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

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Theory predicts that central-bank lending programs put ceilings on private domestic lending rates, reduce *ex post* financing risk, and encourage *ex ante* investment. This article shows that with global banks and integrated financial markets, but domestic central banks, then lending of last resort can be achieved using swap lines. Through them, a source central bank provides source-currency credit to recipient-country banks using the recipient central bank as the monitor and as the bearer of the credit risk. In theory, the swap lines should put a ceiling on deviations from covered interest parity, lower average *ex post* bank borrowing costs, and increase *ex ante* inflows from recipient-country banks into privately issued assets denominated in the source-country's currency. Empirically, these three predictions are tested using 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 days of the week in which the swap line is open, variation in the exposure of different securities to foreign investment, and variation in banks' exposure to dollar funding risk. The evidence suggests that the international lender of last resort is very effective.

Key words: Liquidity facilities, Currency basis, Bond portfolio flows.

JEL Codes: E44, F33, G15.

1. INTRODUCTION

At least since Bagehot (1873), it is widely accepted that central banks play the role of lenders of last resort to prevent disruptions in banks' access to borrowing that can lead to crashes in investment. Whether these lending facilities were crucial in preventing a depression in 2007–08, or whether they sowed the seeds of future crises through moral hazard, is up for debate. Common to both sides of the argument is a presumption that the lender of last resort is effective. Testing this presumption is challenging since most programs either have long precedents with few changes over time, or were introduced as an endogenous response to large shocks with multiple effects. This article uses a facility that has risen in prominence over the past decade, central bank swap

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lines, to test for Bagehot's classic predictions. We exploit experimentation in setting up the terms of the swap line that affected only some financial assets in certain denominations to present credible evidence that the lender of last resort has a large effect on financial prices and investment decisions.

Banks today operate in multiple regions with integrated financial markets, yet they face independent central banks with national currencies and lender of last resort policies. Practice has been ahead of theory, as central banks have set up multiple swap lines worth trillions of dollars, which already receive significant attention in discussions of the global financial architecture, of the role of the IMF, or of monetary policy coordination across borders.[1] How should a domestic central bank lending facility in domestic currency that is used by foreign banks (that have foreign regulators and foreign collateral but domestic investments) work? Which market prices would it affect, and how could one measure its effectiveness? Does such a lender of last resort to foreign banks promote investment in domestic markets *ex ante*, and prevent crashes during crises *ex post*? This paper answers these crucial questions for the modern international financial system theoretically, and empirically evaluates the predicted effects. It concludes that central bank swap lines plug a gap in the international policy framework.

Finally, while swap lines have been used by central banks for decades to intervene in foreign exchange markets, the central bank swap lines that were first established in December 2007 were novel and are interesting in their own right. The lines came into use between September 2008 and January 2009, with the amount drawn peaking at $586bn; see Figure 1. The swap lines were formally reintroduced in May 2010 and in October 2013 they were made into permanent, reciprocal, standing arrangements of unstated sizes between the Fed and a network of five other 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.[2] In March of 2020, the first major internationally-coordinated economic response to the Covid-19 crisis by central banks was to extend the USD swap lines to 9 more countries, with longer maturities, more frequent operations, and a lower cost.[3] In turn, other central banks using other currencies have entered similar arrangements over the past decade, so that by 2020 there was a wide ranging network of around 170 bilateral swap lines. They can generate official cross-border capital flows in excess of the resources of even the IMF.[4] This paper provides an analysis of the role played by the new central bank swap lines as lending facilities of last resort in internationally integrated financial markets.

We start in Section 2 by describing the terms and operation of the existing swap contracts. A swap line is a loan of source-country currency by the source-country central bank to a recipient-country central bank, keeping the recipient-country currency as collateral for the duration of the loan. In turn, the recipient-country central bank lends the currency it received to recipient-country banks. In the end, this results in lending by the source-country central bank to the recipient-country banks, with the recipient-country central bank bearing the credit risk. Through the swap lines, the

1. For discussions of the role that the swap lines may play in the international financial architecture see di Mauro and Zettelmeyer (2017), Eichengreen *et al.* (2018), and Gourinchas *et al.* (2019), and for a discussion of their adoption as a package of responses during the 2007–10 financial crisis see Kohn (2014) and Goldberg *et al.* (2011).

2. The other swap lines between the Fed and central banks that were established in 2008 expired in 2010, with the exception of a limited arrangement with the Banco do Mexico.

3. These facilities were actively used in response to the pandemic crisis. On March 24th, Japanese banks borrowed a combined $89bn from the Bank of Japan; in comparison, the most the Bank of Japan lent in a single day during the financial crisis was $50bn on 21st October 2008. Similarly, the Bank of England and the ECB borrowed more in individual days that week than they had since 2010, and 2011, respectively. Collectively, by 27th March, the swap line stock had reached 43% of the peak balances in 2008 (Bahaj and Reis, 2020a).

4. Many of these involve the People's Bank of China, see (Bahaj and Reis, 2020b).

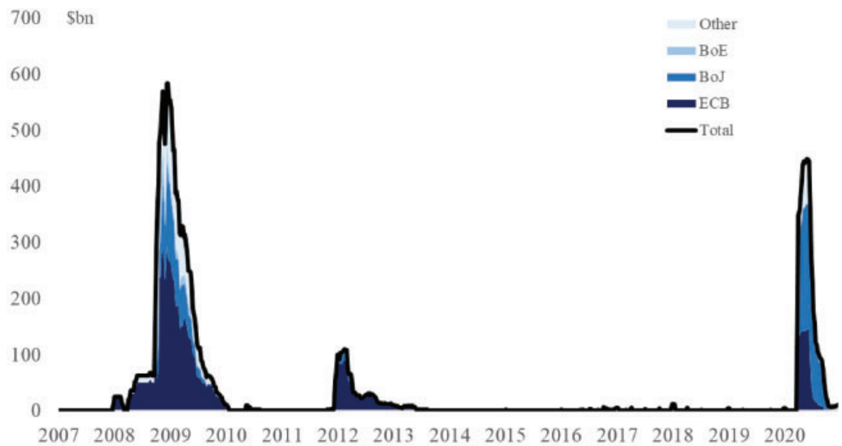


FIGURE 1

Federal Reserve dollar lending through its swap lines.

source central bank can support its domestic markets by lending to foreign banks, supplementing the traditional lending facilities to domestic banks. In short, they are a form of international lending of last resort.

Section 3 provides an integrated model of global banks, forward currency markets, and bond-financed investment that isolates the main mechanisms through which lending of last resort affects financial markets and the macro-economy. The model produces three main lessons. First, a no-arbitrage argument proves that the sum of the gap between the swap rate and the interbank rate in the source country, and the gap between the central bank's policy rate and its deposit rate in the recipient country, provides a ceiling on the deviations from covered interest parity (CIP) between the two currencies. Second, in a world where profit-maximizing financial intermediaries sell forward contracts subject to constraints on the size of their balance sheet, there is an upward-sloping supply curve in the forward market where CIP deviations are determined that becomes horizontal at the ceiling. Lowering the swap line rate truncates the observed distribution of CIP deviations and shifts it to the left when the swap line is available. Third, the demand curve for forward contracts comes from profit-maximizing global banks that lend to source-country firms. Therefore, in general equilibrium, a fall in the swap line rate lowers *ex ante* perceived borrowing costs in the source country, and so raises their investment in the source-country currency.

Sections 4, 5, and 6 test these predictions. We use different sources of data and different identification strategies that exploit changes in the terms of the swap line that affect currencies, banks, bonds, and days near the end of the quarter differentially.

The first set of tests use data on individual quotes in the FX swap market to measure the whole distribution of CIP deviations for major currencies versus the dollar that banks face. The identification strategy relies on a cut in the Fed's swap line rate in November 2011. The timing of this event resulted from negotiation lags between different central banks, and the discussion surrounding the decision did not refer to the measure of CIP deviations that matches the swap line. Hence, the cut in the swap line rate was plausibly exogenous to the CIP deviations in the days preceding it. This validates a difference-in-differences exercise, comparing the behaviour of CIP deviations for currencies issued by central banks with access to the Fed's swap line versus comparable currencies lacking a swap agreement. This approach provides a control for generalized shifts in the supply of FX derivatives, or in the demand for dollar hedging. The data support the prediction that the swap lines introduce a ceiling: the right tail and the mean of the distribution of CIP deviations shift to the left after the rate cut.

The second set of tests, in Section 5, still uses the CIP data, but employs a different source of variation and a different identification strategy. It starts from the fact that CIP deviations spiked at quarter ends after 2016 (Du *et al.*, 2018). The spikes are typically ascribed to regulatory constraints facing the financial intermediaries that supply forward contracts, and are not related to the swap line operations per se. Unlike discount window facilities, which are always open, the swap line lending facilities until 2020 were only open once a week at pre-determined dates. Since the arbitrage argument in the theory should hold only when the swap line is open, this provides a second test of the effectiveness of the swap lines: around quarter-ends, they should put a ceiling only when they are open. Unlike the first exercise, this second test does not exploit any change in policy. The variation across days is purely operational, having to do with the day of the week the swap line happens to be open. We show that, at quarter-ends, the period where CIP deviations spike is precisely bracketed in the window between swap line operations. On the day when the final operation before quarter-end is settled, and so the ceiling should bind, CIP deviations fall sharply. The ceiling provided by the swap line is clearly evident.

The third set of tests uses a new dataset of net purchases of corporate bonds transacted in Europe. The theory predicts that the November 2011 fall in the dollar swap-line rate should increase investment in dollar-denominated assets by financial institutions under the jurisdiction of a central bank with access to these swap lines, relative to banks in other jurisdictions, including in the US, and to non-dollar bonds. This leads to a triple-difference strategy, over the time of the swap rate change, 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.

A follow-up difference-in-differences strategy shows that these portfolio shifts led to an increase in the price of the USD corporate bonds traded by European financial institutions relative to other dollar bonds. The quantity effects from the first strategy have matching effects on prices. The result is consistent with the swap line providing lending of last resort that prevents large price drops in the source-country asset markets. Finally, because the swap line provides insurance to banks against funding risk, a cut in its rate should raise the banks' expected profits. 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 U.S. experienced excess returns. This final result, though, is statistically weaker than the previous ones.

All combined, we find that the international lender of last resort works in the direction predicted by theory. Lowering the lending rate shifts the distribution of CIP deviations, lowers borrowing costs of banks, and increases lending to firms across borders. Our estimates support an important role for the swap lines in the global economy: (1) they perform the function of liquidity provision and lender of last resort with a particular form of cooperation between different central banks; (2) they have significant effects on exchange-rate markets, especially on the price of forward contracts; (3) they incentivize cross-border gross capital flows and they potentially avoid crises in source-country financial prices and in recipient-country financial institutions.

1.1. *Links to the literature*

Our model and results point to the need to incorporate global banks and multiple central banks into models of liquidity shocks in the tradition of Holmström and Tirole (2011) and Poole (1968), or more recently as in Bianchi and Bigio (2021), Piazzesi and Schneider (2018), or de Fiore *et al.* (2018). Empirically, our strategy relies on high-frequency transactions in financial markets and the associated prices to identify causal effects, similar to the large macroeconomic literature that, starting with Kuttner (2001), has studied the effects of conventional and unconventional monetary policies (e.g., Gertler and Karadi, 2015; Swanson, 2017; Jarociński and Karadi, 2020).

Over the past decade, a growing literature has documented CIP deviations (Du *et al.*, 2018) and proposed explanations for them, tied to bank capital regulation (Borio *et al.*, 2016; Avdjiev *et al.*, 2019; Cenedese *et al.*, 2019) or to debt overhang and the cost of unsecured funding (Andersen *et al.*, 2019) and studied how some policies affect them (Natraj, 2019). Our model of financial frictions 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, and show theoretically and empirically how this affects the average size and distribution of both market prices and contract quotes. Moreover, we link these deviations to investment choices with macroeconomic consequences. Our article is one of a more recent set of papers (Rime *et al.*, 2019; Abbassi and Bräuning, 2021) that emphasize the need to look at the distribution of CIP deviations at a point in time because the market for forward contracts is over the counter.

Another set of predictions and tests are with regard to investment flows. Closest to our article is Ivashina *et al.* (2015) who show that, during the Euro-crisis, U.S. money market funds lent less to European banks. In turn, European banks participated less in USD syndicated loans. While their focus was on syndicated lending, our focus is on purchases of corporate bonds in secondary markets. This is by design: the syndication process occurs over a time period, and it takes several weeks to even assemble the syndicate. At lower frequencies, the growing crisis in Europe and the policy responses by the ECB make it impossible to isolate the effect of the swap lines alone. By using high-frequency transactions in financial markets, we eliminate these confounders. Moreover, focusing on corporate bonds as opposed to syndicated loans is arguably more relevant. In 2017, European banks held debt securities issued by foreigners or domestic non-bank corporates as 39% of their total loans to the global corporate sector on average; the equivalent percentage for syndicated loans is a mere 9%.[5]

This is not the first article to study central bank swap lines. An older literature studied the swap lines that supported the Bretton Woods system as well as the Fed's reciprocal swap system between 1962 and 1998. Their main use was to finance foreign exchange rate interventions and to keep currencies pegged to the dollar (*e.g.* Williamson, 1983; Obstfeld *et al.*, 2009). The arrangements we study are instead between floaters, the swap line funds were not used directly by the recipient central banks to intervene in the foreign exchange market, and all the participants are large, advanced economies. The older swap lines were also at times used to resolve liquidity shortages in offshore dollar markets (McCauley and Schenk, 2020), closer to the effects that we study in this article. However, they were not standing facilities with pre-announced terms that could be used for this purpose, and we are not aware of studies that tried to causally identify their direct impact on investment flows or CIP deviations.

On the new central bank swap lines, early studies (Baba and Packer, 2009a,b; Baba, 2009) found a statistically significant correlation between the introduction of the swap lines and their drawings, and CIP deviations across currency pairs in 2007–09, while controlling for variables that could be moving demand for dollars. We stay away from the 2007–09 crisis period, where identification is hopeless, but instead use exogenous changes in the swap line rate and on the intermittent availability of the swap line auctions to make causal interpretations and identify the

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

mechanisms driving the effects.[6] Also, we focus on the impact of changing the swap line rate, a likely active policy lever in the future as the swap lines are here to stay.[7]

2. HOW DO THE SWAP LINES WORK?

The dollar swap lines between the Federal Reserve and the five other advanced country central banks in the swap line network accounted for the bulk of activity during and after the financial crisis. It helps to focus on them for concreteness. Their typical properties are as follows: the Fed, as the source central bank, gives dollars to another, recipient, central bank, and receives an equivalent amount of the recipient's 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 three months), 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.[8] This is a pre-approved lending program, so that the recipient central bank can ask for any amount from the Fed at the announced interest rate, although each request is individually approved by the Fed. These are reciprocal arrangements, so a similar contract would apply if instead it was the ECB lending euros to the Fed (or to another member of the network), although the Fed has never borrowed foreign currency through the network.[9]

The recipient central bank then lends the dollars out to eligible banks in its jurisdiction for the same period of time via a market operation, charging the same rate that the Fed charges it. It asks for the same high-quality liquid assets as collateral that it asks for in other liquidity facilities. The recipient central bank is in charge of determining eligibility, collecting payment, and if the financial institutions default, then the central bank 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 loan of dollars to foreign banks. From the perspective of these banks, the collateral requirements and the terms of the loan are similar to credit from their central banks through domestic lending facilities. What is novel is the presence of an intermediary: the recipient central bank doing the monitoring, picking the collateral, and enforcing repayment. In Supplementary Appendix A.1, we discuss why this division of tasks was preferred to alternatives, and in Supplementary Appendix A.2 how the swap lines interact with other monetary policies.

Because the swap-line rate is set as a spread over the short-term interest rate, it does not directly interfere with conventional monetary policy. Because the terms are set when the contract is signed, there is no exchange-rate risk or interest-rate risk for the participants. The credit risk for the source central bank is negligible, since it is solely dealing with the recipient central bank, with its reputation at stake, while for the recipient central bank, the credit risk is similar to that from any other liquidity facility to its banks. While the policy will have some impact on the equilibrium exchange rate, the source-country currency is not used right away to buy recipient-country currency and affect its price, and the recipients of dollars do not have explicit targets or

6. See also Moessner and Allen (2013) on the 2010–11 euro area sovereign debt crisis, but again using drawings from the swap line which, since operations were full allotment, was determined by the demand from banks.

7. In the other direction, Fleming and Klagge (2010) and Goldberg *et al.* (2011) document the time-series correlation between drawings on the swap lines and different interest spreads.

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

9. Individual source central banks still have some discretion to set their own terms including the lending rate. For instance, the ECB's euro swap line with the Bank of England, established in 2019, uses the ECB's main refinancing rate plus a spread, instead of the OIS rate, to determine the swap line rate.

policies for intervening in the value of their currency vis-a-vis the dollar. Finally, the recipient central bank makes no profits from the operation since it pays the source central bank the interest it receives, while the source central bank profits insofar as it charges a spread over the rate on reserves.

3. THE FINANCIAL MARKET AND MACROECONOMIC EFFECTS OF INTERNATIONAL LENDING OF LAST RESORT

The model builds over three blocks, which require an increasing set of assumptions. It starts with a simple, and quite general, no-arbitrage argument for borrowing by banks. This is then embedded in a model of the financial market for borrowing source-country currency synthetically. Finally, this market is placed within a general-equilibrium model of investment and production.

3.1. *The CIP ceiling*

Consider the following trade: a recipient-country bank borrows source-country currency from its local central bank through the swap line that it must pay back with interest at rate i_t^s at the end of the fixed term. The bank then buys the recipient-country currency with this source-country currency at today's spot rate s_t, while it signs a forward contract to exchange back recipient- for source-country currency at a locked exchange rate of f_t after the same fixed term. It deposits this recipient-country currency at its central bank's deposit facility, earning the interest on reserves i_t^{v*}.[10] Because reserves are usually overnight, while the swap-line loan is for a fixed term, the bank buys an OIS contract that converts the interest on reserves into a fixed rate for the fixed term in order to match the maturity of the trade. This returns $i_t^* - i_t^{p*}$, where i_t^* is the OIS rate for this fixed term, while i_t^{p*} is the reference rate for the OIS contract, which is usually an overnight interbank rate, very close to the policy target of the central bank. Because all the lending and borrowing involves the recipient central bank, this trade involves no risk beyond: (1) the negligible counterparty risk in the forward and swap contracts and (2) the risk of movements in the spread between i_t^{p*} and i_t^{v*}, which rarely changes, and typically only at some policy meetings. While the OIS rate is used to deal with maturity mismatch, there is no direct lending or borrowing between banks in this rate.

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

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

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

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

where i_t is the equivalent OIS rate in source-country currency. 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:

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

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

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

It is well known that a standard central bank domestic lending rate puts a ceiling on the interbank rate. Otherwise, there would be an arbitrage opportunity whereby banks could borrow from the central bank and lend in the interbank market making a sure profit. The proposition follows from the same no-arbitrage logic. The proposition is precise in the sense of indicating the right measures of i_t and i_t^* to calculate the relevant CIP deviation: they are the OIS rates at the relevant maturity as these both match the pricing of the swap line and the cost of hedging the interest rate risk at the deposit facility.[11]

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 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.

This simple ceiling result ignores regulatory and collateral constraints on the banks using the swap line. Supplementary Appendix B considers them and shows that they can add a third, bank-specific, source of variation to the ceiling on CIP deviations if the bank's unsecured and secured funding rates are different and if borrowing and lending from the central bank is subject to bank capital regulation. Finally, note that because the swap lines are reciprocal arrangements, a symmetric argument places a floor on x_t that depends on the swap line rate and interest rates in the other currency with the source and recipient central bank reversing roles. Because, in our data, the CIP deviations for a currency pair are almost always of a single sign and because the Fed has not activated its reciprocal swap lines, in the discussion that follows we focus only on one side of the policy. Without loss of generality, we refer to it always as a ceiling applying to positive x_t, but the reciprocal swap line rate would put a floor on negative x_t.

3.2. *The supply curve of synthetic source-country currency*

Proposition 1 holds no matter what gives rise to CIP deviations. We now embed its argument within a partial-equilibrium model of the market for foreign exchange swap contracts to micro-found the forces that cause the CIP deviations. The model captures two important features of reality. First, since these are over-the-counter markets involving different counterparties, there is a distribution of CIP deviations across different institutions. Second, there is an increasing marginal cost of supplying swap contracts.

3.2.1. Agents and market. Consider a world with two types of atomistic risk-neutral agents: traders and banks. Each separate trader gets matched in an over-the-counter market with a separate bank that needs to swap two currencies for a fixed period in order to borrow source-country currency synthetically. The trader quotes the bank a price $s_t - f_t$ for a swap contract that converts recipient currency to source currency.

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

3.2.2. Frictionless equilibrium. In a frictionless market, each trader is identical and offers the same terms to every bank. The trader would be able to supply one swap contract by first borrowing source-currency at the secured rate i_t, then selling the swap contract to the bank at rate $s_t - f_t$, and then depositing the resultant recipient-currency at zero risk at the central bank at the deposit rate i_t^{v*} (and, as above, purchasing an OIS contract priced at $i_t^* - i_t^{p*}$ to fix the rate on the deposit). As long as: $i_t^{v*} + i_t^* - i_t^{p*} + s_t - f_t - i_t \geq 0$, the trader would find it profitable to supply the swap. Free entry and zero profits by traders would imply that in a frictionless equilibrium $x_t = i_t^{p*} - i_t^{v*}$. With a satiated market for reserves, this difference in interest rates is by definition zero, so CIP would hold.

3.2.3. Intermediary frictions. We assume that traders, however, are part of one representative financial intermediary that faces two frictions. The first one, following Gârleanu and Pedersen (2011), is that a fraction m of the source currency used to fund the swap contract must be financed with the intermediary's own-equity. This margin requirement is commonly enforced by the counterparties in these markets. An alternative justification, following the evidence in Du *et al.* (2018), is that this is a binding leverage requirement imposed by regulators. Either way, the cost of own-equity is $i_t + \Delta_t^e$, higher than the secured funding rate by a spread Δ_t^e. The second friction, following Andersen *et al.* (2019), is that a fraction of the amount borrowed to produce the swap must use unsecured funds, because of a haircut with a cash ratio of ζ. Therefore, each trader must make a funding value adjustment of $(1-\zeta)\Delta_t^u$ to account for the spread the intermediary must pay for unsecured borrowing Δ_t^u. These two frictions—regulatory capital requirements and margins, together with funding value adjustments—are the two leading theories that have been put forward to explain CIP deviations after 2007.

Given these frictions, the profit per swap contract traded is:

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

where the equality follows from the definition of x_t in equation (2). Let $h_t \equiv m\Delta_t^e + (1-m)(1-\zeta)\Delta_t^u$ denote the extra cost of supplying swap contracts relative to the frictionless benchmark. We assume that the shadow cost of equity and collateral apply at the intermediary level and, hence, the atomistic traders take Δ_t^e and Δ_t^u as given.

The literature focusing on these financial frictions predicts that the two spreads, Δ_t^e and Δ_t^u, are each increasing in the volume of trading in swap contracts V_t. Therefore, $h_t = h(V_t)$ is an increasing function, for two separate reasons. First, if there is an alternative use of own-equity that has decreasing returns to scale, then the intermediary will require of its traders a Δ_t^e that is rising in V_t (Gârleanu and Pedersen, 2011). Second, the cost of unsecured borrowing, Δ_t^u, is increasing in the amount borrowed, so supplying more forward contracts increases the funding value adjustment (Andersen *et al.*, 2019).[12]

3.2.4. Matching frictions. If there was perfect competition among traders, the CIP deviation relative to the frictionless case would be driven to h_t. However, the forward market

12. To give a more concrete explanation of this second effect, imagine that the intermediary has assets net of secured borrowing, A_t, unsecured borrowing L_t, a probability of default θ_t, which for simplicity is independent from the activity of its swap traders, and in case of default only a share κ gets recovered by the creditors. Then *pari passu* rules on unsecured creditors imply that under risk-neutrality they would charge: $\Delta_t^u = \theta_t[L_t + V_t(1-m)(1-\zeta_t) - \kappa(A_t + V_t(1-m)(1-\zeta_t)]/[L_t + V_t(1-m)(1-\zeta_t)]$. For a fixed margin, m, this is increasing in V_t.

is over-the-counter, and traders have some market power. To reflect this, we assume that each trader gets matched with a bank that can engage in the arbitrage trade of the previous Section, and they bargain over the terms of the forward contract every period. Indexing an individual counterparty bank by a, its Nash bargaining weight is δ_a, and in the population of banks there is a distribution function $F(\delta_a)$ with $\mathbb{E}_a(\delta)=\bar{\delta}$.

Each bank's outside option is, of course, to go to the central bank swap line. The bank would pay i_t^s by borrowing from the swap line while the traders can supply source-currency synthetically at marginal cost $i_t+(i_t^{p*}-i_t^{v*})+h_t$.[13] The outcome of the bargain that takes into account the bank's payoffs from either option is a forward price such that its associated bank-specific CIP deviation $x_{a,t}$ is:[14]

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

If banks have all the bargaining power, then traders' profits are driven to zero, and the CIP deviation is $(i_t^{p*}-i_t^{v*})+h_t$, 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, differences in bargaining power across banks creates a distribution of CIP deviations, $F(x_{a,t})$, implied by the quotes for FX swaps.[15]

3.2.5. Predictions. *Ex ante*, consider any bank before it knows its type. Their expected bargaining power is the average $\bar{\delta}$. The perceived supply curve of synthetic source currency then looks like the upward-sloping curve in Figure 2. When V_t is low, so the intermediary and traders are supplying few contracts, then the equity and unsecured-funding demands are small, and the marginal costs of supply h_t is small. The cost of the swaps supplied by the traders have an expected cost that is approximately equal to the constant $(1-\bar{\delta})(i_t^s-i_t)$, where CIP does not hold because of the market power of traders. These deviations are expected to be small, only a few basis points, as is typically observed when financial markets are well functioning.

As V_t increases, the CIP deviation is instead given by equation (5) with *ex ante* bargaining power. It accounts not just for market power, but also for the fact that the marginal cost of frictional supply of swaps, h_t, increases with volume. Thus, the supply curve slopes up.

Finally, once h_t is sufficiently high, banks switch to getting foreign currency directly from the swap line. The swap line ceiling binds and the blue line becomes flat. Extra demand for synthetic source currency is satisfied by the central bank, without affecting the costs of traders.

What happens when the swap line rate falls? Graphically, this is captured by the dashed curve. Not only does the CIP deviation at which the ceiling binds fall, but the volume of trade at which this happens (the kink in the supply curve) also shifts to the left making the upward-sloping portion of the curve flatter. These two extra effects result from the banks' outside option cheapening, which improves the bargaining terms they obtain from the traders. This leads to the following empirical prediction.

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

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

13. This abstracts from the extra terms due to collateral and regulation discussed in Proposition 4 in Supplementary Appendix B, but they could be easily included.

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

15. Abbassi and Bräuning (2021) present empirical evidence that market power and the availability of an outside option alter the price banks' pay for FX hedging.

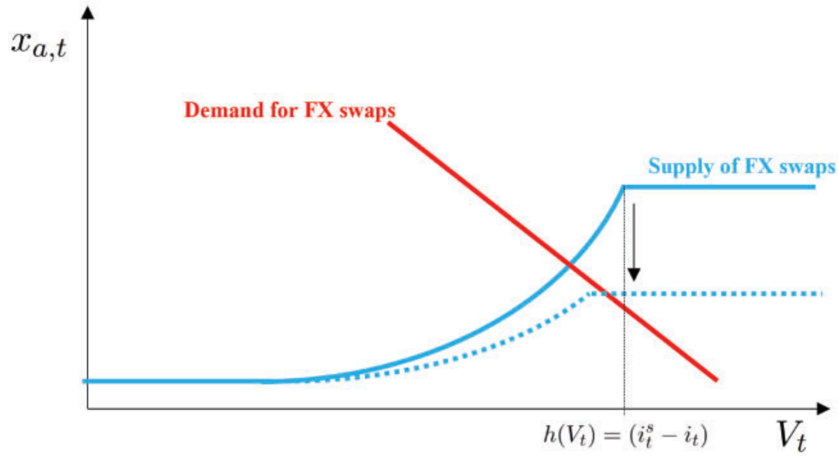


FIGURE 2
Graphical illustration of the effect of a swap line rate cut

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

Proposition 2 turns the ceiling result in Proposition 1 into empirical predictions on the CIP distribution arising from quotes in the swap market. It predicts that reducing the central bank swap line truncates the distribution rightwards, and shifts its mean to the left. The two interest-rate spreads in the two parentheses are chosen by policy and have different sources of variation. The first interest-rate spread is exogenously set by the source central bank. The second interest-rate difference is instead set by the recipient central bank. It is zero if the central bank is running a floor system, where the market for reserves is satiated so the opportunity cost of holding them is zero, and it is positive otherwise.[16]

3.3. *A model of global banks' investment decisions*

Finally, we integrate our theory of banks, central banks, and exchange-rate derivatives markets into a general-equilibrium model of investment in the spirit of Holmström and Tirole (2011), but with global banks and cross-border capital flows.[17] This provides a micro-foundation for the demand curve in Figure 2 and, more important, generates predictions on another market, that for investments in the real economy.

To avoid carrying around needless terms that will be absorbed by constants and fixed effects in the empirical work that follows, we make two simplifications. First, we assume that the recipient-country's monetary policy is running a floor system, so $i_t^{p*} = i_t^{v*}$, and second, we assume that

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

17. We conjecture that similar results would follow in a Diamond-Dybvig setup with global games following the exposition in Rochet and Vives (2010).

all banks are identical in their bargaining power with the intermediary, so $\delta_a = \bar{\delta}$. As a result, the cost of a swap contract provided by intermediaries behind the supply curve is equal to: $i_t + \bar{\delta} h(V_t) + (1-\bar{\delta})(i_t^s - i_t)$ and the ceiling result is $x_t \leq i_t^s - i_t$.

3.3.1. Agents and time. There are two countries, source and recipient, with respective currencies, and three periods. The two key agents are a representative source-country firm and the recipient-country banks. The firm needs to borrow to acquire physical capital and produce beyond what source-country banks can lend to them, on account of limited net worth and limited ability to commit.[18] The recipient-country banks provide long-term lending (2 periods) for purchases of physical capital k_0^* in the first period, and short-term (1 period) lending to purchase k^* in the second period. They collect payment in the third period from the output net of payments to the source-country banks: $F(k_0^*, k^*)$.

3.3.2. Investment in the first best. The marginal product of physical capital is positive and diminishing and the two types of physical capital are complementary in production: $\partial^2 F(.)/\partial k_0^* \partial k^* > 0$. The complementarity arises because k_0^* is an investment in long-term capacity that must be employed and partly replenished with short-term investment k^* before output is realized.

Source-country households, after exhausting their willingness to lend to source-country banks and firms directly, are willing to lend (in source-currency) to recipient-country banks. They charge rate i in the second period and rate ρ in the first period (for a two period loan). Without financial frictions, the standard first-order condition for firms determining the investment financed by short-term borrowing from recipient-country firms is: $\partial F(.)/\partial k^* = i$. Likewise, the amount of long-term investment satisfies $\partial F(.)/\partial k_0^* = \rho$. Together, these two optimality conditions define the first-best level of investments: $\hat{k}_0^*, \hat{k}^*$.

3.3.3. Financial shocks. However, in the second period, the representative recipient-country bank faces an upper bound in attracting source-country resources: $l^* \leq \bar{l} - \chi$. It is standard to justify these financial constraints as a result of limited net worth and limited pledgeability of assets.

Importantly, χ is a random variable that captures a financial shock. High values of χ correspond to financial crises when flight to safety takes place, and foreign investments are treated as riskier. The shock has distribution $G(\chi)$ and domain $[0, \bar{l}]$.[19]

Since first-best investment cannot be financed through this route, banks can turn to borrowing in recipient-country currency at rate i^*. This exposes them to exchange-rate risk, which we assume banks want to fully hedge away. As before, they can obtain synthetic source-country currency from traders at the rate $i^* + x$. However, if x exceeds the ceiling the banks will find it cheaper to instead borrow source-country currency at the swap line at rate i^s.

3.3.4. The demand curve for FX swaps. In period 2, the demand curve in Figure 2 comes out of this model. The firm would like to equate the marginal cost of financing, call it MC, to the marginal product of capital: $\partial F(.)/\partial k^* = MC$. When the financing needs are small relative

18. The lending by source-country banks is immaterial to the results, so we leave it unspecified.

19. We assume that $\bar{l} \geq \hat{k}^*$ so that if χ is low, the recipient-country bank can finance its investment in source-country firms with source-country resources alone.

to the source-currency resources of the recipient-country banks, so $\chi \leq \bar{l}-\hat{k}^* \equiv \underline{\chi}$, then $MC=i$ and 1-period investment is at the first best. The recipient-country banks finance all their loans to the source-country firm by borrowing from the source country. The demand for synthetic currency is zero, so the demand curve is at the vertical axis. If, instead, $\chi > \underline{\chi}$, then the recipient banks switch to recipient-currency funding and must pay to hedge the exchange rate risk, so $MC=i+x$. But then, by the diminishing marginal product of capital, the higher is x, the lower demand will be, and so the demand curve slopes down. Moreover, larger realizations of χ shift the demand curve to the right as a greater volume of borrowing in recipient-country currency needs to be hedged.

Combining supply and demand, $V=\max\{k^*-l^*,0\}$ when the swap line is not in use. The model then provides the following account of the events around 2007–10 described in Ivashina *et al.* (2015). Before 2007, CIP approximately held. The borrowing cost for firms was $MC=i$, and the banks obtained dollars from U.S. money markets suggesting $\chi < \underline{\chi}$ and V in the neighbourhood of zero. Financial intermediaries were viewed as safe and could operate with a high degree of leverage meaning that the $h(.)$ function was shallow even in the event of financial shocks. However, the crisis brought new regulations, debt overhang, and other financial frictions. As a result, the supply curve for forward contracts became steeper. Moreover, U.S. money market funds were no longer willing to give credit to European banks suggesting $\chi > \underline{\chi}$. Hence, the new equilibrium was now in the range shown in Figure 2 with positive CIP deviations.

Our model adds central bank policy to this account. Since the financial crisis, financial shocks that shift the demand curve to the right raise CIP deviations when they are small or moderate. When they are large though, then banks turn to the swap line, $MC=i^s$, and the swap line rate ceiling binds.

3.3.5. Equilibrium investment. Aside from the market for FX swaps, this general-equilibrium model makes new predictions for the investment choices of firms financed by banks.

When the financial shock χ is small in the second period, the financial constraint is slack. The profits of banks are high, as the marginal cost of capital is low. Firms' short-term investment is at the frictionless optimum (conditional on k_0^*). Once the shock becomes larger, then the recipient-country banks start using their country's currency funding and exchange-rate hedging. Marginal cost rises so short-term investment falls. Profits also fall. If the shock becomes larger enough, then banks turn to the swap line, and both investment and profits again become independent of the size of the liquidity shocks. The size of the shock that triggers this switch is $\bar{\chi}$, defined as the solution to $\bar{\delta}h(\bar{k}^*-\bar{l}+\bar{\chi})+(1-\bar{\delta})(i^s-i)=i^s-i$. At this point, investment, $\bar{k}^*$, solves $\partial F(.)/\partial k^*=i^s$, which is independent of the realization of the shock.

The firm chooses long-term capital k_0 in the first period. When recipient-country banks decide to lend to the source-country firm, they take into account that next period they may get hit by a large financial shock, leading to higher costs and lower profits. A lower rate charged on the swap line then has two effects. First, it lowers the threshold χ at which banks switch from the market to the swap line. Second, it lowers the private rates that banks get in the market by improving their outside option relative to the traders. Both contribute to lowering the expected costs from having to respond *ex post* to a financial crisis. Thus, the profits from investing abroad are weakly higher across the realization of 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 realisations of the shock. Supplementary Appendix C proves this formally:

Proposition 3. *An exogenous decrease in the swap-line rate $i^s - i$:*

i. Raises ex ante investment by recipient-country banks in assets denominated in source-currency, k_0^*;
ii. Increases ex ante expected profits of recipient-country banks that lend in source-currency, Π_0.

In short, by introducing a source of backstop borrowing for recipient-country banks, the source-country central bank swap line lowers the expected costs of financial 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.

4. THE SWAP LINE RATE AND CIP DEVIATIONS: EMPIRICAL EVIDENCE

Proposition 2 shows the impact of a cut in $i_t^s - i_t$ on the equilibrium distribution of CIP deviations facing banks. This Section tests this prediction using the empirical distribution of CIP deviations, and plausibly-exogenous variation in the swap line rate.

4.1. *Data and the operation of the swap lines in practice*

Maintaining our focus on USD swap lines, we consider CIP deviations between US dollars and British pounds, Canadian dollars, European euros, Japanese yen, and Swiss francs – the five currencies issued by central banks in the advanced-economy swap-line network. We complement data on these swap-line network currencies with a series of currencies for which swap lines lapsed in February of 2010: Australian dollar, Danish krone, New Zealand dollar, Norwegian krone, and Swedish krona.

The operational details of how the USD swap lines worked dictates our choices of which data to use, and drives some of our identification strategies. In terms of the sample dates, the five central banks within the swap line network with the Fed have carried out regular USD operations from September 2008 until present day (with a short gap between February 1st and May 9th of 2010 when the swap agreement lapsed). The terms and timing of these operations evolved over time. Initially, the operations were *ad hoc*, only sometimes at full allotment, not always synchronized across central banks, and with fluctuating timetables. Many of the changes were responses to the evolving financial crisis creating insurmountable identification problems. Between May 2010 and March 2020, the institutional arrangements were more stable, with weekly dollar operations providing loans of one-week maturity to the recipient banking sector, conducted at full allotment with a fixed interest rate. This is the main period for our analysis.[20]

During this sample period, the swap line was not a lending facility that was open at any time. Rather, operations happened once a week on a predetermined schedule coordinated among the central banks. The ECB, the Bank of England and the SNB carried out a one-week dollar operation every week at the same time. Bids were taken on Wednesday morning and the operation was settled on Thursday. The bids for the Bank of Japan's operation were typically taken one day before but settled on the same day as the European operations.[21] The Bank of Canada has full

20. After March 2020, the operations became daily, 84-day tenor operations were reintroduced, and the swap lines were extended to 9 other central banks on slightly different terms: see Bahaj and Reis (2020a) and Supplementary Appendix E.5.

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

access to the swap line but did not conduct regular USD operations in the sample period. This is consistent with our theory since CAD-USD CIP deviations have been relatively small.[22]

Finally, in terms of the tenor of the credit, daily operations were used sporadically during the financial crisis at times of extreme market stress alongside 1-month and 3-month operations. Between October 2011 and February 2014, there were 3-month operations at a monthly frequency. We focus on one-week maturities as these operations were the most commonly tapped, they were conducted throughout our sample, and were what the central banks in the network finally settled and coordinated on after a few years of experimenting.

Correspondingly, while the theory applies to CIP deviations of different tenors, the cleanest CIP deviation to test it is for one week. We build $x_{j,t}$ for currency j using the one-week forward rate or swap rate to measure $f_{j,t}$. Our first source of data is Datastream, which reports daily forward and spot exchange rates. These can be seen as a draw from the daily distribution of quoted prices for FX contracts faced by individual banks, probably with some reporting bias towards the mean of the distribution. We complement these data with daily OIS one-week rates to compute the CIP deviations based on the argument in the previous Section that these replicate our no-arbitrage trade. The exception is in Section 4.2 when we consider currencies outside the swap network where, due to data limitations, we rely on one week LIBOR rates for all currencies (both daily interest rate fixings, OIS and LIBOR, are sourced from datastream). A second source of data, matching the discussion in Section 3.2, measures bank-specific CIP deviations, $x_{a,t}$. These more granular data are created from tick data on the quotes of foreign exchange swap contracts. Similar to Cenedese *et al.* (2019), we collect the quoted price of every one-week FX swap versus the USD contained within Refinitiv Datascope for the 10 currencies in our sample, and calculate an implicit CIP deviation using the spot exchange rate in the minute of the quote and the relevant daily interest rate fixings. This provides over 1.7 million observations across November 2011 through January 2012 that we will use in the difference-in-differences exercise in the next section. See Supplementary Appendix G for details of all data used in this Section and associated summary statistics.

Figure 3 plots, using daily data, the one-week OIS euro-dollar and sterling-dollar CIP deviations together with the ceiling stated in Proposition 1. Our sample starts on 19th September 2008 when the Fed first expanded its swap lines to cover the five other central banks in the multilateral network and runs until the end of 2015 (see Supplementary Appendix D for other currencies).[23] The period from 2016 onwards will be studied separately in Section 5. The shock to the CIP deviations from the Lehman Brothers failure in September 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.[24] The time-series variation in the ceiling for the sterling-dollar since March 2009 is largely driven by the gap $i_t^s - i_t$, because the Bank of England operated a floor system. The ceiling was 100 basis points between March 2009 and November 2011, and 50 basis points afterwards. In the case of the ECB, the gap $i_{j,t}^{p*} - i_{j,t}^{v*}$, which is the difference between the short-term repo policy rate and the deposit facility rate, has had some time-series variation due to relative movements in the deposit

timetable can vary somewhat due to differences in holidays and other local factors: one relevant case is that there is no operation in the last week of the year due to the holidays.

22. See Terajima *et al.* (2010) for a discussion of the Canadian context. One explanation provided for lower CIP deviations is the presence of a stable USD deposit base in Canada.

23. There were dollar swap lines in place with the ECB and the SNB starting on the 12th December 2007, but for limited amounts (\$20bn and \$4bn, respectively) and, in the case of the ECB, there was no volume in weekly operations until September 2008.

24. These year-end deviations do not reject the presence of a ceiling, because both the ECB and the Bank of England suspend their one-week operations for one week at the end of the year. More on this in Section 5.

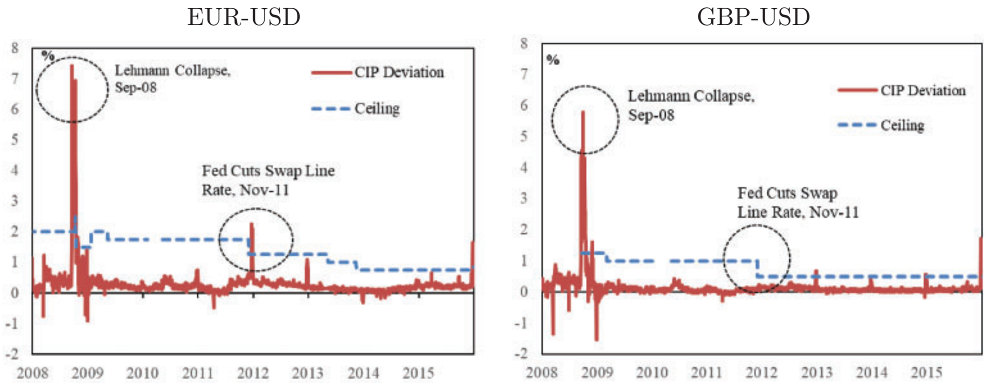


FIGURE 3

CIP deviations and the swap line ceiling

facility and main policy rates.[25] 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 1 February 2010. Without it, one-week DKK-USD CIP deviations exceeded the counterfactual ceiling on 23 trading days through to the end of 2015, excluding year-end periods.

4.2. *A difference-in-differences test*

Consider an unexpected cut in the swap line rate. Proposition 2 characterized its effect on CIP deviations. The accompanying Figure 2 highlights four challenges in testing for these effects by just comparing CIP deviations before and after.

First, while the policy change truncates the distribution of CIP deviations to the right, there may well be little impact if the initial equilibrium is well to the left of the kink point in the supply curve. Therefore, the test of the proposition must use data from a time when there was large demand for cross-currency hedging or little supply. In terms of the model, either demand must be elevated, or supply restricted, so their intersection is near the kink point. This happens naturally during financial crises.

Second, if the policy change is a response to tighter financial regulations or financial fragility of intermediaries that shifted the supply curve to the left, then CIP deviations could either rise or fall. One way to address this would be to compare currencies for which there was an active swap line, with those for which there was not. Both would be similarly affected by the underlying shift of supply to the left, but only those with a swap line would have the counteracting policy response. Comparing the two would isolate the policy's effect.

A third concern arises if the policy change was a response to an out-shift in the demand for currency hedging, which could lead the average CIP deviation to actually rise. In that case, one needs a short window where the crisis is not accelerating, and one needs the change in the swap line rate to be exogenous to the demand shift in that short window.

Fourth, because the intermediaries that supply the forward contracts may be the same across currencies, there may be spillovers across markets. In a crisis, and for a significant cut in the swap

25. There is a short gap in the ceiling in the Figure between February and May 2010 when the ECB and BoE's swap lines with the Fed lapsed.

line rate, the swap line starts being used and the equilibrium moves from being in the upward-sloping part of the supply curve to the horizontal section of the curve. Banks now borrow from the swap line, so part of the quantity in the horizontal axis is now being supplied by the central bank, as opposed to the private intermediaries. This frees capacity of the intermediaries, and so shifts down the supply curve in non-affected currencies, lowering CIP in those currencies as well. Comparing a treated group and a control group of currencies then provides a lower bound on the effects of the swap line on the treated currencies alone.[26]

Combining all four concerns and the needed solutions to them leads to a difference-in-differences strategy, around an unexpected policy change, comparing the behavior of currencies with access to the swap line to those without.

4.2.1. An identification strategy. On the 30th of November 2011, the Fed unexpectedly announced that, for swap line operations from 5th December onwards, it would lower $i_t^s - i_t$ from 1%, the level it had been at since 2007, 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. This provided an unambiguous *tightening of the ceiling* stated in the propositions.

The transcripts of the meeting authorizing the cut (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 about dollar financing in international money markets, and a deepening sovereign crisis in the Euro-area, leading to growing funding difficulties of foreign banks. Of course, the swap line rate change was endogenous with respect to these long-standing concerns. But what is crucial for the identification is that the change is *exogenous with respect to the behavior of one-week CIP deviations in the week or month before*. The transcripts of the meeting have no mention of the one-week currency basis. Our measures of CIP deviations, while elevated for some currencies, were not on a particular trend (see Supplementary Appendix D.2): for instance, one-week EUR CIP deviations had held in a similar range since September, despite the worsening of the crisis. The timing of the change as discussed in the transcripts seems rather to have been determined by the outcome of lengthy discussions with foreign central banks. The change affected all central banks that had established swap line arrangements with the Federal Reserve, despite the fact that negotiations and concerns were focused on the Euro-area in the treated group and the Nordic countries in the control group.

Moreover, the size of the change seems to not have been predetermined. The transcripts show a serious discussion on whether to set the new rate at 0.75%, with the choice for 0.5% driven by a previous agreement with foreign central bankers, in spite of reservations raised by some Board governors. Judging by news reports in the Financial Times, this change came as a surprise to markets, so there is *little anticipation effect*.

It is certainly possible that the policy's effects worked not directly through the ceiling result, but because they gave a signal to the markets from the central bank. However, combining the policy change with a difference-in-difference strategy addresses this concern. So long as the treatment and control groups are comparable, we can isolate the effect of a tighter ceiling generated by the swap line separately from any overall fluctuations in global market conditions or confidence effects generated.[27]

26. A right truncation in the supply curve, that keeps the intersection point in its upward-sloping portion, would instead use private intermediation capacity in the affected currencies, and plausibly then lower intermediaries' capacity in the non-affected currencies, raising their CIP deviation.

27. Supplementary Appendix D.5 discusses another relevant date, 9th of May 2010 when the swap lines were re-activated after lapsing in February. Because at this time the equilibrium was far from the kink point in the supply curve, applying a similar empirical strategy does not have the statistical power to detect an effect.

4.2.2. Results. Even though there are only five currencies in each group, there are thousands of observations per day on price quotes ($x_{a,t}$), with which to test Proposition 2. We combine them into one week of data, comparing the pre-announcement week of 23–29 November with the week after the first operations in USD at the new rate had taken place and banks had been credited the funds, that is 8–13 December. There are no significant *common* policy changes by all central banks in either the treatment or control groups during this time.[28] An alternative is to use instead the daily data for CIP deviations, that is more commonly used in the literature. In this case, a one-week window is not enough, since there are only 10 observations of $x_{j,t}$ per day. We instead build a window of one month before and after December (so January versus November). One virtue of this wider window is that it allows us to test whether the swap line rate change had a longer lasting effect. Moreover, CIP deviations are usually volatile around year end, so leaving the very end of December out avoids spikes that could potentially biasing the results.

Each row of Figure 4 shows an implementation of our test by comparing histograms of CIP deviations before and after the policy change, for treated versus non-treated currencies. In the first row is our baseline comparison of quote-implied CIP deviations in the week before the cut in the swap line rate and the week after the first operation under the new terms. The shift to the left of the distribution of the treated relative to the untreated is clear, as is the effect that the reduced ceiling has in almost entirely eliminating any observations between the new and the old ceiling.[29]

At the same time, there is a visible shift to the right among the non-swap line currencies in the figure. This is inconsistent with the policy shift easing the capacity constraints facing the dealers in FX swap markets. As discussed at the start of this sub-section, that would lower CIP deviations in the control group. Also, consistent with our discussion of contamination there, the swap line drawings increase in 2010–12, and the volume of privately supplied contracts, measured by the reported FX quotes, falls in swap-line currencies relative to the non-swap line currencies. Therefore, the fourth concern discussed in Section 4.2 does not seem to be present.

Instead, the rise in CIP in the non-swap line currencies suggests that during this period there is a shift to the right of the supply curve that is relatively homogeneous across all countries. In terms of the theory, this would be a common shock to dealer capacity to supply forward contracts (a shock to one of the terms in h_t). There are many likely candidates during this period for such a shock: the publication of the Eurozone bank stress tests, credit ratings downgrades that were common at this time of crisis, and political risk associated with the EU fiscal compact. Being a common shock, the difference-in-differences strategy should deal with it.

Finally, since the change in the swap line rate comes with higher usage of the swap line by banks, it lowers collateral requirements, since the central bank facilities have a more generous use of collateral than private intermediaries. Similarly, perhaps the cut in the swap line rate lowered the stigma associated with using the swap line. These cases are covered in an extension of the theory in Supplementary Appendix B. They imply that lowering the swap line rate by 50 bp may lower the theoretical ceiling by even more than 50 bp. This makes it even more likely that the new ceiling now binds, explaining why the effects are so large and clearly visible in the figure.

The second and third row expand the comparison to the month of November versus the month of January. This provides histograms with more observations and indicates whether the effects appear to be permanent as the theory suggests. The second row shows even more starkly that the right mass beyond the ceiling is almost entirely cut out by the swap line. Extending the sample

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

29. 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 4 in Supplementary Appendix B.

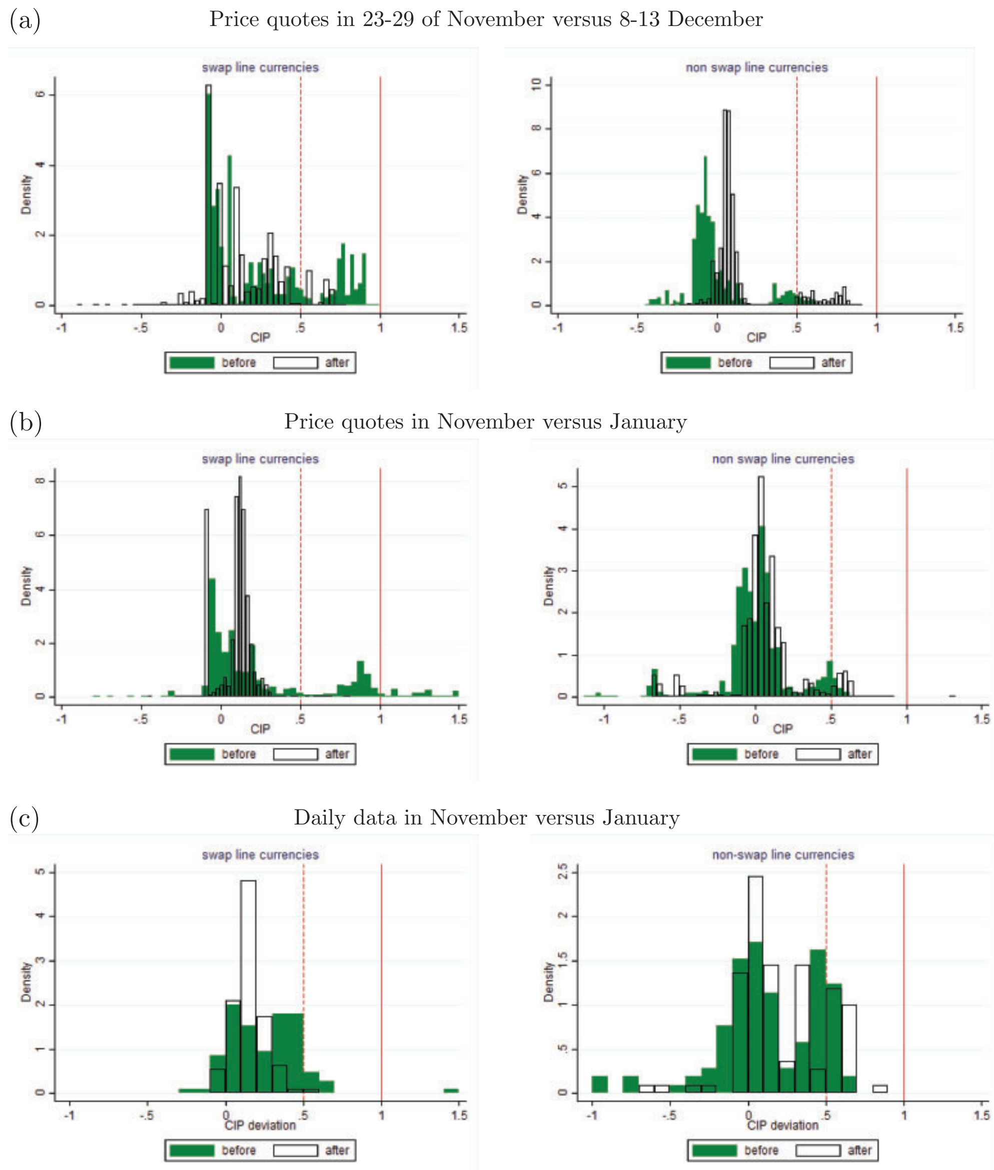


FIGURE 4

CIP deviation histograms for treated and non-treated currencies

removes the shift to the right of the control group, confirming that the common confounding shock was transitory, unlike the permanent effects from the policy change.

The third row shows the effect on daily data. With a single draw from the distribution of quotes per day, observations near the ceiling are rarer. Yet, it is still clearly visible that the CIP deviations in currencies affected become smaller on average and in variability relative to the CIP deviations for currencies which do not have a swap line or whose terms did not change.

Table 1 formally tests for this difference presenting numerical estimates and their associated standard errors (see Supplementary Appendix D.3 for a breakdown of the differences). The first column uses the baseline sample, corresponding to the first row in the figure. The fall in the ceiling by 0.5% lowered the average CIP deviation price quote by 0.28 percentage points relative to currencies not covered by these swap lines. The next three rows show the effects on different percentiles of the distribution. As the theory would predict, the effect is larger the higher the percentile in the distribution. In the top decile of the distribution, the 0.5% fall in the swap-line ceiling lowered the average CIP price quote deviation by 0.59 percentage points.

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

Column (3) corresponds to Figure 4(b). With the wider window, there is more variation and a possible assessment of more permanent effects. Interestingly, the point estimate of the mean is very similar. Across these first columns, the predictions of Proposition 2 are confirmed.

Column (4) present the regression results matching panel (c) in Figure 4, using only the daily market-close CIP deviation. As these draws are not so close to the ceiling, the effect on the top decile is quantitatively only half of that on the price quotes, but it is still large and statistically significant. On average, a cut in the swap line ceiling lowers observed market CIP deviations by 0.18 percentage points.

4.2.3. Robustness. There is significant heterogeneity in $x_{j,t}$ both through time and across currencies (see Table A.9 in the Supplementary Appendix). Some currencies have positive deviations while others have negative ones. Likewise, the underlying interest differentials are of differing signs. Given the limited number of currencies in our sample, in our baseline we combined them together. This maximized statistical power. Columns (4)–(6) consider different subsamples to explore the extent to which the treated and control groups are comparable.

Column (4) excludes the euro. Perhaps the policy was a response about the European sovereign debt crisis specifically, and so there was an endogeneity with respect to the shocks affecting demand in that market.[30] With 4 treated and 5 control currencies, the estimated effects on the mean and on the 90th percentile are still large and statistically significant at the 5% level.

Column (5) pursues an alternative strategy by making the treatment and control groups more similar. If the confounding factor affected those in the European continent, then we can still detect the effect if we compare treated and control groups that are all drawn from European currencies with elevated CIP deviations. This leaves us with six currencies. The results are still present, but estimated less precisely.

Column (6) goes a step further by looking at an even smaller sample, that includes only four currencies in Europe that had the most elevated CIP deviations prior to the announcement. The support for Proposition 2 is robust.

Supplementary Appendix D.4 contains further robustness checks. Our results are robust to: (1) reweighing observations by currencies as we have more quotes for some currencies than for others; (2) looking only at non-European countries; (3) enlarging the monthly window to 2 or 3 months with daily data and (4) using the central banks' interest rate on excess reserves rather than Libor rates. Computing CIP deviations at a 3-month rather than one week tenor leads to weaker results; while 3-month operations were also taking place in November 2011, they only took place at a monthly frequency which could explain the limited effect. Supplementary Appendix D.7

30. On 8th December, there was also a relevant policy announcement by the ECB with regard to its LTRO program which is potential confound.

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

	(1) *Baseline: 23/11-29/11 versus 8/12-13/12, Quotes*	(2) *23/11-29/11 versus 1/12-7/12, Quotes*	(3) *Nov versus Jan, Quotes*	(4) *Nov versus Jan, Daily data*	(5) *23/11-29/11 versus 8/12-13/12, No Euro, Quotes*	(6) *23/11-29/11 versus 8/12-13/12, European Currencies, Quotes*	(7) *23/11-29/11 versus 8/12-13/12, EUR, CHF vs DKK, NOK, Quotes*
Mean	−0.281***	−0.225***	−0.285	−0.184**	−0.212**	−0.118	−0.452***
	(0.108)	(0.082)	(0.184)	(0.090)	(0.098)	(0.145)	(0.072)
Median	−0.208	−0.197	−0.015	−0.146	−0.187	−0.024	−0.375***
	(0.192)	(0.157)	(0.245)	(0.136)	(0.156)	(0.214)	(0.142)
75 %tile	−0.286	−0.283	−0.407	−0.156	−0.223	−0.491**	−0.608***
	(0.199)	(0.172)	(0.336)	(0.113)	(0.142)	(0.203)	(0.091)
90 %tile	−0.586***	−0.207	−0.703*	−0.281***	−0.354***	−0.401**	−0.522***
	(0.172)	(0.126)	(0.360)	(0.101)	(0.132)	(0.182)	(0.105)
N	288374	283932	1228637	430	253889	120555	95434

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

looks at the robustness of the results to measuring CIP deviations using OIS rates, and to only looking at currencies with access to the swap line. The results are roughly unchanged.

As mentioned above, the swap lines lapsed in February 2010 and were reauthorized in May 2010. The reauthorization presents an alternative event when the swap line ceiling came into effect rather than there being just a reduction in its level. We consider this event in Supplementary Appendix D.5. However, as CIP deviations in the period prior to the reauthorization were already far from the ceiling it is difficult to identify an empirical effect and drawings from the swap line were modest. Moreover, this event appears to have been anticipated and coincide with important confounds which makes drawing inference from it difficult relative to the November 2011 rate cut.

Supplementary Appendix also presents four falsification tests following the same methodology. The first is a placebo that compares August to October (in Supplementary Appendix D.4). In Supplementary Appendix D.6, we consider three other dates when the swap line agreements were extended but the swap line rate was unchanged: the extensions on 21st December 2010, 29th June 2011, and 13th December 2013. The policy change we used in our main specification contained both a change in the rate and an extension of the arrangement of the swap lines, so these results suggest that the key variation comes from changes in the swap line rate, as highlighted by the ceiling expressions in the propositions. In a similar vein, we also show that constructing standard errors by bootstrapping alternative event windows as well as currencies leads to the same conclusion.

Last, in Supplementary Appendix D.8, we look beyond a difference-in-differences specification based on a single change in the swap line rate. We use daily time-series variation in recipient-country central bank deposit rates that induce changes in the ceiling defined in Proposition 1. The estimates are still large and statistically significant.

4.3. *Summing up*

A central bank swap line is a lending program of last resort that puts a ceiling on CIP deviations, which moves monotonically with the swap line rate. Theory predicts that lowering this rate should (1) lower the average observed CIP deviation and (2) shift the distribution of CIP quotes to the left. We found that when the swap line rate fell in 2011 exogenously with respect to CIP deviations in the previous weeks, the distribution of quotes shifted to the left and their average were lower.

5. THE CEILING AND THE AVAILABILITY OF THE SWAP LINE: EMPIRICAL EVIDENCE

The ceiling result in Proposition 1 holds whenever the trade underlying it is available. At the same time, the power of the tests of Proposition 2 in the previous section relies on CIP deviations being elevated and close to the ceiling. This Section tests proposition 1 directly, by focusing on dates when CIP deviations are high, and on variation over days when the swap line is available or not.

Since the start of 2016, there have been clear spikes in CIP deviations at the end of most quarters across many currencies (see Supplementary Appendix E.1).[31] Whereas the identification strategy in the previous section relied upon a single policy change that took place in the midst of a crisis, the post-2016 quarter-end spikes occur outside of crises. Moreover, they seem to be driven by

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

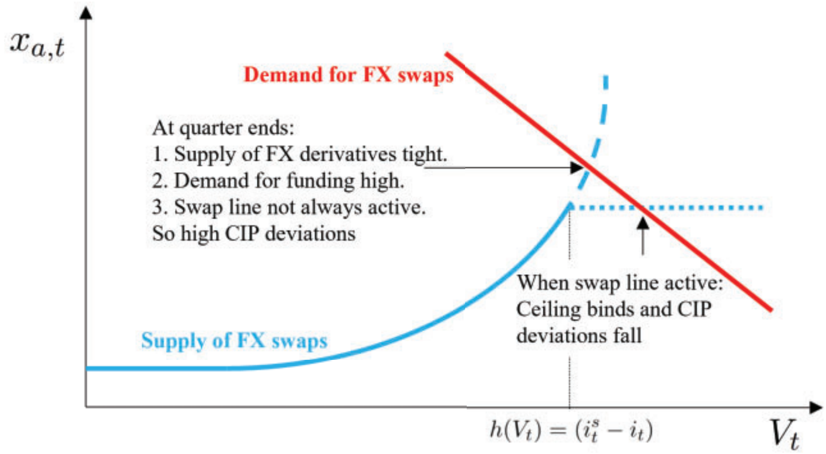


FIGURE 5
Empirical strategy: spikes in CIP deviations at quarter ends

regulatory constraints that in some jurisdictions apply using end-of-quarter positions (Du *et al.*, 2018).[32]

At the same time, the swap lines were not a standing facility. Unlike the discount window, they were not available at any time, on demand. Rather, as described before, in this post-2016 period there were weekly operations in USD with a one-week tenor. When there was no operation, the ceiling did not have to strictly apply as the arbitrage trade behind our theoretical results is not available. At the same time, the swap line operations take place at pre-determined, regular dates, regardless of changes in CIP. While the theoretical predictions apply across dates and frequencies, these institutional features of its operations imply that variation in how far the quarter-end is from the next swap-line operation date provides a causal test of its effects.[33]

5.1. *Another identification strategy*

To understand the new strategy, Figure 5 uses again our supply-demand diagram from Figure 2.

Quarter-ends are periods where the demand for currency hedging is potentially high, as some banks need to hedge out risk before they report positions to their regulators. Moreover, it is a time when repo rates in US money markets spike. The demand line is therefore further to the right than usual. At the same time, at quarter-ends, the regulatory constraints on intermediaries bind and the cost of unsecured funding rises (in line with a rise in $h(.)$). The supply curve is therefore shifted up. Hence, these are periods when CIP deviations spike, and the demand and supply curves in Figure 5 often intersect above the ceiling provided by the swap line.[34]

Because the swap line is only available intermittently, the supply curve alternates between the dotted segment and the dashed one. In the days when the swap line is not available, the dashed

32. The spikes are at the 1-week tenor that we focus on; they are not visible at 3-month tenors. This is consistent with the regulatory story: any 3-month FX swap will be on the intermediary's balance sheet come quarter-end no matter when it is signed, whereas a one-week swap will only be on the balance sheet if it is settled within the final week of the quarter.

33. After March 2020, the operations became daily. The swap line became close to a standing facility, eliminating the gaps in availability that provide the basis for this empirical strategy.

34. Banks could build stocks of dollars in anticipation of these spikes, but they seem to find this costly.

line is the effective supply, and the equilibrium has a high CIP deviation. In the days when it is available, our theoretical results predict that the ceiling binds, so the supply curve has the dotted segment, and banks draw from the swap line and CIP deviations fall under the ceiling.[35]

Importantly, the days when the swap line operations take place are *predetermined* months in advance and are *common knowledge* to the banks that have access. Therefore, the treatment provided by these days is clearly exogenous with respect to whether supply and demand happen to have shifted, and there are no anticipation or signalling effects. Moreover, the operations are full allotment at a fixed rate that had not changed for years, so there is no discretionary policy action adjusting the price or the quantity of dollars available in response to the quarter end spikes. Finally, in our sample period, there were no unscheduled swap line operations conducted or any tweaks to the terms of the operation in response to the quarter end spike.

Finally, note that after the bids for the weekly operation are taken, the banks can no longer go to the swap line. Likewise, only after the funds are disbursed from the next operation (so the next settlement cycle is completed) do banks have the resources to engage in the arbitrage trade. Therefore, the relevant date when the ceiling holds is the settlement date where bids where taken at or prior to time t. Again, this is predetermined and common knowledge.

5.2. *Graphical results*

Figure 6 plots in panel (a) the positive differences between the CIP deviations and the swap line ceiling for the five currencies, together with their median, in the days before and after the end of the 2nd quarter of 2017 as an example (the other quarters with sustained ceiling violations are shown in Supplementary Appendix E.2). The dashed vertical lines correspond to the two nearest swap line operations to the end of the quarter. The first shows the date of the bid on the second-to-last European operation of the quarter, while the second is the settlement date for the final operation of the quarter.

The plot shows that when an operation happens the ceiling is not violated. Only in between the two auctions do the CIP deviations spike. They do so immediately after the second-to-last opportunity to bid for dollars from the swap line in the quarter, consistent with potential regulatory window-dressing. But they spike down below the ceiling once the next swap-line operation is settled, consistent with the propositions we derived.

Panel (b) of Figure 6 shows only the median across currencies, but now for all quarter ends (excluding year ends as no swap line operation takes place). The final operation of the quarter in Europe is always settled on a Thursday, regardless of the date, so Figure 6 does not align with time to quarter-end. A similar pattern is visible. The ceiling is violated only when the arbitrage trade behind Proposition 1 is not available.[36]

5.3. *Statistical test 1: persistence of violations*

We conduct a more formal test of the theory through a regression. Using the daily data on CIP deviations from the start of 2016 until 17th April 2019, we estimate the probability that the ceiling is violated for currency j date $t+h$ conditional on it being violated at date t. We do so over two

35. The presence of the swap line may still affect the equilibrium CIP deviations outside of when it is available. That does not invalidate the identification strategy: what matters is that the ceiling result only applies at the dates when the swap line is available.

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

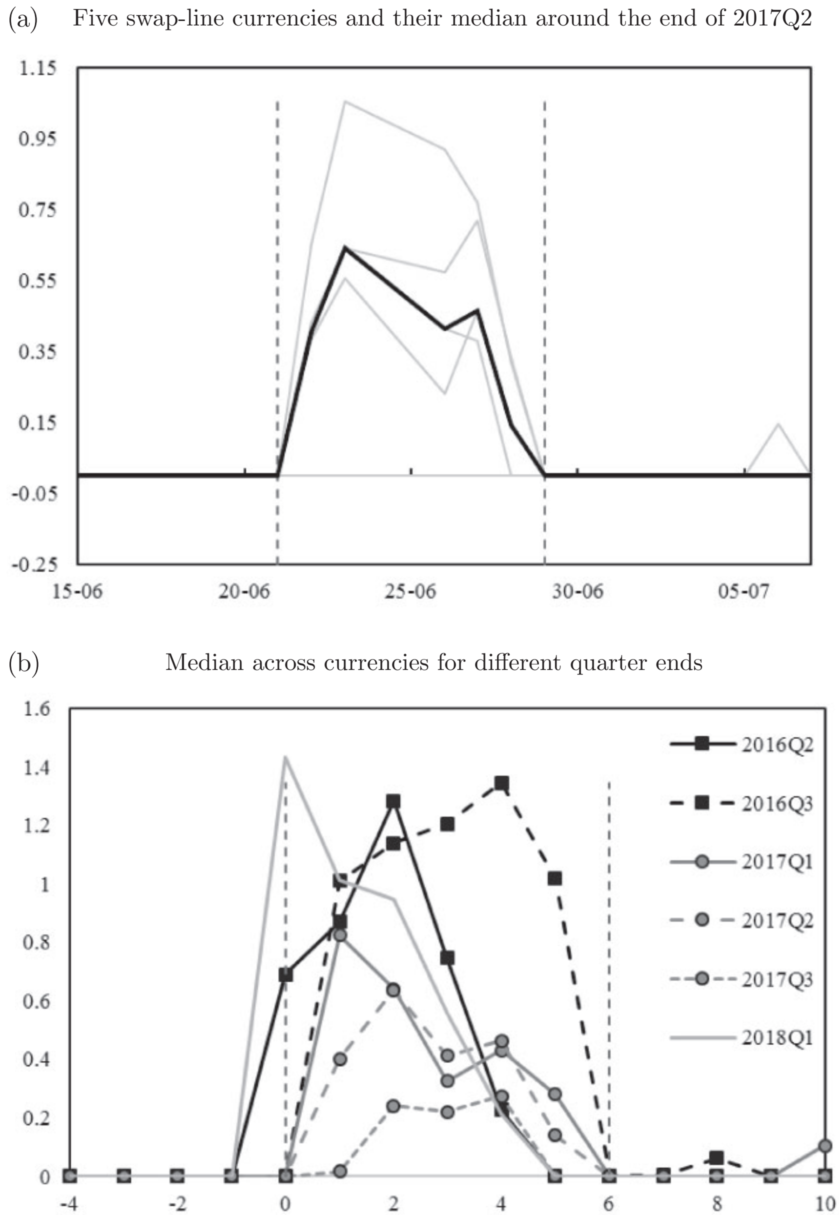


FIGURE 6

Daily CIP deviation minus swap line ceiling around quarter ends

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

samples: one in which a swap line operation was settled between t and $t+h$ and one in which it was not. More formally, we estimate the linear probability model for each currency j:

$$\mathbf{1}(viol_{j,t+h}) = \beta^h_{j,0} \times (1-\mathbf{1}(Settled_{j,t+h})) \times \mathbf{1}(viol_{j,t}) + \beta^h_{j,1} \times \mathbf{1}(Settled_{j,t+h}) \times \mathbf{1}(viol_{j,t}) + \varepsilon_{j,t+h}, \tag{6}$$

where $\mathbf{1}(viol_{j,t})$ is the indicator for whether the CIP deviation for currency j violated the swap line ceiling on trading day t and $\mathbf{1}(Settled_{j,t+h})$ is an indicator for whether a central bank of currency j settled a swap line operation between trading day t and $t+h$—in line with the logic discussed above, we exclude the settlement of operations where the bids were taken in trading day t or earlier. Since, during this time period, the operations were scheduled well in advance at regular dates, we can consider $Settled_{j,t+h}$ to be exogenous to $\varepsilon_{j,t+h}$.

Panel (a) of Figure 7 plots the estimates of $\beta^h_{j,0}$ and $\beta^h_{j,1}$ with h on the horizontal axis for the EUR.[37] The difference between the days when the swap line is effectively present or not is visible. When USD can be obtained from the swap line, the probability of the ceiling being violated is sharply estimated to be zero: a ceiling violation at $t-1$ never persists through a swap line operation that settles at $t+1$. The spikes and associated violations emphasized in the work of Du *et al.* (2018) only happen when the swap line is not in operation.

5.4. *Statistical test 2: conditional violations*

A second formal test asks a related but different question. Conditional on there being a ceiling violation at date $t-i$, and given that the next operation settlement is at date t, then what is the probability of a ceiling violation in period h from $t-i$ onwards? Panel (b) of Figure 7 shows the estimated answers varying h on the horizontal axis. The hypothesis in this article is that at $h=0$, that is when a swap line operation is settled, then this probability should be zero. For the four cases plotted in the figure for the EUR, on whether a violation of the ceiling happened $i=2,3,4$, or 5 days earlier, the probability of a violation of the ceiling is always very close to zero. As one moves away from the auction settlement, then the probability of there being a spike in CIP increases. The swap lines, when in operation, are effective at imposing a ceiling.

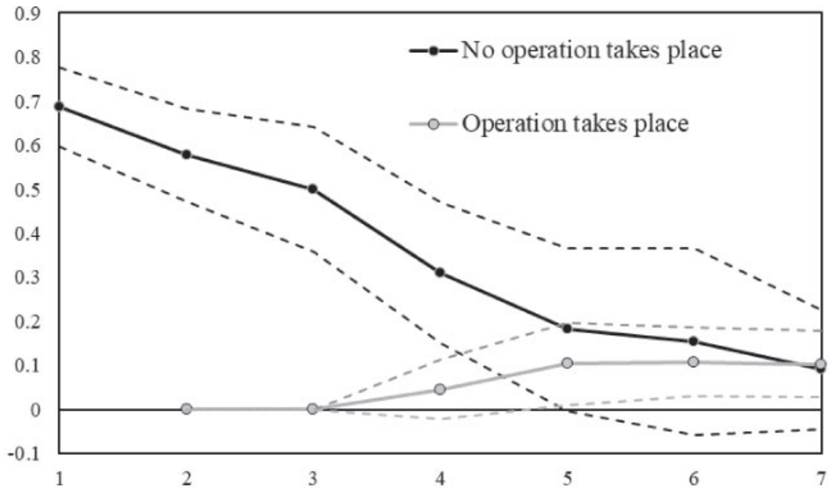
5.4.1. Robustness. Supplementary Appendix E.3 reports estimates of equation (6) for the GBP and the CHF, complementing the results for the EUR we displayed.[38] The patterns are similar. In general, these exercises work less well for the JPY, where the estimates of $\beta^h_{j,0}$ and $\beta^h_{j,1}$ are not statistically significantly different from one another. Yen CIP ceiling violations also occasionally persist through the swap line operation at quarter end. One explanation for this is that the BoJ's longer settlement cycle (coupled with time differences) makes identifying the impact of the dollar operation and the point at which the ceiling must bind much more difficult. Nonetheless, if the yen CIP deviation is elevated, it still tends to fall sharply once a BoJ operation takes place (see Figure A9 in the Supplementary Appendix).

Of course, these results assume that banks are actually willing to tap the swap line when CIP deviations approach the ceiling. We confirm this is the case in Supplementary Appendix E.4. Allotments at the regular swap-line operations are increasing in the CIP deviation the previous

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

38. As the Bank of Canada has not been conducting USD operations, a similar exercise for the CAD is not possible.

(a) Probability of breaking ceiling, conditional on breaking it at date 0, if there is swap-line auction settlement in between or not



(b) Probability of breaking ceiling when moving away from swap line settlement at date 0

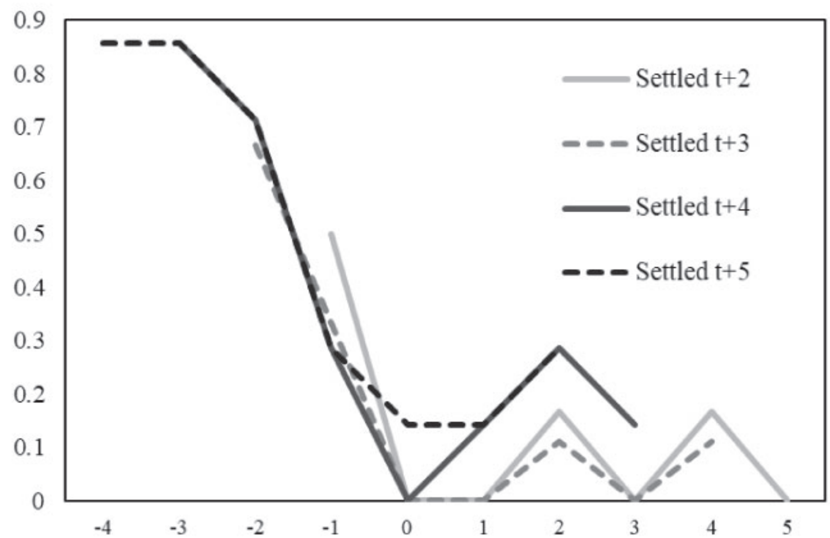


FIGURE 7

Linear probability estimates of CIP deviation for EUR breaking the ceiling

Notes: Panel (a): Estimates of equation (6) for the EUR using one-week OIS CIP violations vis-a-vis the USD. Black solid line is $\beta^h_{j,0}$, grey solid line is $\beta^h_{j,1}$; x-axis is h. Dashed lines are two Newey-West standard errors based on a 10-period window. Note that $\beta^1_{j,1}=0$ by construction as no operation is settled at $t+1$ with bids taken after t so the estimate is omitted. Panel (b): See text.

day. Large allotments coincide with the spikes at quarter end. This finding holds in the period prior to 2016 as well.[39]

39. We estimate the demand for USD liquidity by foreign banks at the swap line, by regressing data on the allotment at USD operations by the ECB and the BoJ against $x_{j,t-1}$. Because banks could obtain as many dollars as they wanted at

Finally, the outbreak of the Coronavirus in the first quarter of 2020, and the economic containment measures that followed, came with spikes in CIP deviations starting in the week of 9–13 March. These provide another test of the presence of the ceiling around settlement dates. Supplementary Appendix E.5 discusses these. The results broadly confirm the theoretical predictions and empirical results in this Section.

5.5. *Summing up*

Because the swap line operations were conducted only intermittently (until spring 2020), the ceiling they put on CIP deviations is tight only on the dates at which the swap line operations are settled. We find that quarter-end spikes in CIP in 2016–19 only break the ceiling in the days when the swap line is not available and, as soon as an operation takes place, the CIP deviations fall sharply below the ceiling predicted by the theory.

6. THE SWAP LINE RATE AND INVESTMENT FLOWS: EMPIRICAL EVIDENCE

This section tests the predictions in Proposition 3 that a lower swap line rate raises the investment of recipient-country banks in assets denominated in source-country currency and increases the profitability of those banks. The start of our identification strategy is again the Fed's decision to lower the interest rate on the swap line from a 1% to 0.5% spread over the OIS one-week rate on 30 November of 2011. As discussed before, the timing and size of this change was determined by negotiations with other central banks, and nowhere in the transcripts of the meeting does the behavior of purchases of USD assets in the previous week enter as a consideration for why the rate was lowered on this particular date. At the same time, the theory predicts an increase in USD asset purchases, not in purchases overall, by recipient-country investors. All combined, this leads to a triple-differences strategy, that compares *across time*, before and after the swap-line rate change, *across banks*, between those whose terms for borrowing dollars changed and those for which they did not, and *across assets*, between corporate bonds that are denominated in dollars versus other currencies.

Ultimately, the estimates answer the following question: for banks that 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? The data are now different, focusing on investment flows, and the variation we exploit is now across institutions within the same currency pair.

6.1. *The data on investment flows*

We use data on the daily asset purchases by banks operating in Europe in corporate bonds. The focus on corporate bonds to test the theory is motivated by several considerations. First, corporate bond holdings by banks in Europe are relatively large. As described in the introduction, Euro-area banks have non-sovereign bond holdings worth approximately one third of all their loans to the corporate sector. Second, unlike loans, bonds are continuously traded so financial investments can change daily, allowing for our high-frequency identification strategy. Third, by looking at a narrow window around the swap line announcement date, changes in bond issuance or in the characteristics of the firms behind these bonds are likely too small to bias our results.[40] Fourth,

a stable pre-announced spread, the supply of dollars was horizontal and known, so this regression identifies the demand for central bank dollar liquidity as a function of the CIP deviation.

40. See Liao (2020) for how CIP deviations can affect the supply of bonds at lower frequencies.

there are enough bonds traded that the several categories for our triple-differences strategy have enough observations to obtain precise estimates.

We use the ZEN database compiled by the UK Financial Conduct Authority. It covers the universe of all trades by EEA-regulated financial institutions in bonds that are admitted to trading on regulated markets and issued by entities where the registered office is in the U.K., plus all trades by U.K.-regulated financial institutions in bonds admitted to trading on regulated markets. A shorthand way of parsing these definitions is that the data cover the trading in corporate bonds of financial institutions operating in London, a major financial centre. 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 contain 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 which the swap line is irrelevant.[41] These form our control group.[42]

From these millions of observations on individual transactions, we aggregate to measure the net daily flow from *financial institution a* into a corporate *bond b* at each trading day *date t*. We scale this by the average of the absolute values of the daily flow from this financial institution towards all bonds over the 25 trading days centred around the 30th of November 2011 which form our sample period. This delivers our measure: $n_{a,b,t}$, which measures the demand by financial institution a for bond b at day t, relative to the typical activity of the institution.[43]

We impose the following restrictions for a financial institution or bond to be included in the sample: (1) the bond b must have been issued before 14th November 2011, so our results are not affected by the supply of corporate bonds; (2) 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; (3) the institution a must be a bank, and trade any bond at least 80% of the days, and trade on average four different bonds per day, so that we consider active traders. This leads to a sample with 26 banks of which 19 are headquartered in swap-line countries, and 790 bonds of which 69 are denominated in dollars. These sample selection criteria ensure that our sparse data are 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.

Supplementary Appendix G.2 contains more information on the ZEN dataset, how it was cleaned, including the treatment of outliers, and our sample, including descriptive statistics. Across bonds, there are not meaningful differences between dollar and non-dollar denominated bonds in our sample in terms of liquidity, face-value, maturity, or rating. Across banks in our sample, they all have a presence in the U.S. and are large global financial institutions: the smallest had assets worth \$40bn in 2011 and all but two had balance sheets exceeding \$500bn. Because of the small number of institutions in the control group coupled with restrictions on the disclosure of confidential data, we cannot present separate summary statistics between the two types of banks' trading activities.

41. In principle a foreign subsidiary of, say, an Australian bank in London could access the swap line through the Bank of England. However, as discussed in Supplementary Appendix A.1, central bank lending facilities are not perfectly accessible for foreign banks, which motivates the existence of swap lines in the first place. Empirically, this would bias the results towards finding no effect of the swap line rate cut. Nonetheless, we obtain similar results comparing banks headquartered in swap line countries with those based in the U.S.

42. The majority of the bonds in the sample are in currencies of the countries in the swap line network, so changes in the operation of the network that affect all would be parsed out by the control group.

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

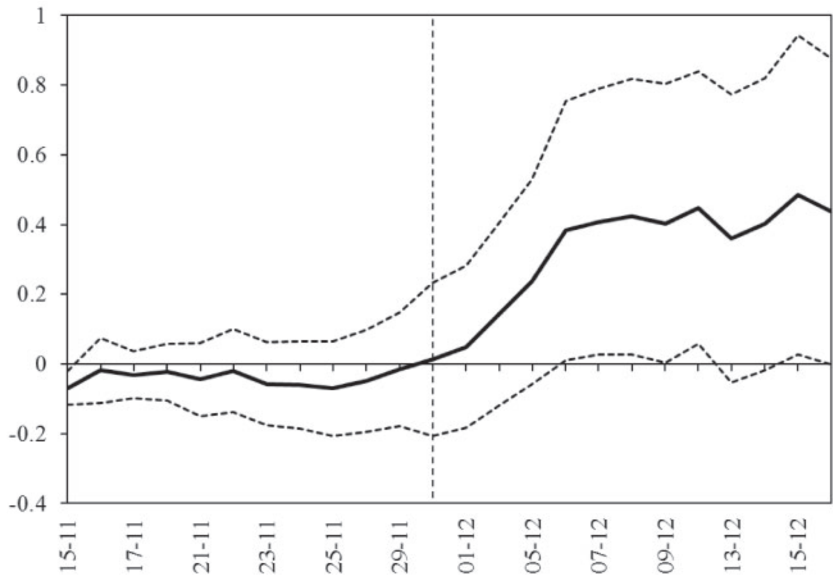


FIGURE 8

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

Notes: Cumulative estimates of β_t from equation (7). Dashed lines are 90% confidence intervals clustered at the bank, the bond and the trading day level.

6.2. *A test on quantities using bond flows*

We start by estimating the following regression:

$$n_{a,b,t} = \beta_t \times SwapLine_a \times USDBond_b + \alpha_{a,t} + \gamma_{b,t} + \varepsilon_{a,b,t}, \tag{7}$$

where $SwapLine_a$ is a dummy for whether institution a is headquartered in a country that has a central bank with a dollar swap line with the Fed, and $USDBond_b$ is a dummy for the currency of denomination of the bond being the dollar. The terms $\alpha_{a,t}$ and $\gamma_{b,t}$ denote bank-time and bond-time fixed effects. Figure 8 plots the cumulative coefficient estimates of β_t from the date of the swap line rate change onwards.

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

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

$$n_{a,b,t} = \beta \times Post_t \times SwapLine_a \times USDBond_b + \alpha_{.,t} + \varepsilon_{k,j,t}, \tag{8}$$

where $Post_t$ is a dummy variable for the window after the 30th November 2011, and $\alpha_{.,t}$ is a vector of fixed effects. Relative to the estimates in Figure 8, this regression averages the effect over the days in the window, and allows us to explore different combinations of fixed effects and calculate the associated standard errors, which are multi-way clustered at the institution, bond, and day level.

The length of the window is set at five trading days, both before and after the announcement date. The results in Figure 8 suggest that the effects of the swap lines accumulate for 5 days, after which they are roughly constant. This is also consistent with the windows we used in our CIP regressions in Section 4. One difference relative to those regressions is that, since the arbitrage trade was only available once the swap line opened, the date of treatment for the CIP regressions was when the lower rate became effective. Instead, for bond flows, what is relevant is the announcement date, since it is the anticipation of having the swap line available *ex post* that spurs investment. This was transparent in the model of Section 3 where the presence of the swap line in period 2 drove higher investment in period 1. Therefore, the window now is 5 days before and after November 30.

The first column of Table 2 presents the results. The baseline estimate is that a 50 basis points cut in the swap-line rate, in the five days following the announcement, induced banks covered by this liquidity insurance to increase their net purchases of the average dollar denominated bond by 0.08% of the bank's average absolute daily flow.

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

The third column controls for bond characteristics, using fixed effects on the issuer and the duration of the bond, interacted with both financial institution and time. This deals with possibly unobserved differences between USD bonds and the other bonds. One particular example would be if different bonds would differ in their acceptability as collateral between the central bank and private lenders. Again, point estimates barely change.

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

The last four columns dig further by considering alternative samples and interactions. The fifth column drops from the criteria selecting the sample the requirement that the financial institutions must trade bonds frequently. The recipient-country banks in the model actively invest in U.S. bonds; otherwise the swap line would have no effect on their investment flows. Adding the financial institutions that do not invest in U.S. bonds we find that, 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 column introduces a dummy variable that separates the effect of the swap line rate on bonds that have a high credit rating and those that do not. Perhaps the recipient-country banks only actively trade higher-credit ratings bonds, or perhaps risk affects investment decisions in a way that was left out of the model where banks were risk neutral. The data show that the portfolio tilting towards USD bonds occurs through both lower and higher rated bonds with no statistically significant differential effect.

The seventh column includes the interaction of the swap line rate change with a dummy variable to indicate if the location of the issuer of the bond is the same as the location of the bank. Perhaps the investment flows from recipient-country banks are going to recipient-country firms issuing dollar denominated bonds and so the swap line does not influence cross-border capital flows. This does not seem to be the case, since the interaction coefficient is small and not statistically significant, consistent with the setup of the model. Local issuers do not seem to be favoured by their banks.

The eighth column investigates this further, by including a dummy variable for whether the USD bond was issued by a U.S. firm (versus a foreign firm). The coefficient is positive and statistically significant at conventional levels, consistent with the shifts in investment coming with cross-border capital flows into the U.S.[44]

Finally, in Supplementary Appendix F.1, we present some robustness regressions that: (1) consider a falsification study using an event window four weeks previously, (2) control for the flow in the previous day to deal with possible inertia in portfolio adjustment, and (3) collapse the sample into pre- and post-announcement means and bootstraps errors at the bank level. These have no material impact on the results.

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

6.3. *A test on asset prices using bond yields*

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

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

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

44. Note, however, that our results show that there are capital inflows also into other non-U.S. locations that issue USD bonds, that some of these may be from the foreign operations of U.S. companies, and that the sample size in this last column is small.

TABLE 2
Fixed-effects panel regression estimates of the effect of swap line rate changes on investment flows

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Fixed Effects				Alternative Sample		Interactions	
	Baseline	*Currency, bank*	*Currency, bank, bond char.*	*Saturated*	*Include infrequently trading banks*	*Credit rating (High: A- and above)*	*Local Issuer*	*U.S. issuer*
$Post_t \times Swap_a \times USDBond_b$	0.077* (0.035)	0.077* (0.038)	0.077* (0.037)	0.079* (0.039)	0.103 (0.055)	0.0628 (0.036)	0.0866** (0.040)	0.0767* (0.038)
$Post_t \times Swap_a \times USDBond_b \times Highrating_b$						0.0261 (0.035)		
$Post_t \times Swap_a \times USDBond_b \times LocalIssuer_{ab}$							−0.0413 (0.0335)	
$Post_t \times Swap_a \times USDBond_b \times USIssuer_b$								0.0353*** (0.010)
N	205227	205227	205227	205227	284225	205227	205227	205227
$bank \times period$ f.e.	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$bank \times currency$ f.e.	No	Yes	Yes	No	No	No	No	No
$bank \times issuer$ f.e.	No	No	Yes	No	No	No	No	No
$bank \times duration$ f.e.	No	No	Yes	No	No	No	No	No
$bank \times bond$ f.e.	No	No	No	Yes	Yes	Yes	Yes	Yes
$period \times currency$ f.e.	No	Yes	Yes	No	No	No	No	No
$period \times issuer$ f.e.	No	No	Yes	No	No	No	No	No
$period \times duration$ f.e.	No	No	Yes	No	No	No	No	No
$period \times bond$ f.e.	No	No	No	Yes	Yes	Yes	Yes	Yes

Notes: Estimates of equation (8). 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): includes an additional interaction term with a dummy variable which takes a value of 1 if the bond has a high credit rating (rated A- and above). Column (7): includes an additional interaction term with a dummy variable which takes a value of 1 if the bond has an issuer located in the same jurisdiction as the Bank (treating the euro-area as a single jurisdiction). Column (8): includes an additional interaction term with a dummy variable which takes a value of 1 if the bond has an issuer located in the US. Standard errors, clustered at the bank, the bond and the trading day level, are in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.

after the announcement relative to the 5 days prior.[45] 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 3. The treatment of lowering the costs of emergency dollar borrowing of recipient-country banks by changing the swap-line rate lowered the yield on the USD corporate bonds that these banks invested in by 8.6bp.

One concern may be that the swap-line rate change, by improving the profitability and so the stability of the recipient country banks, works as a systemic shock to those economies, making all of their bond yields decline. Our results may be driven by USD-denominated bonds issued by Euro-area firms, that are both most likely to be held by Euro-area banks and benefit from this aggregate shock to their economies.[46] 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 asset purchase flows. The estimate rises by one standard error to a 12.2bp price effect.

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

To get a sense of the magnitude of these estimates, Gertler and Karadi (2015) estimate that in response to a conventional monetary policy shock that raises the one-year yield by 50 bp, the commercial paper spread rises by 12.5bp. We find that an unconventional monetary policy shock to the swap line rate of 50bp lowers the corporate bond yield by up to 12.2 bp among our subset of corporate bonds. A comparison with other unconventional monetary policies is more challenging. A rough benchmark is the estimate in Swanson (2017) that \$215bn of Fed asset purchases in 2009 to 2015 lowered corporate bond yields by 5bp. The November 2011 swap line rate cut led to a \$110bn increase in the Fed's balance sheet and the fall in yields was approximately twice as large. Such large effects may perhaps not be surprising from a financial-markets perspective given the large portfolio flows we already found. But, from the perspective of the effectiveness of the influence of the lender of last resort activities *ex ante*, before crises, they are striking and novel to the literature.

6.4. *A test on bank valuations using stock prices*

Proposition 3 predicted that the value of foreign banks increases when the swap-line rate falls. In the model, this happens because cheaper access to the swap line reduces the risk that foreign banks will be forced to discontinue their investments when hit by a financial shock. The model assumed that banks were global, and its predictions applied only to those with a U.S. (the source-country) presence. Perhaps the swap line rate change also affected other banks, through general-equilibrium effects that we did not model. Still, by comparing banks with a U.S. presence with other banks, we can isolate the direct effect on investment suggested by our model. 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: (1) the days before and

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

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

TABLE 3
Yield impact on frequently traded USD denominated bonds

	Nearest neighbour	Exact match on Euro issuers	Exact match on industry
$frequentlytraded_b$	−0.086**	−0.122***	−0.080**
	(0.034)	(0.036)	(0.034)
N	5,474	5,474	2,656

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 neighbour estimates, using Abadie and Imbens (2011) bias correction, that single matches on five bond characteristics: (1) credit rating, converted into a numerical scale, (2) log residual maturity, (3) coupon, (4) log of the face value outstanding, and (5) average yield in the 5 days prior to 30th November. Column (2): includes exact match on whether the bond issuer is located in a Euroarea country. Column (3): includes an exact match on issuer industry, industry classification level 3 of 4 in the BAML dataset; control sample modified to overlap with the industry classifications in the treated sample; two treated bonds which appear uniquely in an industry classification dropped. Robust standard errors in brackets. *** denotes statistical significance at the 1% level; ** 5% level;* 10% level.

after the swap-line rate change by the Fed, (2) foreign banks in countries covered by the dollar swap lines and so affected by the rate change, and (3) foreign banks with a U.S. presence versus foreign banks without a U.S. presence.[47]

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.[48]

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

Figure 9 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 U.S. and that have access to swap line dollars 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 4 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 in Figure 9. When weighing banks equally, those that were treated by the swap-line change and have a U.S. presence experience a

47. Before March of 2010, banks with a U.S. presence could borrow from the Fed through the Term Auction Facility. Insofar as the swap lines allowed a broader set of banks to borrow dollars as well, it may have benefited the other banks more. In our narrow 5-day window though, there was no TAF-like alternative, so the regressions will only capture the direct effect in the model.

48. Note that all the banks we used in the bond flows regression have a US presence.

49. Supplementary Appendix F.2 presents similar estimates (and slightly smaller standard errors) from using an alternative measure of excess returns using the Fama-French factors.

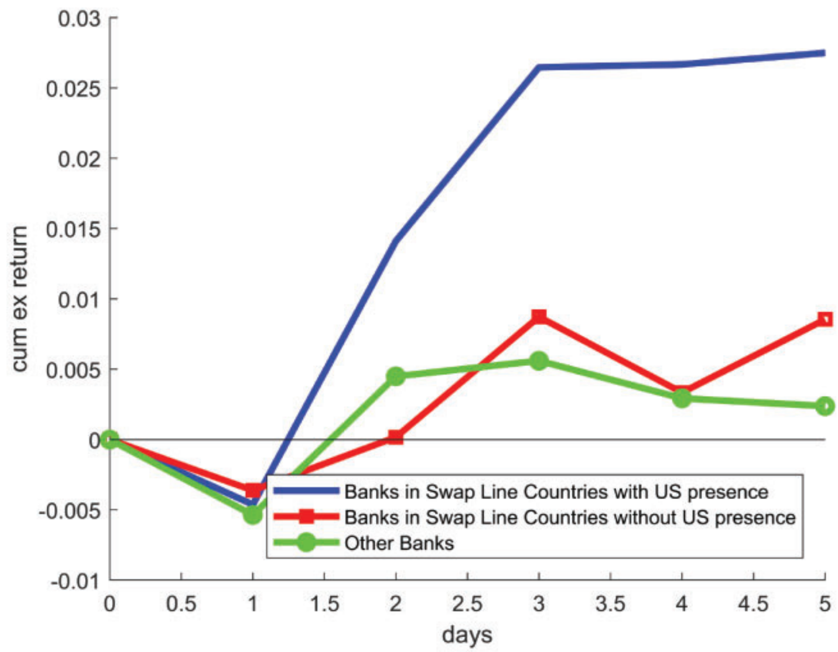


FIGURE 9

Cumulative bank excess returns averaged across different banks after treatment date

TABLE 4

Average bank excess returns after swap line rate change

	Swap line banks		U.S. banks	Other banks
	U.S. presence	*No U.S. presence*		
Average	0.0265*	0.0087	0.0062	−0.0014
	(0.0140)	(0.0068)	(0.0084)	(0.0098)
Size weighted	0.0251**	0.0281***	0.0290*	0.0070
	(0.0125)	(0.0086)	(0.0154)	(0.0095)
N	36	72	310	24

Notes: Excess returns are computed accumulating over 3 days using a beta-to-local market return that is estimated over the 100 days prior to 01/11/11. Swap line banks are headquartered in Canada, Euro-area, Japan, Switzerland, or the U.K. U.S. presence is taken from "U.S. Agencies and Branches of Foreign Banking Organisations" dataset. Bootstrapped standard errors 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.

2.7% excess return, while those without a U.S. presence, or those not covered by the swap line because they are based in the United States or elsewhere, did not. This supports the prediction of the model, and was already visible in Figure 9.

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

In comparison with other monetary policies, a conventional 50 bp interest-rate cut leads to a rise in equity prices of between 2% and 4% (Jarociński and Karadi, 2020; Swanson, 2017), similar to the response we find from a 50 bp cut in the swap line rate. At the same time, Swanson (2017) estimate that \$215bn of Fed asset purchases only increased equity prices by around 0.2%, a smaller effect than the one we estimate.

6.5. *Summing up*

A cut in the swap line rate led to a quick portfolio adjustment by major financial institutions outside the U.S.. Consistent with now having cheaper insurance against financial risk, they held more USD-denominated bonds, whose prices rise as result, so the Fed supported its domestic markets by lending to foreigners. The data also suggests that the foreign banks' value rose.

7. CONCLUSION

This article studied the role and effectiveness of central bank lending programs in general, and of central bank swap lines in particular. We showed that the swap lines are a vehicle for a central bank to lend to foreign banks, using the foreign central bank as an agent in assessing eligibility and bearing the credit risk. The swap lines are therefore an example of classic Bagehot lending of last resort, but now done across borders.

In a world in which globally operating banks borrow in different currencies to invest across borders, central bank lending plays an important role after those investments have been made. We showed that the swap lines put a ceiling on CIP deviations equal to the swap-line spread chosen by the source central bank, plus the difference between policy and deposit rates of the recipient country's central bank. In practice, there is variation in this ceiling both from domestic and foreign policy sources that allows us to estimate the effect of this ceiling in the distribution of CIP deviations across currencies with respect to the dollar. Credibly identified estimates suggest that a 1% fall in the ceiling lowered the average CIP deviation across price quotes by 0.56%, and the 90th percentile by 1.17%. In days of swap-line operations, the ceiling binds tightly across time and currencies, with CIP deviations spiking in quarter ends only for the few days when there is no swap-line auction.

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

These effects may explain why, out of the many unconventional monetary policies to respond to the financial crisis, the central bank swap lines are one of the few that survived well beyond it. Central bank lending across borders is a key part of the international financial architecture promoting capital flows across borders. It was in the front line when a shock like the Covid-19 crisis arrives (Bahaj and Reis, 2020a). Still, many interesting questions are left open for how central bank lending should work. 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 in available foreign currency to global banks through the swap lines raise or lower welfare in the global macroeconomic equilibrium? Are banks investing too heavily in foreign assets or relying too much on foreign borrowing leading to macro-financial fragility, and is this fragility addressed by the swap lines? Alternatively, 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? How do the swap lines, IMF programs, and other regional programs interact in shaping the international financial safety net?

What this article has shown is that central bank lending policies can be very effective, as hypothesized by Bagehot (1873). Overall, the swap lines lower the cost of hedging source-country currency risk while encouraging investment in assets denominated in that currency, raising the prices of those assets and the stock prices of the investors. Perhaps because of this, the number of central bank swap lines has been growing every year. Already today, any study of liquidity provision or of the international financial system will be incomplete without a discussion of the role of central bank swap lines.

Data Availability Statement

The data underlying this article are available in Zenodo, at https://doi.org/10.5281/zenodo.5512110

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Supplementary Data

Supplementary data are available at *Review of Economic Studies* online. And the replication packages are available at https://doi.org/10.5281/zenodo.5512110

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