It then follows that:

$$\min\{\xi i^s_t + (1-\xi)i_{a,t}, \xi^o i^o_t + (1-\xi^o)i_{a,t}\} = \xi\min\{i^s_t, i_t + x_t\} + (1-\xi)i_{a,t} \quad \text{(A3)}$$

Thus, the bank will not use the swap line, unless $x_t \geq i^s_t - i_t$. Given the reasonable assumptions that: (i) $i_{a,t} \geq i_t$, 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:

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

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

The ceiling result then becomes:

$$x_t \leq (i_t^s - i_t) + (i_t^{p*} - i_t^{v*}) + (1-\xi)(i_{a,t} - i_t^s) + \zeta_{a,t} \tag{A5}$$

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

B Data Appendix

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

B.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 Thomson Reuters 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. 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 A1 presents summary statistics by currency vis-a-vis the USD for three alternative measures of CIP deviations: (i) where i and i^* are defined as 1-week OIS rates; (ii) where i and i^* are defined as 1-week LIBOR rates; (iii) where i and i^* are defined as the interest rate on excess reserves (IOER) charged by the central bank.

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.

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 UKUSDWF. The 1-week 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.

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 TDJPYSP. 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).

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 TDCADSP. 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.

CHF The 1-week OIS rate is Bloomberg ticker BBCHF1W. The spot price of a USD in CHF is Datastream ticker TDCHFSP. 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 Libor rates for our CHF basis. Our regression results 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 until 17th of December 2014, and from then on the interest rate on Sight Deposits, as reported by the SNB.

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.

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.

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 Nationalbank's official certificates of deposit rate sourced directly from DNB statbank table DNRENTD and the Danmarks Nationalbank's Current Account Rate, Datastream ticker DKFOLIO.

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.

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.

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.

Table A1: CIP deviations summary statistics (1 week vs USD)

	mean	std. dev.	median	25th %-ile	75th %-ile	N
OIS based CIP Deviations						
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						
EUR	.18	.29	.14	.06	.22	1900
GBP	.12	.22	.09	.04	.14	1900
JPY	.23	.33	.15	.11	.23	1900
CHF	.24	.36	.18	.08	.29	1900
CAD	.05	.12	.05	.00	.10	1900
SEK	.17	.30	.12	.06	.21	1900
DKK	.44	.35	.37	.27	.53	1900
NOK	.28	.32	.21	.17	.31	1899
AUD	-.28	.32	-.21	-.31	-.17	1899
NZD	.02	.30	.047	-.02	.11	1900
Interest Rate on Excess Reserves based CIP deviations						
EUR	-.03	.53	-.04	-.18	.07	1900
GBP	.06	.45	.00	-.07	.08	1900
JPY	.2	.55	.09	.03	.18	1900
CHF	.19	.55	.09	-.02	.22	1900
CAD	-.23	.34	-.28	-.37	-.17	1897
SEK	-.68	.6	-.82	-.92	-.56	1900
DKK	.25	.66	.13	.00	.34	1900
NOK	-1.1	.16	-1.1	-1.1	-1.0	1096
AUD	-.35	.65	-.37	-.48	-.27	1900
NZD	-.19	.41	-.19	-.28	-.10	1900

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

B.2 Data on Central Bank Auctions

We use data on auctions by the ECB and the Bank of Japan. Summary statistics are presented in Table A2. The data description for each central bank is below.

ECB: The auction data was downloaded from the ECB's history of open market operations website. Dollar Auctions are those where the operation currency is listed as USD. We define a one week auction 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 auction (26th September 2009) have unlimited allotments at a fixed rate.

Euro auctions 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 auctions all of which have a positive amount allotted.

BoJ: The auction 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 auctions 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 auction replaces the weekly auction over the year end of 2012). The first auction 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 auctions, 90 had a positive amount allotted.

B.3 Bond flow data

B.3.1 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[19]: *Global*

[19]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.

Table A2: Auction summary statistics

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

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

Broad Market Corporate Index; 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.

B.3.2 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 trading one 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.

B.3.3 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.

B.3.4 Summary Statistics

Table A3 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.

Table A3: 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

B.4 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.

C Robustness Results

This section describes further robustness checks on the regressions in tables 1 and 4.

C.1 Robustness of difference-in-differences CIP estimates

Table 1 presented difference-in-differences estimates of the effect of the swap line on CIP deviations. Table A4 considers some of their robustness. It 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 final 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.

C.2 Robustness of triple-diff bond flows estimates

Table 4 presented triple-difference estimates of the effect of the swap line on demand for dollar denominated bonds. Table A5 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

Table A4: Robustness of difference-in-differences estimates on CIP deviations

	$x_{j,t}$: D-in-D Estimates				
	(1)	(2)	(3)	(4)	(5)
	Baseline	*Interest on Excess Reserves*	*2 month window*	*3 month window*	*Falsification (Aug vs Oct)*
Mean	-.184**	.035	-.121	-.074	-.065
	(.092)	(.056)	(.079)	(.079)	(.090)
Median	-.146	-.071	-.113	-.113	-.046
	(.147)	(.149)	(.326)	(.326)	(.084)
25th Percentile	-.155	-.093	-.163	-.127	.062
	(.113)	(.134)	(.123)	(.096)	(.160)
10th Percentile	-.281***	-.284***	-.252***	-.254**	-.179
	(.090)	(.102)	(.104)	(.100)	(.267)

*Notes: This table presents robustness checks on the specification in column 5 of table 1. Column (1): Baseline specification as in table 1. Column (2): recomputes the CIP deviation using the interest rate on excess reserves rather than Libor rates. Column (3): two-month event window, Oct-Nov 2011 versus Jan-Feb 2012. Column (4): three-month event window, Sep-Nov 2011 versus Jan-March 2012. Column (5): placebo study, August 2011 versus October 2011. Standard errors, block bootstrapped at the currency level, in brackets. *** denotes significance at the 1% level; ** 5% level;* 10% level.*

Table A5: 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 (9) as robustness of table 4. 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.*

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.