Central Bank Swap Lines*

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Abstract

Swap lines between advanced-economy central banks have become a permanent component of the global financial architecture since the crisis. We show that they: (i) provide credit from the source central bank to the recipient-country banks using the recipient central bank as the monitor and the bearer of the credit risk, (ii) put a ceiling on deviations from covered interest parity thereby reducing ex post funding risk, and (iii) ex ante encourage inflows from recipient-country banks into assets denominated in the source-country’s currency. We find support for these predictions using difference-in-difference empirical strategies exploiting variation in the terms of the swap line over time, variation in the central banks that have access to the swap line, variation in the exposure of different securities to foreign funding, and variation in banks’ exposure to dollar funding risk.

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1 Introduction

At least since Bagehot (1873), it has become universally accepted that central banks should provide emergency lending facilities because they put bounds on fluctuations in market prices and attenuate funding crises preventing crashes in investment. In response to the 2007-08 financial crisis, many central banks announced myriad new liquidity facilities. Bernanke (2015), among many others, argues that these were crucial in preventing an economic depression. However, testing the effects that lending facilities and their terms have on market rates and on the reaction of economic agents to funding shocks is challenging, since these policies have either been around for a long time or, in the case of the recent crisis, were introduced and changed in response to the state of the economy. This paper uses a new facility, whose terms were experimented with and that had implications for financial assets only in certain denominations, to provide evidence that central bank lending facilities have a large effect on financial prices and investment decisions.

This facility is a modern central bank swap line. Today, there are an estimated 160 bilateral swap lines between central banks around the world, many of them standing facilities without explicit limits, with the People’s Bank of China alone having more than 100 active swap lines involving more than 40 other countries and a formal limit that exceeds $1 trillion. Discussions of the global financial architecture, of the role of IMF, or of monetary policy coordination today are incomplete unless they devote significant attention to the central bank swap lines (di Mauro and Zettelmeyer, 2017). Yet, little is known about how these work, what their effect is on exchange rates and financial prices, and how they affect capital flows or investment decisions.

Central bank swap lines lines became prominent during the great financial crisis. 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 with a dozen other central banks. The lines came into use between September 2008 and January 2009, with the amount drawn peaking at $586bn; see figure 1. The swap lines were formally reintroduced in May 2010 and made into permanent standing arrangements in October 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 countries’ financial systems had extensively issued Swiss franc mortgages.

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

1The other swap lines between the Fed and other central banks have expired, with the exception of a limited arrangement with the Banco do Mexico.
an integrated model of banks, forward exchange-rate markets, and bond-financed investment, and an empirical identification strategy that relies on a change in the terms of the swap line that affect different currencies, banks, and bonds differentially, to conclude that central bank swap lines lowered funding costs of banks and in doing so increased funding to firms across borders.

We start by describing the terms and operation of the swap contracts. This clarifies that the swap lines provide a substitute for lending by the source central bank to the recipient-country banks, using the recipient central bank as an agent that bears the credit risk. As such, the swap lines are consistent with controlling inflation and the lender of last resort role, and they are not, at least directly, tied to intervening in exchange rates, bailing out or transferring wealth to foreigners, or nationalizing private risk. We discuss why they 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 ceiling on the deviations of covered interest parity (CIP) between the two currencies. Breaking this ceiling would give rise to an arbitrage opportunity. We embed this arbitrage argument in a model of financial intermediaries that supply forward contracts, and allow for the collateral and regulatory requirements associated with the central bank swap lines, to show that the presence of a ceiling is robust and to arrive at the prediction that cutting the swap line rate will cut the right tail of CIP deviations and reduce
their average value. We turn to the data on CIP deviations since 2008 to confirm these predictions 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 economic effects of the swap lines. We embed our partial-equilibrium model of financial markets into a general-equilibrium model of global banks that finance investment subject to cross-border funding shocks. The model predicts that the swap line reduces funding risk. A fall in the swap-line rate increases investment by recipient-country banks in source-country currency-denominated assets.

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

A follow-up difference-in-difference strategy shows that these portfolio shifts led to an increase in the 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.

To be able to identify causal effects, our empirical strategy relies on high-frequency transactions in financial markets and the associated prices, similar to the large macroeconomic literature that in the past decade has studied the effect of conventional and unconventional monetary policies (e.g., Gertler and Karadi, 2015). This frequency limits the direct macroeconomic conclusions that can be stated for sure. Still, all combined, the theory and empirical estimates 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. In terms of further research, our model and results 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), or more recently as in Bianchi and Bigio (2014) or Piazzesi and Schneider (2018).

Relative to the literature, Ivashina, Scharfstein and Stein (2015) show that, during the Euro-crisis, U.S. money market funds lent less to European banks. In turn, European banks participated less in 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 syndicated lending, our focus is on purchases of corporate bonds in secondary markets. This is by design: the syndication process occurs over a time period, as book-running alone takes several weeks. At lower frequencies, the intensifying crisis in Europe, and corresponding policy interventions by the ECB, would make it impossible to isolate the effect of the swap line alone. By using high-frequency transactions in financial markets, we eliminate these confounds. From the perspective of banks, debt securities are more important than syndicated loans: in 2017, European banks held on average on their balance sheets debt securities issued by foreigners or domestic non-bank corporates of 39% of their total loans to the global corporate sector, whereas the equivalent percentage for syndicated loans is 9%. Moreover, we differ from Ivashina, Scharfstein and Stein (2015) by studying a policy tool that can affect cross-border funding and by linking outcomes in markets for currency, corporate borrowing, and bank stock prices.

Over the past decade, a growing literature documented deviations from CIP (Du, Tepper and Verdelhan, 2018) and proposed explanations for them, tied to capital regulation (Borio et al., 2016; Avdjiev et al., 2018; Cenedese, Corte and Wang, 2018) or to debt overhang (Andersen, Duffie and Song, 2018). Our model of financial fictions in forward contracts builds on this work to generate CIP deviations in equilibrium. We add the result that central bank swap lines put a ceiling on CIP deviations, affecting their average size and distribution. Moreover, we link these deviations to funding and investment choices with macroeconomic consequences.

A few policy papers, mostly originating in the Federal Reserve system, describe the mechanics of the Fed swap lines and justify their adoption as a response to vague funding pressures in dollar markets. The best of these papers is Goldberg, Kennedy and Miu (2011), which is also the only one that we are aware of that proposes CIP deviations as one of two possible concrete measures of these funding pressures as they relate to the swap lines. New to our work, we: argue for an equivalence between swap lines and standard domestic liquidity facilities so that the former can be used to understand the latter; use theory to prove a tight link between one particular measure of CIP deviations and the swap line rate; provide a credible empirical identification strategy to

\[^2\text{Sources: ECB Statistical Bulletin, MFI Balance Sheets, tables 2.4.1, 2.4.3 (loans) and 2.6.1 (debt securities). Syndicated loan volumes, ECD SDW series BSLM.U2.N.A.A20S.A.1.U2.2240.Z01.E}\]
test for a causal link; use theory to link swap line and funding and investment decisions; and test this link with novel data on investment choices, bond prices, and equity returns. In the academic literature, we are only aware of Baba and Packer (2009) linking central bank swap lines with CIP deviations. They document a partial correlation between the quantity of dollars lent out under the swap lines and one particular measure of CIP deviations. In contrast, we provide a concrete explanation of how the swap lines actually work, a theory linking the swap lines to CIP deviations and investment choices, and we identify causal effects. The correlations that either of these two papers document cannot be used to confirm or reject our predictions. In short, they provide complementary perspectives on some of the analysis in section 2 of this paper.

Finally, an older literature studied central bank swap lines with developing countries that were employed to peg their currencies to the dollar (see Obstfeld, Shambaugh and Taylor, 2009, for a recent example). The arrangements we study are instead between floaters, all of which are large, advanced economies.

2 Role in central banking: how the swap lines work

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

2.1 The swap-line contract

The typical properties of a dollar swap line are as follows: the Fed gives dollars to another central bank and receives an equivalent amount of their currency at today’s spot exchange rate. At the same time, the two central banks agree that, after a certain period of time (typically one week or one month), they will re-sell to each other their respective currencies, at the same spot exchange rate that the initial exchange took place at. The Fed charges an interest rate that is set today as a spread relative to the USD overnight index swap (OIS) rate, paid at the fixed term, and settled in USD. 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 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 there is no direct effect on inflation.

In terms of the risks borne by each central bank, for both there is no exchange-rate risk or interest rate risk, as the terms are set when the contract is signed. For the source central bank, there is negligible credit risk since it is solely dealing with the recipient central bank, with its reputation at stake. For the recipient central bank, there is credit risk, 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. 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 conditionality.

3There 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 Köhn (2014).
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.

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.\(^4\)

### 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 longer 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.\(^5\) 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 relative to the branch/subsidiary’s balance sheet and would require collateral transfers from the parent, which recipient-country regulators would be uneasy with.\(^6\)

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\(^4\) Actually, insofar as the source central bank is charging a spread over the overnight rate, but the recipient central bank bears the credit risk, then the source central bank is actually receiving a transfer from foreigners in risk-adjusted terms.

\(^5\) For example, in 2008Q3 the total assets of foreign banking offices in the US were $1169bn (U.S. Flow of Funds, table L.111), compared to the peak swap line drawing a few weeks later of $586bn.

\(^6\) In regular times, with smaller shocks, global banks use internal capital markets for funding, as documented by Cetorelli and Goldberg (2012). However, when it comes to emergency funding after large shocks, the swap lines are preferred to the discount window. An alternative was the Term Auction Facility (TAF), which ran from December 2007 to March 2010, allowing many foreign banks to get dollars from the Fed directly, albeit a smaller set of banks than the ones that have access to their own-country swap line and subject to a narrower set of accepted collateral. Unlike the swap line, the TAF kept the credit risk and the need for monitoring at the Fed.
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, and swap them into source-country currency using a derivatives contract removing the exchange-rate risk. Even at the height of the financial crisis, the foreign exchange market for dollars never closed. The seller of 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: the CIP ceiling

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 $i_s$, at the end of the fixed term. The bank then buys its domestic currency with this foreign currency at today’s spot rate $s_t$, while it signs a forward contract to exchange back domestic for foreign currency at a locked exchange rate of $f_t$ for the same duration as the swap line. It deposits this domestic currency at its central bank’s deposit facility, earning the interest on reserves $i_v^*$. 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 OIS contract 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 an overnight interbank rate very close to

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7For concreteness, take the term to be one week since this is the duration of the most-used swap lines that we will focus on in the empirical work. Note that when we refer to overnight interest rates, like the interest on reserves or the policy rate, these are more accurately risk-neutral expectations of these rates over the week. Since policy rates are changed infrequently at policy meetings, most weeks, the risk-neutral expectation and the actual rate are the same.
the policy target of the central bank. Because all the lending and borrowing involves the recipient central bank, this trade involves no risk beyond (i) the negligible counterparty risk in the forward and swap contracts and (ii) the risk of movements in the spread between \(i^p_t\) and \(i^v_t\), which rarely changes, and typically only at some policy meetings. While the OIS rate is used, there is no direct lending or borrowing between banks in this trade.

The principle of no arbitrage opportunities implies that:\(^8\)

\[
i^s_t \geq s_t - f_t + (i^v_t + i^s_t - i^p_t).
\]

(1)

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

\[
x_t = s_t - f_t + i^*_t - i_t.
\]

(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:

\[
x_t \leq (i^s_t - i_t) + (i^p_t - i^v_t).
\]

(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. The proposition is precise in the sense of indicating the right measures of \(i_t\) and \(i^*_t\) to calculate the relevant CIP deviation: they are the OIS rates at the relevant maturity as these both match the pricing of the swap line and the cost of hedging the interest rate risk at the deposit facility.\(^9\)

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

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\(^8\) These are all expressed as the logs of gross returns.

\(^9\) 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 \(x^\text{libor}_t\) be the LIBOR CIP deviations, the result in the proposition becomes: \(x^\text{libor}_t \leq (i^s_t - i_t) + (i^p_t - i^v_t) + (i_t - i^\text{libor}_t) - (i^*_t - i^\text{libor}_t)\), again a precise ceiling.
3.2 Theory: the CIP distribution

There are two leading theories for why CIP stopped holding after 2007. This section shows that the ceiling result applies to either of them and clarifies how the ceiling affects the distribution of forward price quotes and CIP observations. Whereas proposition 1 relies on minimal assumptions, a theory of CIP requires a model of the market for exchange-rate swap contracts.

Consider a world in which there is one representative intermediary quoting prices \( s_t - f_t \) for a swap contract that converts funding between recipient currency and source currency. This intermediary is composed of many atomistic risk-neutral traders, each of whom gets matched in an over-the-counter market with a bank. In a frictionless market, an individual trader would be able to sell one unit of protection by borrowing source-currency at the secured rate \( i_t \), convert into recipient-currency at the spot rate \( s_t \), and deposit at zero risk in a frictionless reserves market at the deposit rate \( i^* \). As long as:

\[
i^* + s_t - f_t - i_t \geq 0\]

it would do so. Free entry and zero profits by traders would imply that in a frictionless equilibrium \( x_t = i^*_t - i^*_t \). With a satiated market for reserves, this would be exactly zero, and CIP would hold.

We assume two frictions in the operation of intermediaries. First, following Gărlăeanu and Pedersen (2011), assume that a fraction \( m \) of the operation must be financed with own-equity of the intermediary. This margin requirement is commonly enforced by the counterparties in these markets. An alternative justification, following the evidence in Du, Tepper and Verdelhan (2018), is that this is a binding leverage requirement imposed by regulators. Either way, the cost of own-equity is \( i_t + \Delta e_t \), higher than the secured funding rate by a spread \( \Delta e_t \). Second, following Andersen, Duffie and Song (2018), assume that a fraction of the amount borrowed to produce the swap must use unsecured funds, because of a haircut with a cash ratio of \( \zeta \). Therefore, the trader must make a funding value adjustment of \( (1 - \zeta)\Delta u_t \) to account for the spread the intermediary must pay for unsecured borrowing \( \Delta u_t \). These two frictions—capital requirement and margins, together with funding value adjustments—are the two leading theories put forward to explain CIP deviations.

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

\[
i^*_t + s_t - f_t - m(i_t + \Delta e_t) - (1-m)(\zeta i_t + (1-\zeta)(i_t + \Delta u_t)) - m \Delta e_t - (1-m)(1-\zeta)\Delta u_t, \quad (4)
\]

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

The literature focussing on these financial frictions predicts that the two spreads, \( \Delta u_t \) and \( \Delta u_t \), are each increasing in the volume of trading in swap contracts \( V_t \). Therefore, \( h_t = h(V_t) \) is an increasing function, for two separate reasons. First, if there is an alternative use of own-equity that has decreasing returns to scale, then the intermediary will require of its traders a \( \Delta e_t \) that is rising in \( V_t \) (Gărlăeanu and Pedersen, 2011). Second, if the intermediary has assets net of secured borrowing,
$A_t$, unsecured borrowing $L_t$, a probability of default $\theta_t$, which for simplicity is independent from its forward-contract traders’ activity, and in case of default only a share $\kappa$ gets recovered by the creditors, then pari passu rules on unsecured creditors imply that under risk-neutrality they would charge: 
$$
\Delta^u_t = \theta_t [L_t + V_t(1-m)(1-\zeta_t) - \kappa(A_t + V_t(1-m)(1-\zeta_t))]/[L_t + V_t(1-m)(1-\zeta_t)] \quad \text{(Andersen, Duffie and Song, 2018)}.
$$
For a fixed margin, this is again increasing in $V_t$.

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

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

If banks have all the bargaining power, then traders’ profits are driven to zero, and the CIP deviation is $h_t$, driven by the need for margins and unsecured funding in the intermediary’s operations. If traders have all the bargaining power, then the CIP ceiling in proposition 1 binds. In between, different bargaining powers across banks lead to a distribution of CIP quotes $F(x_{a,t})$. Financial market data providers typically report daily prices at close which can be thought of as independent draws from this distribution.

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

**Proposition 2.** A decrease in the policy choice $(i_s^* - i_t) + (i_p^* - i_v^*)$ leads to:

i. A lower ceiling in the distribution of bank-specific CIP quotes, since $F(i_s^* - i_t + i_p^* - i_v^*) = 1$.

ii. A lower mean of the distribution of CIP deviations: $E_a(x_{a,t}) = i_p^* - i_t^* + \bar{\delta} h_t + (1 - \bar{\delta})(i_s - i_t)$.

Proposition 2 shows that the ceiling result in proposition 1 predicts that reducing the central bank swap line truncates the CIP distribution rightwards, and shifts its mean to the left. The two interest-rate spreads in the two parentheses are chosen by policy and have different sources of variation. The first interest-rate spread is exogenously set by the source central bank. The second interest-rate difference is instead set by the recipient central bank. It is zero if the central bank is running a floor system, and positive otherwise.\[11\] The empirical work exploits these two potentially independent sources of variation to test the proposition.

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10Of course, $h_t \leq i_t^* - i_t$, otherwise equilibrium in the market for forward contracts would have zero traders, and all borrowing would happen through the swap line.

11Strictly speaking, $i_v^*$ is the overnight interbank rate used as the reference for the OIS contracts, but this is often the target of central bank policy. Importantly, whenever the central bank policy rate moves, which is the source of variation we will empirically use in one of our tests, the overnight interbank rate moves monotonically (and almost
Proposition 1, and the central bank trade behind it, ignored bank regulation and the collateral involved. We now discuss their role.

The loans to banks from the central bank through the swap line are secured and a haircut applies to the collateral. Letting $\xi^c$ denote the cash coefficient applied to the collateral offered by the bank, the cost of borrowing from the central bank is $\xi^ci^s_t + (1 - \xi^c)i^u_{a,t}$ where $i^u_{a,t}$ is the unsecured financing rate in dollars facing bank $a$; if $\xi^c = 1$, then we recover the analysis in the proposition. Alternatively, the bank could get dollars in the private market, at a different rate and potentially different collateral requirements. Letting that alternative contract have rate and cash coefficient $(i^o_t, \xi^o)$ then, in the propositions, the $i^s_t$ term would be replaced by $\min\{\xi^ci^s_t + (1 - \xi^c)i^u_{a,t}, \xi^oi^o_{a,t} + (1 - \xi^o)i^u_{a,t}\}$. 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.

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. 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 ($i^*_{pt} \approx i^*_t$) and buy forward contracts, resulting in the funding cost: $i^o_t = i^*_t + x_{a,t}$. Moreover, the collateral requirements for borrowing from the central bank either domestic currency or foreign currency through the swap lines were very similar, so $\xi^c \approx \xi^o$.\textsuperscript{12} Thus, if the alternative source of funding is also the recipient-country central bank, but in recipient-country currency that is turned into synthetic dollars, banks would choose to not borrow from the swap line as long as $x_{a,t} \leq i^*_t - i^*_t$. This is, of course, consistent with our ceiling result.

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

\textsuperscript{12} They were exactly the same for the BoJ and the SNB, and likewise for the ECB at one week maturity (the ECB charges an additional haircut on collateral for the longer-dated swap line loans). The BoE is an exception because it charges an extra 6% haircut on non-USD denominated collateral used to borrow from the swap line. All central banks have the same collateral eligibility criteria between domestic and foreign currency operations.
Combining the different arguments in this discussion, a revised proposition that takes into account both collateral and capital regulation is (the proof is in the appendix):

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

\[
x_{a,t} \leq (i_t^s - i_t) + (i_t^{ps} - i_t^{vs}) + (1 - \xi_c)(i_{a,t}^u - i_t^s) + \psi_{a,t}.
\]  

(6)

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

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

### 3.4 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 on 19th September 2007 when swap lines were put in place between dollars and British pounds, Canadian dollars, European euros, Japanese yen, and Swiss francs to form the first multilateral swap-line network. We complement data on these swap-line network currencies with a series of currencies for which swap lines lapsed after 2009: Australian dollar, Danish krone, New Zealand dollar, Norwegian krone, and Swedish krona.

The five central banks (excluding the Fed) within the swap line network have carried out regular USD operations from September 2008 until present day (with a short gap between February 1st and May 9th 2010 when the swap agreement lapsed). There is coordination on the timing and maturity of each operation. So, for example, the Bank of England and the European Central

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Our results are robust to starting on the 13th October 2008 when the swap line drawings became full allotment, fixed rate operations. There were dollar swap lines in place with the ECB and the SNB starting on the 12th December 2007, but for limited amounts ($20bn and $4bn, respectively) as opposed to standing facilities, and in the case of the ECB there was no volume in weekly operations until September of 2008.
Bank carry out a one-week dollar operation every week at the same time. There are operations at other maturities beyond one week: for instance, at certain points, operations at a three month maturity also occurred at a monthly frequency (these were discontinued in 2014). For the purpose of our empirical analysis, we will focus on one-week maturities as these operations were the most commonly tapped, they were conducted throughout our sample, and 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 most of what follows we use OIS 1-week rates to compute the CIP deviations based on the argument in the previous section that these replicate our no arbitrage trade. The exception is in section 3.5 when we consider currencies outside the swap network where, due to data limitations, we rely on LIBOR rates for all currencies.

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. The time-series variation in the ceiling for the sterling-dollar since March 2009 is all driven by the gap $i^*_t - i_t$, because the Bank of England operated a floor system. The ceiling was 100 basis points between September 2008 and November 2011, and 50 basis points afterwards. In the case of the ECB, the gap $i^*_j - i^*_j$, which is the difference between the short-term repo policy rate and the deposit facility rate, has had some time-series variation due to relative movements in the deposit facility and main policy rates. Among the control group, Denmark provides auxiliary evidence for the ceiling. The Danish krone has a stable exchange rate peg to the euro but the Danmarks Nationalbank’s swap line with the Federal Reserve lapsed on October 30, 2009. Without it, 1 week DKK-USD CIP deviations exceeded the counterfactual ceiling on 23 trading days through to the end of 2015, excluding year-end periods.

### 3.5 A difference-in-differences test

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

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14These year-end deviations do not reject the presence of a ceiling, because both the ECB and the Bank of England suspend their one-week operations for one week at the end of the year.
However, and crucial for identification, the minutes of the meeting have no mention of the very recent past behavior of 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 rather to have been partly determined by the outcome of lengthy discussions with foreign central banks. The change affected all central banks that had established swap line arrangements with the Federal Reserve, despite the fact the negotiations and concerns were focused on the Euro-area in the treated group and the Nordic counties in the control group. Moreover, the size of the change seems to have been partly random, 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 Fed governors. Finally, judging by news reports in the Financial Times, this change came as a surprise to markets, so there is little anticipation effect. In conclusion, the size and timing of the change in the ceiling at this date was exogenous with respect to the CIP deviations in the few weeks before, validating the identification restriction for a difference-in-difference empirical strategy.

We 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 these spikes biasing the results.\(^\text{15}\)

\(^{15}\)This date is well before regulations being discussed and approved that could interfere with the swap line, so the considerations on regulation discussed in the extended proposition 3 should not apply. Moreover, the reduction in the swap-line rate comes with potential higher use of the central bank facilities, which tend to have more generous
During December of 2011, there are no other significant policy changes by all central banks in our treatment group, with the exception of the ECB, which cut rates on the 8th, while among the control group the Danmarks Nationalbank cut rates the same day and the Riksbank and Norges Bank one week later on the 15th. With our wide window, these should not bias the result in any clear direction.

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.

Following section 3.2, figure 5 presents a more granular, higher-frequency picture by showing a proxy for bank-specific CIP deviations, $x_{a,t}$, created from tick data on the quotes of foreign exchange swap contracts. Similar to Cenedese, Corte and Wang (2018), we collect the quoted price of every 1-week FX swap versus the USD contained within Thomson Reuters Datascope for the 10 currencies in our sample, and calculate an implicit CIP deviation using the spot exchange rate in the minute of the quote and the relevant daily interest rate fixings. This provides over 1.2 treatment of collateral, thus lowering the shadow value of collateral, so the ceiling would still unambiguously fall in proposition 3.
Figure 4: Daily CIP deviation histograms for treated and non-treated currencies

Figure 5: Quote-specific CIP deviation histograms for treated and non-treated currencies
million observations across November 2011 and January 2012. Because of the wider dispersion of CIP deviations at the bank level, also documented by Rime, Schrimpf and Syrstad (2017), these data allow us to test the ceiling result more sharply. As in figure 4, the shift to the left of the distribution is clear. Further than figure 4, figure 5 shows that the right mass beyond the ceiling is almost entirely cut out by the swap line, just as a ceiling result predicts.16

Table 1 displays the numerical estimates and their associated standard errors for the analysis based on the daily data in figures 3-4. The first line of results shows that the fall in the ceiling by 0.5% lowered the average CIP deviation 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 0.28 percentage points.

The appendix shows that these estimates are robust to measuring CIP deviations using the interest on excess reserves at the central bank, or to enlarging the window to 2 or 3 months or narrowing it to 2 weeks. Altering the treatment and control groups to just focus upon European currencies yields similar results. Moreover, five falsification tests following the same methodology find no significant effect. The first was a placebo that compared August to October. The other four used dates of announcements of extensions of the swap line arrangements, on May 9th 2010, December 21st 2010, June 29th 2011 and December 13th 2013. The policy change we used in our main specification contained both a change in the rate and an extension of the arrangement of the swap lines, so these results suggest that the key variation comes from changes in the swap line rate, as highlighted by the ceiling expressions in the propositions.

3.6 A test using time-series domestic variation

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

The baseline regression is:

\[ x_{j,t} = \alpha_j + \beta c_{j,t} + \varepsilon_{j,t} \]  (7)

16 A few very large deviations from CIP may reflect quotes where either no trade took place or between banks that are highly collateral or capital constrained as in proposition 3.
Table 1: Difference-in-differences estimates of the effect of the swap line rate change on CIP deviations

<table>
<thead>
<tr>
<th>x_{j,t}</th>
<th>Swap Line Currencies</th>
<th>Non-Swap-Line Currencies</th>
<th>D-in-D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Mean</td>
<td>.248</td>
<td>.153</td>
<td>.136</td>
</tr>
<tr>
<td>Median</td>
<td>.261</td>
<td>.117</td>
<td>.120</td>
</tr>
<tr>
<td>75th Percentile</td>
<td>.411</td>
<td>.209</td>
<td>.456</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>.471</td>
<td>.279</td>
<td>.523</td>
</tr>
</tbody>
</table>

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 estimated using bootstrapping. *** denotes statistical significance at the 1% level; ** 5% level; * 10% level.

where $\alpha_j$ 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 by trading day and by currency.\textsuperscript{17}

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 rates. The estimate slightly rises.

Relative to the baseline, we also conducted some robustness checks. First, we dropped from the sample all weeks that had a policy meeting, so that the arbitrage trade is not exposed to the risk of changes in $\bar{i}_t^p - \bar{i}_t^r$ as discussed in section 3. The coefficient falls by a negligible amount to 0.17. Second, the inclusion of the period between February to May 2010 when the swap line agreements lapsed could attenuate our estimates. Dropping this time period from the sample increases the

\textsuperscript{17}We also did block bootstrapping to deal with small cluster bias, and found the results to be unchanged.
Table 2: Regression estimates of the effect of swap line ceiling changes on CIP deviations

<table>
<thead>
<tr>
<th></th>
<th>Baseline $x_{jt}$</th>
<th>Censored $x_{jt}$</th>
<th>Time fixed effect $x_{jt}$</th>
<th>Shorter sample $x_{jt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling ($c_{jt}$)</td>
<td>0.1996*** (0.037)</td>
<td>0.6578* (0.249)</td>
<td>0.1675** (0.057)</td>
<td>0.248*** (0.039)</td>
</tr>
<tr>
<td>N</td>
<td>9500</td>
<td>950</td>
<td>9500</td>
<td>8195</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.08</td>
<td>0.16</td>
<td>0.67</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Notes: Estimates of equation (7). The dependent variable is the 1-week CIP deviation of the CAD, CHF, EUR, GBP, and JPY vis-a-vis the USD. The sample runs from 19th September 2008 (the date of the first multilateral Federal Reserve swap agreement) through to 31st December 2015. All regressions include currency fixed effects. Column (1): panel least squares estimator. Column (2): panel least squares estimator conditional on $x_{jt}$ 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.

3.7 Estimating the demand for funding liquidity by foreign banks

Do higher CIP deviations result in higher drawings from the swap line? Figure 6 shows the allotment for the ECB and Bank of Japan 1-week operations, which had significant amounts outstanding throughout the sample.$^{18}$

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

$$\log(q_{jt}) = \alpha_j + \beta_j x_{jt} - 1 + \varepsilon_{jt}. \quad (8)$$

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

Table 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 predicts, and surprisingly close to each other.$^{19}$ The last column of the table presents a different estimate, of the

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$^{18}$The BoJ commenced 1 week auctions on the 29th of March 2011.

$^{19}$We have also estimated a Heckman model to adjust for any potential selection effect from the operations where
Figure 6: Allotment at USD operations by ECB and BoJ, and CIP deviations

![Graph showing USD operations by ECB and BoJ](image)

Table 3: Auction allotments and funding costs

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

Notes: Estimates of equation (8). 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 allotted 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.
elasticity of euros lent out by the ECB in its 1 week operations with respect to the marginal cost of funds, the 1 week euro LIBOR-OIS spread. The elasticity is 1.6%, not statistically significantly different from the elasticity of demand for dollars from the ECB by the same set of banks. This confirms the tight link between conventional lending facilities and the unconventional swap lines that was the main result of section 2.20

4 The economic effects of the swap lines

We have so far established in theory and in the data that the central bank swap lines are a lending facility, 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, also in theory and in the data, that this has economic effects in the investment decisions of firms following banks’ funding decisions and the risks they face.

4.1 A model of global banks’ investment decisions

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

Consider a simple model of funding risk affecting banks that live for three periods, in the spirit of Holmström and Tirole (2011), but with global banks and cross-border funding.21 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 \(i^s\).

no amount was allotted. This yielded very similar results.

20From the perspective of the recipients, Rose and Spiegel (2012) find a cross-sectional relation between the amount of dollars lent out by the Fed, and the CDS rates of the recipient countries.

21We conjecture that similar results would follow in a Diamond-Dybvig setup following the exposition in Rochet and Vives (2010).
4.1.1 Investment in the first best

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

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: \( \frac{\partial^2 F(\ldots)}{\partial k_0^* \partial k^*} > 0 \). Following Holmström and Tirole (2011), we think of \( k_0^* \) as investment in long-term capacity, which must be employed and partly replenished with short-term investment \( k^* \) before output is realized. This creates a demand for funding to invest \( k^* \).

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

4.1.2 Funding shocks and sources of funding

However, in the second period, the representative recipient-country bank faces an upper bound in attracting source-country funders: \( l^* \leq \bar{l} - \chi \). It is standard to justify these constraints on funding as a result of limited net worth and limited pledgability of assets. Importantly, \( \chi \) 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 \( \chi \) correspond to funding crises in which, as happened in 2007-10 when U.S. money market funds were unwilling to extend repo loans to European banks, the first-best investment cannot be funded through this route.

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

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

### 4.1.3 Equilibrium

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

The left-side panel of figure 7 presents the implications for CIP deviations as a function of the funding shock. When there is plentiful funding, CIP holds and in equilibrium there is no volume of trade in exchange-rate derivatives. As funding becomes scarcer, \( \chi \) starts exceeding \( \bar{\chi} \), and the exchange-rate intermediaries start operating at an increasing cost, which leads to rising CIP deviations. If the funding needs become more extreme, then banks start turning to the swap line and the swap line rate ceiling binds.

The right-side panel of figure 7 shows instead how profits in the second period depend on the funding shock.\(^{22}\) 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

\(^{22}\)So, \( \pi(k_0) = \max_{k^*} \{ F(k_0^*, k^*) - ik^* - H(\cdot) \max\{k^* + \chi - \bar{l}, 0\} - (i^s - i) \max\{k^* - \bar{k}^*, 0\} \} \).
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.

4.1.4 The effect of the swap line on investment

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

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

(9)

where $\tilde{\pi}(\cdot)$ and $\tilde{\pi}'(\cdot)$ are the profit functions, independent of $\chi$, when the funding shocks are below $\chi$ and above $\bar{\chi}$, respectively. By the envelope theorem, if there were no funding shocks, only the first term on the right-hand side would be non-zero, and this would reduce to $\tilde{\pi}'(k_0^*) = \partial F(\cdot)/\partial k_0^* = \rho$. The first-best level of capital would be reached. Otherwise, capital investment is now lower because, as figure 7 shows, for a range of realizations of the funding shock, the profits are lower. When recipient-country banks decide to invest in the source-country firm, they take into account that next period they may get hit by a large funding shock, leading to higher costs and lower profits.
A lower rate charged on the swap line now has two effects. First, it lowers the \( \bar{\chi} \) as banks switch from market to swap-line funding sooner. Second, it lowers the private rates that banks get in the market by improving their outside option relative to the traders. The effect on CIP deviations and on the profits of banks in period 2 are displayed in figure 7.

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

Collecting all the results gives the proposition:

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

i. Lowers the ceiling and expected realization of CIP deviations, \( x \);

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

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

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

### 4.2 Data and empirical strategy

We start by testing the prediction that a lower swap-line rate, by lowering the costs of liquidity for recipient-country banks after a funding shock, will induce them to invest more in source-currency denominated assets.

The start of our identification strategy to assess this prediction is again the Fed’s 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 $t$. 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.

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 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.

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

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 $n_{a,b,t} = \frac{\tilde{n}_{a,b,t}}{\sum_{t=1}^{25} \sum_{b} |\tilde{n}_{a,b,t}|}$. 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.
4.3 Results on bond flows

Figure 8 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. Moreover, this shift is apparently permanent as there are no countervailing negative flows later in the window.

Figure 9 plots instead the coefficient estimates of $\beta_t$ from the following regression:

$$n_{a,b,t} = \beta_t \times \text{SwapLine}_a \times \text{USDBond}_b + \alpha_{a,t} + \gamma_{b,t} + \varepsilon_{a,b,t}$$

(10)

where $\text{SwapLine}_a$ is a dummy for whether institution $a$ is a bank headquartered in a country that

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26 In the CIP estimates, we used a wider window to avoid bias due to the end-of-year spikes in CIP, and because comparing histograms required having enough daily observations. For these bond flows regressions we use a more conservative narrower window, since neither of these two concerns apply.

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

The first column of table 4 presents the statistical estimates of $\beta$ in the regression:

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

(11)

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 9, 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 0.077% of the bank’s average absolute daily flow.
Table 4: Fixed-effects panel regression estimates of the effect of swap line rate changes on investment flows

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
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<td>0.0770*</td>
<td>0.0772*</td>
<td>0.0788*</td>
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<td>(0.041)</td>
<td>(0.042)</td>
<td>(0.062)</td>
<td>(0.064)</td>
<td>(0.042)</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<tr>
<td>bank × currency f.e.</td>
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<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>bank × issuer f.e.</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
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<td>No</td>
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<tr>
<td>bank × duration f.e.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
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</tr>
<tr>
<td>bank × bond f.e.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>period × currency f.e.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>period × issuer f.e.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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</tr>
<tr>
<td>period × duration f.e.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>period × bond f.e.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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

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

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

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28 We also included a dummy variable for whether the USD bond was issued by a US or foreign firm. The coefficient was positive but statistically insignificant at conventional levels.
How large are these effects? Within our sample, there are 69 USD denominated bonds, 19 banks, effects over 5 days, and the average absolute flow from a firm is $45 million. Multiplying all to our estimates gives an increase in gross flows of $230 million. This is 4.8% of the absolute flow over five days among the swap line banks in sample. Extrapolating out of sample, the net flow from foreigners into bonds issued by U.S. non-financial excluding the government in the 2017 flow of funds was $172bn, which times our aggregated estimate of 4.8% suggests a $8.31 billion shift in capital flows driven by a 0.5% change in the swap line rate. This is a large effect. It provides strong evidence that liquidity policies affect investment decisions.

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. Through this diff-in-diff strategy and by enlarging the sample of bonds considered, we can address the concern of whether there is something special about the bonds that are actively traded by foreign banks.

The treatment is not randomly assigned, so we use a nearest-neighbour matching procedure that weights observations to build treatment and control groups that have similar relevant bond level characteristics. Specifically we match on credit rating (converted to a numerical scale), log residual maturity, coupon, log of the face value outstanding, and average yield in the 5 days prior to treatment. We then consider the change 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

29Reading the Financial Times issues in this narrow window revealed no other reference to news about corporate bond prices, beyond discussions about the swap line rate change.
Table 5: Impact of swap line rate change on the yield of frequently-traded USD-denominated bonds

<table>
<thead>
<tr>
<th></th>
<th>Nearest Neighbor</th>
<th>Exact Match on Euro Issuers</th>
<th>Dropping Euro-area Issuers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$foreignheld_b$</td>
<td>-0.0860**</td>
<td>-0.1221***</td>
<td>-0.1264***</td>
</tr>
<tr>
<td></td>
<td>(0.036)</td>
<td>(0.036)</td>
<td>(0.038)</td>
</tr>
<tr>
<td>$N$</td>
<td>5474</td>
<td>5474</td>
<td>5257</td>
</tr>
</tbody>
</table>

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.

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.\textsuperscript{30} 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.

To get a sense of the magnitude of these estimates, Gertler and Karadi (2015) estimate that in response to a conventional monetary policy shock that raises the one-year yield by 50bp, the commercial paper spread rises by 12.5bp. We find that an unconventional monetary policy shocks to the swap line rate of 50bp lowers the corporate bond yield by 12.2bp. Such large effects may perhaps not be surprising from a financial-markets perspective given the large portfolio flows we already found. But, from the perspective of the effectiveness of 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.

\textsuperscript{30}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.
4.5 The effect of swap lines on bank valuations

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

We test this by asking whether banks in countries that receive dollar swap lines have excess returns around the swap-rate change dates. Again, this is a triple-difference exercise, that compares: (i) the days before and after the swap-line rate change by the Fed, (ii) foreign banks in countries covered by the dollar swap lines and so affected by the rate change, and (iii) foreign banks with a U.S. presence versus foreign banks with no U.S. 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.31

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 2011.32 The window after the announcement over which the excess returns are cumulated is five days as in the bond yield regressions.

Figure 10 presents the results. It compares the average excess returns for banks in the jurisdictions covered by the swap line whose rate changed and who have a significant U.S. presence with two control groups: banks not covered by the swap-line rate change, and banks in the swap lines but without a U.S. presence. Clearly, it is those banks that are connected with the United States and that have access to swap line dollar emergency funding that experience the excess returns following the announced increase in the generosity of the swap line. The shareholders in these banks appear to value the liquidity insurance offered by the swap facility.

Table 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

31 Note that banks we used in the bond flows regression have a US presence.
32 The appendix presents also similar estimates (and slightly smaller standard errors) from using an alternative measure of excess returns using the Fama-French factors.
Figure 10: Cumulative bank excess returns averaged across different banks after treatment date

Table 6: Average bank excess returns after swap line rate change

<table>
<thead>
<tr>
<th>Swap Line Banks</th>
<th>US Presence</th>
<th>No US Presence</th>
<th>US Banks</th>
<th>Other Banks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
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<td>0.0087</td>
<td>0.0063</td>
<td>-0.0033</td>
</tr>
<tr>
<td></td>
<td>(0.0140)</td>
<td>(0.0068)</td>
<td>(0.0084)</td>
<td>(0.0098)</td>
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<td>0.0281***</td>
<td>0.0290*</td>
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<tr>
<td></td>
<td>(0.0125)</td>
<td>(0.0086)</td>
<td>(0.0154)</td>
<td>(0.0103)</td>
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<td>N</td>
<td>36</td>
<td>72</td>
<td>310</td>
<td>24</td>
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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.
However, once weighted by market size, there are significant excess returns for all but the non-treated, non-U.S. bank returns. The difficulty is that U.S. presence is strongly correlated with bank size, and that around the date of the swap changes, all large banks had positive excess returns. The data do not allow us to separate the effects of size from those of U.S. presence.

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. It made three contributions. 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 renminbi wanted to compete with the dollar for the status of dominant currency? Does the increase foreign funding by global banks allowed by the swap lines raise or lower welfare in the global macroeconomic equilibrium? Are foreign banks investing too much in domestic assets or relying too much on domestic funding leading to macro-financial fragility, and is this enhanced by the swap lines? By lowering the cost of a financial crisis, do the swap lines make a crisis more likely? How can the two central banks in a swap-line arrangement coordinate their choices and how does this spill over to conventional monetary policies?

What 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.
References


Piazzesi, Monika, and Martin Schneider. 2018. “Payments, Credit and Asset Prices.” Stanford manuscript.


Appendix – For Online Publication

Appendix A provides the proof of proposition 3. 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 3

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

$$ (1-\omega) \min \{\xi^c i_t^a + (1-\xi^c) i_t^u, \xi^o i_t^o + (1-\xi^o) i_t^u\} + \omega \lambda_{a,t} \geq s_t - f_t + (i_t^{ps} - i_t^{vs}). \tag{A1} $$

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

$$ x_{a,t} \leq (1-\omega) \min \{\xi^c i_t^a + (1-\xi^c) i_t^u, \xi^o i_t^o + (1-\xi^o) i_t^u\} - i_t + (i_t^{ps} - i_t^{vs}) + \omega \lambda_{a,t}. \tag{A2} $$

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

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

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

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

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

Therefore, we can dispense with the min operator in the ceiling expression.
The ceiling result then becomes:

\[ x_{a,t} \leq (i_t^a - i_t) + (i_t^{ps} - i_t^*) + (1 - \xi^c)(i_{a,t}^u - i_t^*) + \psi_{a,t}, \]  

(A5)

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

B 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. Tick data on FX swaps and spot exchange rates are taken from Thomson Reuters Datascope. Here we list specific data series along with the source used to construct CIP deviations \( x_{j,t} \), and swap line ceilings \( c_{j,t} \).

Table 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. For the tick data: the 1 week EUR FX swap versus USD has Datascope RIC EURSW=, the spot exchange rate is EUR=.

**GBP:** The 1-week OIS rate is Datastream ticker OIGBPSW. The 1-week LIBOR rate is Datastream ticker BBGBP1W. The spot price of a USD in GBP is Datastream ticker 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. For the tick data: the 1 week GBP FX swap versus USD has Datascope RIC GBPSW=, the spot exchange rate is GBP=.

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

**CAD**: The 1-week OIS rate is Bloomberg ticker CDSO1Z Curncy. The 1-week LIBOR rate is Datastream ticker BBCAD1W. The spot price of a USD in CAD is Datastream ticker 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. For the tick data: the 1 week CAD FX swap versus USD has Datascope RIC CADSW=, the spot exchange rate is CAD=.

**CHF**: The 1-week OIS rate is Bloomberg ticker BBCHF1W. The spot price of a USD in CHF is Datastream ticker TDCHFS. 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 SWSNB (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. For the tick data: the 1 week CHF FX swap versus USD has Datascope RIC CHFSW=, the spot exchange rate is CHF=.

**Non-Swap Line Currencies data**: 1-week OIS rates are not always available for all the currencies that are not part of the swap line network. Hence we exclusively compute bases using LIBOR and the central bank interest on excess reserves (this also applies to the equivalent USD interest rates).
**AUD**: The 1-week LIBOR rate is Datastream ticker GSAUD1W. The spot price of a USD in AUD is the inverse of Datastream ticker AUSTDOI. The 1-week forward price of USD in AUD is Datastream ticker USAUDWF. The interest rate on excess reserves is the RBA cash rate, Datastream ticker RBACASH, less 25 basis points. For the tick data: the 1 week AUD FX swap versus USD has Datascope RIC AUDSW=, the spot exchange rate is AUD=.

**DKK**: The 1-week LIBOR rate is Datastream ticker CIBOR1W. The spot price of a USD in DKK is Datastream ticker DANISH$. The 1-week forward price of USD in DKK is Datastream ticker USDKKWF. The interest rate on excess reserves is the daily minimum of the Danmarks 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. For the tick data: the 1 week DKK FX swap versus USD has Datascope RIC DKKSW=, the spot exchange rate is DKK=.

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

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

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

**Computing CIP deviations from FX swap quotes**: We download all available quotes for 1 week FX swaps versus USD for the ten currencies in our sample on Thomson Reuters Datascope over the period November 2011 to 31st January 2012. We then drop quotes that occur over the weekend, on holidays or between 21:40-06:50 London time. This leaves us with 1,228,637 unique quotes across 10 currencies in November 2011 (671,388) and January 2012 (557,249). We take the mid swap price in swap points and match each quote to the mid-spot exchange rate in the minute that the quote was taken. The mid spot is calculated as the average of the mid open and mid
close in the minute interval; these are computed directly by Datascope using the intraday summary feature. This enables us to calculate the implicit outright forward price in the swap and hence the log forward premium. Note that GBP, AUD and NZD swaps and spot exchange rates are quoted in USD per local currency unit and hence we transform the quotes accordingly. We then use the relevant daily interest rate fixing (OIS/LIBOR) to compute the CIP deviation.

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

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>std. dev.</th>
<th>median</th>
<th>25th %-ile</th>
<th>75th %-ile</th>
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</tr>
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<td>1900</td>
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<td><strong>Interest Rate on Excess Reserves based CIP deviations</strong></td>
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<td>-.10</td>
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</table>

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 Operations

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

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

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

<table>
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<th>Table A2: Operation summary statistics</th>
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<td><strong>ECB USD Operation</strong></td>
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<td>-----------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Number of Bidders</td>
</tr>
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<td><strong>ECB EUR Operations</strong></td>
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<td>Amounts Alloted (Eur mn)</td>
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<tr>
<td>Number of Bidders</td>
</tr>
<tr>
<td><strong>BoJ USD Operations</strong></td>
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<tr>
<td>Amounts Lent ($mn)</td>
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</table>

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

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33 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.
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 access to a swapline.

**Bonds:** The intersection 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.

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.

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

C Robustness Results

This section describes further robustness checks on the regressions in tables 1 and 4.
Table A3: Summary statistics for the bond flows data

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>std. dev.</th>
<th>median</th>
<th>25th %-ile</th>
<th>75th %-ile</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>By Bond</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All bonds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trades per day</td>
<td>3.9</td>
<td>3.3</td>
<td>2.8</td>
<td>1.8</td>
<td>4.8</td>
<td>790</td>
</tr>
<tr>
<td>Daily volume ($ '000s)</td>
<td>2496</td>
<td>2083</td>
<td>1950</td>
<td>1095</td>
<td>3191</td>
<td>790</td>
</tr>
<tr>
<td>Average net daily flow ($ '000s)</td>
<td>15</td>
<td>404</td>
<td>15</td>
<td>-195</td>
<td>234</td>
<td>790</td>
</tr>
<tr>
<td>Residual Maturity (years)</td>
<td>6.3</td>
<td>6.1</td>
<td>4.6</td>
<td>2.7</td>
<td>7.2</td>
<td>790</td>
</tr>
<tr>
<td>High Rating (A- or greater = 1)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>790</td>
</tr>
<tr>
<td>Face Value ($ mn)</td>
<td>1116</td>
<td>643</td>
<td>1024</td>
<td>683</td>
<td>1365</td>
<td>790</td>
</tr>
<tr>
<td>USD bonds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trades per day</td>
<td>3.6</td>
<td>2.3</td>
<td>3.1</td>
<td>2.1</td>
<td>4.8</td>
<td>69</td>
</tr>
<tr>
<td>Daily volume ($ '000s)</td>
<td>1832</td>
<td>2018</td>
<td>1075</td>
<td>419</td>
<td>2007</td>
<td>69</td>
</tr>
<tr>
<td>Average net flow ($ '000s)</td>
<td>-35</td>
<td>278</td>
<td>-18</td>
<td>-146</td>
<td>108</td>
<td>69</td>
</tr>
<tr>
<td>Residual Maturity (years)</td>
<td>7.2</td>
<td>7.9</td>
<td>4.3</td>
<td>2.5</td>
<td>7.8</td>
<td>69</td>
</tr>
<tr>
<td>High Rating (A- or greater = 1)</td>
<td>.61</td>
<td>.49</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>69</td>
</tr>
<tr>
<td>Face Value ($ mn)</td>
<td>1271</td>
<td>734</td>
<td>1000</td>
<td>750</td>
<td>1750</td>
<td>69</td>
</tr>
<tr>
<td><strong>By Bank</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trades per day</td>
<td>119</td>
<td>99</td>
<td>98</td>
<td>30</td>
<td>190</td>
<td>26</td>
</tr>
<tr>
<td>Daily volume ($ '000s)</td>
<td>75833</td>
<td>69965</td>
<td>59441</td>
<td>10099</td>
<td>122618</td>
<td>26</td>
</tr>
<tr>
<td>Average trade size ($ '000s)</td>
<td>616</td>
<td>314</td>
<td>618</td>
<td>421</td>
<td>793</td>
<td>26</td>
</tr>
<tr>
<td>Average net flow ($ '000s)</td>
<td>447</td>
<td>11882</td>
<td>21</td>
<td>-3723</td>
<td>5359</td>
<td>26</td>
</tr>
<tr>
<td>Activity measure ($ '000s)</td>
<td>44906</td>
<td>39253</td>
<td>38174</td>
<td>6090</td>
<td>78302</td>
<td>26</td>
</tr>
</tbody>
</table>
### Table A4: Robustness of Difference-in-Differences Results on CIP deviations

<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) Interest on Excess Reserves</th>
<th>(3) 2 month window</th>
<th>(4) 3 month window</th>
<th>(5) 2 week window Falsification (Aug vs Oct)</th>
<th>(6) Just European Currencies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>-.184**</td>
<td>.035</td>
<td>-.121</td>
<td>-.074</td>
<td>-.155*</td>
<td>-.065</td>
</tr>
<tr>
<td></td>
<td>(.092)</td>
<td>(.056)</td>
<td>(.079)</td>
<td>(.079)</td>
<td>(.085)</td>
<td>(.090)</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>-.146</td>
<td>-.071</td>
<td>-.113</td>
<td>-.113</td>
<td>-.176</td>
<td>-.046</td>
</tr>
<tr>
<td></td>
<td>(.147)</td>
<td>(.149)</td>
<td>(.326)</td>
<td>(.326)</td>
<td>(.141)</td>
<td>(.084)</td>
</tr>
<tr>
<td><strong>75 %tile</strong></td>
<td>-.155</td>
<td>-.093</td>
<td>-.163</td>
<td>-.127</td>
<td>-.282**</td>
<td>.062</td>
</tr>
<tr>
<td></td>
<td>(.113)</td>
<td>(.134)</td>
<td>(.123)</td>
<td>(.096)</td>
<td>(.112)</td>
<td>(.160)</td>
</tr>
<tr>
<td><strong>90t %tile</strong></td>
<td>-.281***</td>
<td>-.284***</td>
<td>-.252***</td>
<td>-.254**</td>
<td>-.154*</td>
<td>-.179</td>
</tr>
<tr>
<td></td>
<td>(.090)</td>
<td>(.102)</td>
<td>(.104)</td>
<td>(.100)</td>
<td>(.087)</td>
<td>(.267)</td>
</tr>
</tbody>
</table>

Standard errors blocked bootstrapped at the currency level in parentheses.

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


### 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 fifth column conducts a pre-event falsification test and compares August 2011 to October 2011. We do not obtain statistically significant differences. This suggests that our results are not just a manifestation of a pre-existing trend. The sixth column shows results when we just use European currencies increasing the similarities.

The change in the swap line rate on November 30th 2011 occurred simultaneously with an extension of the swap arrangements. Our predictions relate to the swap line rate not to the length of the swap line arrangement. To rule out that the extensions explain our results we consider as placebos four other event dates: May 9th 2010; December 21st 2010; June 29th 2011 and December 13th 2013. These all correspond to dates where the swap arrangements were renewed or extended...
Figure 11: Daily CIP deviations histograms for treated and non-treated currencies around swap line extensions

May 9th 2010: Apr v Jun  Dec 9th 2010: Nov v Jan
June 29th 2011: Jun v July  Dec 13th 2012: Nov v Jan

without any change in the swap rate. Figure 11 summarises the results in the form of histograms. As can be seen these extensions are not associated with any major shift in the distribution of CIP deviations.

For swap line currencies, Figure 12 presents the equivalent to Figure 5 when computing the CIP deviation using OIS rates rather than LIBOR rates. The shift in the distribution following the tightening of the swap line rate is clear.

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 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.

C.3 Robustness of bank equity returns estimates

Table A6 presents the equivalent to Table 6 when we compute excess returns additionally controlling for the Fama-French size (SML), book to market (HML), profitability (RMW) and investment (CMA) factors from Fama and French (2015). This makes no meaningful difference to the results.
Table A5: Robustness of fixed-effects panel regression on investment flows

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

Notes: Further estimates of equation (11) 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.

Table A6: Average bank excess returns after swap line rate change: excess returns relative to 4 Fama-French factors

<table>
<thead>
<tr>
<th></th>
<th>Swap Line Banks</th>
<th>US</th>
<th>No US</th>
<th>US Banks</th>
<th>Other Banks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US Presence</td>
<td>Presence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.0272**</td>
<td>0.0101</td>
<td>0.0048</td>
<td>-0.0033</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0131)</td>
<td>(0.0067)</td>
<td>(0.0105)</td>
<td>(0.0112)</td>
<td></td>
</tr>
<tr>
<td>Size Weighted</td>
<td>0.0241**</td>
<td>0.0298***</td>
<td>0.0206***</td>
<td>0.0029</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0122)</td>
<td>(0.0084)</td>
<td>(0.0054)</td>
<td>(0.0106)</td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td>36</td>
<td>72</td>
<td>309</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

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