Central Bank Swap Lines: Micro-Level Evidence

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Abstract

In this paper we investigate the price, volatility and micro-level effects of central bank swap lines during the 2020 pandemic. These policies lowered the ceiling on covered interest rate parity violations and reduced volatility following settlement of swap line auctions. We then combine dealer-level dollar repo auctions by the Bank of England with a trade repository that includes the universe of FX forward and swap contracts traded in the UK. We find evidence of a substitution channel: dealers that draw on swap lines reduce their demand for dollars at the forward leg in the FX market. We also find evidence that dealers that draw on swap lines increased their net supply of dollars to non-financial institutions, supporting the rationale for swap lines in providing cross-border liquidity to the real economy.

Keywords: swap lines, monetary policy, foreign exchange swaps, covered interest rate parity, central banking.

JEL Classifications: E44, F30, F31, F32, F41, G11, G12, G15, G18, G20

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1 Introduction and Motivation

"The net effect (of central bank swap lines) is to provide source currency funds for banks in the recipient country. Why they need these funds in the first place is less well understood…Ultimately, research to answer this question will likely have to use bank-level data on drawings."[1] **Bahaj and Reis, 2021**

A currency swap line is an agreement between two central banks to exchange currencies. A source central bank exchanges currency for the domicile currency of the counterparty central bank. The counterparty central bank can then auction the source currency they receive to domestic banks. Multiple swap line networks exist, and the focus of this paper is the network of swap lines between the Federal Reserve, Bank of England (BOE), Bank of Canada (BOC), European Central Bank (ECB), Bank of Japan (BOJ) and Swiss National Bank (SNB). [2]

The dollar's continued dominance as the global reserve currency has led to swap lines being used as policy tool by the Federal Reserve Reserve in response to the crisis of 2008, and the facilities have been used again in response to the international spillovers of Covid in March, 2020. The Federal Reserve acts as a source central bank by exchanging dollars for the domicile currency of the counterparty central bank. The terms of the auction are set so that any funds lent are at a premium to a risk-free interbank dollar borrowing rate.

The primary reason for swap lines is to mitigate the financial stability risks of dollar shortages. Dollar liquidity stresses can impair the functioning of global markets and spill back into domestic markets, and have significant negative macroeconomic effects (Eguren Martin, 2020; Committee on the Global Financial System, 2020). Swap lines can alleviate market dysfunction by reducing dollar constrained institutions' reliance on the FX market for dollar funding, and enable top-tier banks to borrow dollars close to the risk-free rate and lend in the FX market to conduct arbitrage. These channels have clear price effects, with evidence that swap lines lower the ceiling on Covered Interest Rate parity (CIP) deviations (Bahaj and Reis, 2021a, 2020a; Eren et al., 2020; Goldberg and Ravazzolo, 2021; Choi et al., 2021).

This paper uses micro-level evidence on the response of currency exposures of FX forward and swap participants to the central bank swap line. While the price impact of swap line auctions has been studied, there is less research using micro-level data to shed light on how

[1] Excerpt taken from Bahaj and Reis (2021b)

[2] Other swap line networks include the ECB's agreements with Bulgaria, Sweden, Denmark, Croatia and China. China's People's Bank of China (PBOC) has extended a network of swap lines with Asia, Europe and the U.S with the aim to increase trade invoicing in RMB, see Bahaj and Reis (2020b) for more details.

financial institutions' demand and supply of dollar funding in the FX market respond to swap line auctions. This is an important question for policy makers to understand if central bank lending is an appropriate tool in reducing bank currency exposures during financial crises. Therefore, micro-level data on FX forward and swap transactions is useful to help disentangle competing explanations of demand and supply in the FX market in response to central bank swap lines.

We use two confidential data sets from the Bank of England (BOE). First, we have detailed data on dollar repo auctions made by the BOE to private institutions. To our knowledge, we are the first paper to use this confidential drawings of repos data.[3] Second, we combine the data on BOE drawings of swap lines with the BOE trade repository data, which contains details on both FX forward and swap contracts in which one of the counterparties is based in the UK (Cenedese et al., 2019). We can use this rich data set to measure the demand and supply of dollars at the forward leg of FX transactions for dealers and different client segments that include commercial banks and non-financial (corporate) institutions. Using this data set, we can test the effects of swap line auctions of the Federal Reserve to the BOE on the FX exposures and pricing of dealers that accessed the swap line. We can observe whether the price effects observed in Bahaj and Reis (2021a, 2020a); Eren et al. (2020) are consistent with a substitution channel, in which there is a decline in the demand for dollar funding by dollar-constrained financial institutions, or alternatively, if dealers that draw on swap lines increase their supply of dollar funding in the FX market to take advantage of the cheap source of dollar funding from the Federal Reserve.

We then proceed to test the effects of central bank swap lines with three pieces of empirical evidence. First, we quantify the price and volatility effects of swap lines on the FX market. To measure frictions in FX markets, we use deviations of CIP as a proxy for the scarcity of dollar liquidity in cross-border markets (Du et al., 2018). Supporting the hypothesis of Bahaj and Reis (2020a), we find that the decline in the penalty rate from 50 to 25 basis points above the OIS rate enforces a lower ceiling on CIP deviations for the 1 week maturity. In addition, we use a control-treatment methodology using advanced country CIP deviations. The identifying assumption of these procedures is the permanent swap lines initiated between the Federal Reserve and the BOC, BOE, BOJ, ECB and SNB, whereas temporary swap arrangements with advanced economy central banks act as an appropriate control group. We find significant treatment effects, with swap line allotments in the month following the introduction of Covid swap lines reducing CIP deviations by approximately 10 basis points

[3] We show in a validation check that the BOE dollar repos quantitatively matches the dollar swap line auction data released by the New York Federal Reserve.

relative to the control group.

Second, we use high frequency tick data on forward and spot prices to construct a measure of realized intra-day volatility of FX forwards from 1 week to 3 month maturities. Using this measure, we specify a modification of the Heterogeneous Autoregressive (HAR) model of Corsi (Corsi, 2009; Ferrara et al., 2021) to estimate the volatility of forward premia during the pandemic. Across maturities and currency pairs, we find significant declines in the volatility of forward prices on the day after the auction, with an estimated decline of 1.5 to 3.0 per cent. The results are consistent with settlement of central bank auctions occurring 1 to 2 trading days after the trading date.

Third, we test for the effects on FX exposures of dealers that received a swap line. We use a difference-in-difference (DiD) specification to test if dealers that received dollars from the BOE (treated group) changed their FX exposures relative to dealers that did not receive a swap line (control group). The granularity of data allow us to identify FX exposures at a dealer-counterparty level. Following Cenedese et al. (2019) and Khwaja and Mian (2008), we use dealer-counterparty and counterparty-time fixed effects to control for idiosyncratic demand for FX hedging by counterparties. Focusing on transactions between dealers and commercial banks, we find that dealers that drew on 3 month BOE repo lines reduced their demands for dollars at the forward leg of FX forward and swap contracts during the 3 month window where BOE Repo agreements were made with these dealers. In addition, treated dealers reduced their supply of dollars to commercial banks, with no significant effects on dealers' net FX exposures. Our results support the substitution effect for exposures with commercial banks. As dealers now receive dollars via the swap line, they reduce their demands for dollars at the forward leg in the months of swap line auctions. On the contrary, we find less evidence for dealers using swap line funding for arbitrage: in fact, we find a significant reduction in the supply of USD by dealers.

For transactions between dealers and non-financial institutions, we find a significant decline in dealer demand for dollars. Similar to our results for transactions between dealers and commercial banks, our findings support the substitution effect. In addition, we show that dealers that draw on BOE repos are increasing their net supply of dollars to non-financial institutions relative to the control group of dealers.[4] This suggests that swap lines play an important role in providing marginal dollar liquidity to the non-financial sector. Liao and Zhang (2020) support this by finding countries with larger corporate hedging demand as

[4]In the sign convention of our paper, the results show the dollar funding gap for dealer transactions with non-financial institutions decrease. This is equivalent to dealers increasing their net supply of dollars to non-financial institutions.

indicated by the Net International Investment position data borrow more from swap lines. Finally, we strengthen our results on the substitution channel and the net dollar supply to non-financial institutions through a series of robustness tests, such as a dynamic DiD framework and accounting for long-term maturities. We also rule out our results being driven by a confounding factor of dealer credit risk that can jointly explaining FX exposures and the propensity to draw BOE repos. An analysis of the drawings of BOE repos reveals that dealers that used the lines are typically larger and better capitalized, with a larger distance to the leverage ratio and tier 1 capital ratio limit. In addition, they typically have a lower ratio of risk-weighted assets to total assets and higher cash in reserve.

The remainder of the paper is structured as follows. In section 2 we summarize the contributions of our paper to related literature. In section 3 we summarize the institutional details of Covid Swap Lines and describe the data sources for our empirical work. In section 4 we conduct our empirical analysis. Section 5 concludes.

2 Related Literature

The literature on CIP violations focuses on supply and demand fundamentals in the FX market that explain persistent violation of deviations. On the supply side, papers focus on the costs of dealer balance sheets and and regulatory requirements (Cenedese et al., 2019; Du et al., 2018; Liao, 2020; Bräuning and Puria, 2017; Avdjiev et al., 2019). An alternative strand of literature focuses on CIP deviations reflecting differences in funding costs in segmented markets, hedging demands, liquidity and counterparty risk, and unconventional monetary policies (Rime et al., 2022; Andersen et al., 2019; Baba and Packer, 2009; Mancini Griffoli and Ranaldo, 2009; Borio et al., 2016; Bahaj and Reis, 2020a; Ivashina et al., 2015; Iida et al., 2018; Syrstad, 2020; Viswanath-Natraj, 2020). In this literature, our paper is closely related to Cenedese et al. (2019), which uses the outstanding derivative trades reported to the trade repositories to which the BOE has access under the European Market Infrastructure Regulation in order to identify the impact of Basel III capital regulations. The leverage rule exploits an interesting natural experiment: a subset of dealers faced regulatory reporting of their leverage ratio over the entire quarter, instead of reporting at quarter-ends. This led to an asymmetric pricing of forward premia, as affected dealers quoted significantly higher forward premia relative to a set of dealers in the control group. Their design follows Khwaja and Mian (2008) to control for demand shocks, by restricting their data to counterparties that transact with multiple dealers. Dealer-counterparty and counterparty-time fixed effects control for demand channels in affecting FX pricing, and help to identify the asymmetric pricing effects of a treated vs non-treated dealer, controlling for counterparty effects. We follow a similar design in this paper, and in addition focus on the FX exposures of dealers that received the BOE repos relative to a set of dealers that did not receive BOE repos.

There is a large literature on the price effects of Federal Reserve swap lines in 2008 (Bahaj and Reis, 2021a; Goldberg et al., 2011) and more recently in the Covid period (Bahaj and Reis, 2020a; Goldberg and Ravazzolo, 2021; Aizenman et al., 2022; Choi et al., 2021). Topics include price effects, the macro-financial determinants of swap line access, and the effect of alternative cross-border liquidity programs such as the Fed FIMA facility.[5] Additional topics include Bahaj and Reis (2020b) for effects of swap lines on emerging markets, and Eguren Martin (2020) for a theory of swap lines in a macroeconomic framework. To study price effects, Bahaj and Reis (2020a) exploit the reduction in the penalty rate on Federal Reserve swap lines on November 30th, 2011, which changed from OIS+100 to OIS+50 basis points. They find that the penalty rate leads to a ceiling on CIP deviations that falls with the reduction in the penalty rate, as central banks can first borrow dollars via a swap line and lend them at the recipient central bank to take advantage of CIP arbitrage. Turning to more recent evidence on price effects of central bank swap lines during the pandemic, a number of papers find evidence of swap lines reducing forward premia (Bahaj and Reis, 2020a; Eren et al., 2020).

A final strand of research focuses on using micro-level evidence on FX derivative positions during quarter-ends (Abbassi and Bräuning, 2020) and the balance sheet effects of central bank swap lines (Aldasoro et al., 2020; Eren et al., 2020). In Abbassi and Bräuning (2020), the authors find evidence that quarter-ends result in an increase in demand for dollars as banks seek to hedge dollar exposures off balance-sheet. Aldasoro et al. (2020) show that based on the balance sheet mechanics of dollar liquidity swap line operation, for banks in the US, the use of swap lines results in an increase in liabilities to bank abroad, predominantly in the form of the net due position vis-à-vis a parent bank, in tandem with an increase in reserves at the Federal Reserve. Syrstad and Viswanath-Natraj (2020) use transaction level data from the inter-dealer market, and find central bank swap lines in the 2008-2010 period reduced order flow (net pressure to obtain USD through FX swaps). We support their results through documenting a relative decline in dollar exposures for dealers that draw on BOE dollar repos.

[5] The FIMA facility introduced in March 2020 supports dollar liquidity by exchanging cash for US Treasuries as collateral with FIMA participants. This is an alternative arrangement to swap lines as FIMA participants obtain short-term funding directly from the Federal Reserve as opposed to a counterparty central bank.

3 Data and Definitions

3.1 Federal Reserve Swap lines and BOE Repos

The BOC, BOE, BOJ, ECB and the SNB set up a network of bilateral central bank swap lines with the Federal Reserve, which have been in place on a standing basis since 2013. The existence of a swap line allows the counterparty central banks to provide foreign exchange operations to their respective domestic markets. The two central banks can agree bilaterally the terms and conditions of swap line use.

The timing of the swap line auctions and the arrangement between the BOE and the Federal Reserve is provided in figure 1. There are three major steps in a swap line between the Federal Reserve and a counterparty central bank. First, the Federal Reserve swaps USD for the counterparty central bank's currency at a specified exchange rate. Therefore there is no exchange rate risk in the swap contract. The recipient central bank then distributes these dollars in their jurisdiction. For BOE, this is through dollar repo auctions. At the maturity of the contract, the currencies are re-exchanged at the same exchange rate. Crucially, swap lines are offered at a penalty rate and the central bank that provides the repo line bears the counterparty risk of this operation. The penalty rate is typically a spread above the US OIS rate. Major changes to the Covid swap line include the addition of auctions for swaps at a 3 month maturity, catering for longer-term hedging demands of counterparties, an increase in frequency of Federal Reserve auctions to daily frequency, and a change in the swap line rate changed from OIS+50bp to OIS+25bp.

Publicly available data from the New York Federal Reserve contain details on the amount, currency, tenor and counterparty central bank of each auction. Using this, we can construct a measure of swap line amounts for each currency pair. This is the total amount of swap lines drawn during the Covid crisis less any swap lines that have matured. We plot the outstanding swap lines to major counterparty central banks in figure 2. The majority of swap lines were drawn in the first quarter of 2020, and peaked at the end of May 2020.

The NY Fed data provides us aggregate data on the swap line auctions between the Federal Reserve and the counterparty central bank. However, to analyze effects on FX exposures of individual dealers, we require auction data disaggregated to the dealer level. We use a confidential dataset from the BOE which contains detailed individual dealer-level drawings on dollar repos in the months of March to June 2020. Details of the dataset include maturity, amount, announcement and settlement date of the auction, and a dealer identifier.

Participants eligible for BOE dollar repos are in accordance with the Sterling Monetary

Framework (SMF). All participants are charged the same penalty rate the BOE pays to the Federal Reserve, which is OIS+25bps. Once the results of the BOE repos are announced, the BOE executes a swap of GBP for USD with the Federal Reserve for the full amount bid by the participants. The swap between central banks is executed on the same day as the BOE repo, with settlement the day after. The dollars are then deposited in dealer accounts on the day of settlement.[6]

To test the validity of our BOE Repo data, we can construct an aggregate measure of BOE repos across all dealers for all maturities. This aggregate measure should in principle be equal to the outstanding swap lines between the Federal Reserve and the Bank of England. In Figure 3, drawings from the BOE repos are compared to the aggregate auctions of funds from the Federal Reserve to the BOE based on New York Federal Reserve data. We find that both series follow each other closely, suggesting that the confidential BOE repo line data that we have matches publicly available aggregate data.

3.2 Bank of England trade repository data

The 2007 to 2008 global financial crisis marked an important turning point as G20 leaders put forward in September 2009 an initiative to significantly reform the level of transparency in OTC derivatives markets. As part of this initiative, it was agreed that all derivatives contracts would be reported to trade repositories in order to provide policy makers and regulators access to both high-quality and high-frequency data. Within the European Union (EU), the European Market Infrastructure Regulation (EMIR) was introduced in support of this initiative, requiring large EU firms to report the details of any derivative transaction to a European Securities and Markets Authority (ESMA) approved trade repository by the following business day.

The Bank of England trade repository data contains details on the outstanding FX derivative trades for all transactions with at least one counterparty in the UK, with coverage representing over 42% of the entire global FX forward and swap markets (Cenedese et al., 2019).[7] The dataset covers trades in FX forwards, currency swaps, futures and options for

[6] In addition, the recipient central bank requires participants in auctions to post collateral. See https://www.bankofengland.co.uk/markets/eligible-collateral for more details on eligible collateral, split in three buckets in terms of liquidity. Collateral types A, B and C can be used in dollar repo operations. Type A collateral includes Sterling and foreign currency securities expected to remain liquid in almost all market conditions, type B collateral includes sovereign debt that will normally be liquid, and type C collateral includes less liquid mortgage backed securities. Depending on the risk characteristics of the collateral, the BOE may apply haircuts to mitigate counterparty risk.

[7] This is based on estimates in Cenedese et al. (2019) that show the sample coverage is approximately 42% of global outstanding trades in FX forward and swap markets based on the BIS derivative statistics.

all currency pairs. We restrict our analysis to FX forwards and swaps, and focus on major bilateral currency pairs, such as EUR/USD, JPY/USD, GBP/USD. For each transaction, we observe information about counterparties (i.e., legal identifier and corporate sector) and the contract characteristics (e.g., price, notional amount, maturity date, execution date, execution time). We use the state reports collected within the trade repository data to collect all the outstanding derivative positions in the FX outright forward and forward legs of FX markets at the end of each month from September 2019 to November 2020.

We use the dataset to construct FX exposures of dealers with respect to different client segments, including commercial banks and non-financial institutions.[8]

For each FX forward and swap transaction, we have an identifier which allows us to determine which counterparty is buying and selling USD at the forward leg of the swap. Figure 4 defines how Buy and Sell transactions are measured. A dealer that buys USD at the forward leg and sells GBP forward is recorded as a Buy transaction. Conversely, a dealer that sells USD at the forward leg and buys GBP forward is recorded as a Sell transaction. We can aggregate the Buy and Sell transactions to measure outstanding exposures for a specific dealer-counterparty pair. We can also construct the dollar funding gap, which we define as the dealer net position for dollars at the forward leg of FX forward and swap transactions.[9]

3.3 Other Data

Forward Prices and CIP Deviations

Our measure of CIP deviations $x_{\$,d}$ is expressed as the difference between the local dollar borrowing rate less the synthetic dollar borrowing rate, where $r^f_\$$ is the US interest rate, r^f_d is the base interest rate (eg. GBP). We use daily spot, forward and OIS benchmark rates

[8] The classification of non-financial counterparties is based on the statistical classification of economic activities in the European Community (NACE) as defined in Regulation (EC) No 1893/2006 of the European Parliament and of the Council. For EMIR reporting purposes the industry classification is: 1 = Agriculture, forestry and fishing, 2 = Mining and quarrying, 3 = Manufacturing, 4 = Electricity, gas, steam and air conditioning supply, 5 = Water supply, sewerage, waste management and remediation activities, 6 = Construction, 7 = Wholesale and retail trade, repair of motor vehicles and motorcycles, 8 = Transportation and storage, 9 = Accommodation and food service activities, 10 = Information and communication, 11 = Financial and insurance activities, 12 = Real estate activities, 13 = Professional, scientific and technical activities, 14 = Administrative and support service activities, 15 = Public administration and defence; compulsory social security, 16 = Education, 17 = Human health and social work activities, 18 = Arts, entertainment and recreation, 19 = Other service activities, 20 = Activities of households as employers; undifferentiated goods – and services – producing activities of households for own use, 21 = Activities of extraterritorial organisations and bodies.

[9] An alternative measure of the dollar funding gap is to then calculate the difference between dollar assets and dollar liabilities, which is a proxy for FX hedging demands if banks maintain currency neutrality of the bank balance sheet. This method is used in Eguren Martin et al. (2018).

for the 1 week, 1 month and 3 month maturities available from Bloomberg. Our measure of CIP deviations is expressed in equation (1).

$$x_{\$,d} = \underbrace{1 + r^f_{\$}}_{\text{direct}} - \underbrace{\frac{F}{S}(1 + r^f_d)}_{\text{synthetic}} \tag{1}$$

where S is the spot rate and F is the forward rate, calculated as the mid-point using bid and ask quotes. A negative $x_{\$,d}$ indicates that synthetic dollar borrowing costs exceed local borrowing costs. The forward premium $\frac{F}{S}$ is annualized in percentage points. Figure 6 presents CIP deviations (benchmark OIS rate) for advanced economies for maturities of 1 week, 1 month and 3 month. After an initial spike in CIP deviations in March, as dollar liquidity became scarce, we observe a sharp reversal of CIP deviations following the introduction of swap line arrangements between the Federal Reserve and counterparty central banks.

Balance Sheets

Quarterly data on total assets, liabilities, Tier 1 Capital and Leverage Ratios, cash and risk-weighted assets from Bloomberg. The balance sheet data is at the parent firm level. We resample the quarterly data to monthly data by repeating the quarter-end data within the quarter. For example, the balance sheet data of October and November 2019 is the same as the quarter-end data (December 2019). The minimum Tier 1 Capital and leverage ratio are based on the banking regulation of parent firm headquarters. All data are measured in USD.

4 Empirical Evidence

4.1 Research Hypotheses

H1: *The reduction in the penalty rate of Covid swap lines from OIS+50 basis points to OIS+25 basis points lowers the ceiling on CIP deviations.*

Bahaj and Reis (2021a, 2020a) show that the swap lines have significant price effects in narrowing CIP deviations. By lowering the discount rate on borrowing dollars from the Fed, it necessarily requires CIP deviations to fall as well, otherwise there exist arbitrage opportunities for dealers. For example, a dealer can use the repo line from the BOE to borrow dollars and then lend them in the FX swap market by swapping dollars for GBP, and then investing the proceeds with the Bank of England at an excess reserve rate, which we denote $i^{GBP}_{reserve}$.

Given the duration of the loan (which is 1 week, 1 month or 3 month based on the swap auction), the dealer hedges interest rate risk by purchasing an OIS contract. The cost of the contract is equal to $i^{GBP}_{ois} - i^{GBP}_{interbank}$, where $i^{GBP}_{interbank}$ is a reference rate for the OIS contract, typically an interbank (LIBOR) rate. The net profits Π made by the dealer is expressed in equation (2).

$$\Pi = f - s + i^{GBP}_{reserve} + i^{GBP}_{ois} - i^{GBP}_{interbank} - i_{swapline} \tag{2}$$

We substitute in the formula for the interest rate on the swap line $i_{swapline} = i^{USD}_{ois} + \delta$ where δ is the penalty on the borrowing rate. Second, we express the CIP deviation measured using an OIS benchmark, $x_{ois} = f - s + i^{GBP}_{ois} - i^{US}_{ois}$. We can re-write arbitrage profits of the dealer in terms of the CIP deviation in equation (3).

$$\Pi = x_{ois} - \delta + i^{GBP}_{reserve} - i^{GBP}_{interbank} \tag{3}$$

The penalty on the swap line rate enforces a ceiling on CIP deviations. Using the principle of no-arbitrage, $\Pi \leq 0$ implies the following ceiling on CIP deviations in equation (4), consistent with Bahaj and Reis (2021a).

$$x_{ois} \leq \delta + i^{GBP}_{interbank} - i^{GBP}_{reserve} \tag{4}$$

The ceiling on CIP deviations is based on two components. The first measures the penalty imposed by the Federal Reserve. The decline in the penalty rate from OIS+50 to OIS+25 basis points reduces the ceiling on CIP deviations, all else equal. The second component measures frictions in interbank markets. If hedging interest rate risk is costly for the arbitrageur, the spread between the interbank rate and the reserve rate increases the ceiling on CIP deviations. We measure both of these components and test whether the decline in the penalty rate on March 19th, 2020 resulted in a decline in the probability of ceiling violations.

In Appendix A, we provide a simple model framework to discuss these issues more formally. Arbitrageurs provide dollars and make CIP arbitrage profits, and customers use FX swaps to meet their dollar liquidity needs. In equilibrium, we show that CIP deviations are less than than the penalty rate on borrowing dollars in the FX market.

H2: *There is a reduction in the price dispersion of dealer quotes and a decline in the intra-day volatility of CIP deviations*

A common motivation for swap lines is that it reduces pricing inefficiencies in the swap market. One channel is by enabling dealers that access the swap line to manage their inventory and FX hedging positions. These dealers can now charge more favorable forward rates for dollar liquidity for other customers in the market.

H3: *Dealers that indirectly receive swap line funding reduce demand for dollars in the FX market (substitution effect) or increase the supply of dollars (arbitrage activity). In both cases, we expect the dollar funding gap to decline.*

If a dealer requires a set amount of dollar liquidity, it could obtain that through USD repos with a central bank or FX forward and swap trades with other market participants. A reduction in the demand for dollar funding in the FX forward and swap market is a substitution effect. In Appendix A, we show through our model that dealers that access swap lines reduce their demand for dollar funding in the FX forward and swap market. With limits to arbitrage, the decline in demand result in general equilibrium effects of a lower CIP deviation.

An alternative channel is that swap line auctions channel dollar funding to institutions that provide arbitrage capital. These institutions can conduct arbitrage, by borrowing from a central bank via the swap line and lending these dollars in the FX market. In this case, we predict an increase in the supply of dollars at the forward leg of FX forwards and swaps.[10] We hypothesize that in both cases, the dollar funding gap, defined as the net dealer demand for dollars at the forward leg of FX forwards and swaps, should decrease.

4.2 Price Effects

4.2.1 Ceiling test

Bahaj and Reis (2021a, 2020a) show that lowering the penalty rate on borrowing dollars in the swap line imposes a ceiling on CIP deviations. We hypothesize the decline in the swap line borrowing rate from OIS+50 basis points to OIS+25 basis points should reduce

[10] Disentangling the demand and supply factors during quarter-end reporting has been studied in (Abbassi and Bräuning, 2020). Using micro-level evidence, the authors find evidence that, contrary to prior literature, quarter-ends result in an increase in demand for dollars via FX forward and swap contracts as banks seek to hedge dollar exposures off balance-sheet.

the ceiling on CIP deviations. Figure 5 plots the ceiling based on equation (4). The dotted line corresponds to the decline in the penalty rate on March 19th, 2020. The plots show a reduction in the ceiling on CIP deviations for the 1 week, 1 month and 3 month maturities for all 3 currencies.

We test the hypothesis through a probit specification in equation (5), where $x_{i,j,t}$ represents the CIP deviation for currency i and maturity j, and $Post_t$ is is a dummy variable that takes a value of 1 from March 19, 2020, which is the first auction (settlement) day after the new swap policy announcement. Using the OIS rate as a benchmark, and we test for ceiling violations for the EUR/USD, GBP/USD and JPY/USD at the swap line maturities of 1 week, 1 month and 3 month. The outcome is a dummy variable that takes a value of 1 when the CIP deviation violates a ceiling threshold, where we measure the penalty rate $\delta = 25bp$. For interbank rates we use a LIBOR reference rate for each duration, and for the rate of renumeration on excess reserves we use the bank rate for the BOE, the deposit facility rate for the ECB and the policy rate for the BOJ.

$$\mathbb{1}[|x_{i,j,t}| > 25bp + i^i_{interbank} - i^i_{reserve}|] = \beta Post_t + \epsilon_{i,j,t} \tag{5}$$

The results are presented in table 3. The probability of ceiling violations reduce following the change in the penalty rate across currency pairs and maturities. The decline in ceiling violations is most pronounced for the EUR and JPY 1W and 1M maturities. The results suggests that mis-pricing in the FX market is reduced with the provision of swap lines, and is most effective at reducing the ceiling on 1 week CIP deviations. However, we find little evidence the swap lines reduced the ceiling for 3M JPY/USD CIP deviations, and could suggest limits to arbitrage at longer maturities and increased hedging demand by non-financial counterparties at the 3 month maturity in the JPY/USD FX markets.

4.2.2 DiD specification

While we have shown the Fed policy of lowering the penalty rate by 25 basis points leads to a statistically significant reduction in the ceiling on 1 week CIP deviations, we also want to test if CIP deviations changed relative to a control group that did not activate the swap lines.

We test a DiD specification in equation (6), where we compare currencies that activated the swap line (EUR, GBP, JPY) to a control group of currencies that did not activate the swap line (AUD and NZD). The outcome variable of the framework is $\Delta x_{\$,i,t}$, which is the first difference in the CIP deviation in basis points. $SwapLine_i$: is a dummy variable for whether the currency i sovereign central bank has a swap arrangement with the Federal Reserve. We control for currency differences in CIP deviations with a fixed effect α_i. Following Cerutti et al. (2019), we use controls of interest rates, the VIX, bid-ask spreads and dealer leverage ratio. In addition, we use the broad dollar index based on Avdjiev et al. (2019), and changes in the VIX index, which is connected to CIP deviations through bank leverage in Bruno and Shin (2015). Changes in the bid-ask spread is an indicator of illiquidity and volatility in foreign exchange markets. A final determinant of CIP deviations that we use is the capital growth ratio used in He et al. (2017). This follows empirical work which documents that the leverage ratio determines asset prices through affecting the marginal value of wealth for the U.S investor. All variables with the exception of the Post dummy variable are in first-differences.

$$\Delta x_{i,t} = \alpha_i + \beta \times Post_t \times SwapLine_i + controls_t + \epsilon_{i,t} \tag{6}$$

Table 4 reports the results. With controls, the DiD coefficient estimates a statistically significant net reduction in synthetic funding costs of 10.7 basis points relative to the control group. In an alternative specification in columns (III) and (IV), we test the interaction of allotments with the post date. $Allot_{i,t}$ measures the change in outstanding swap lines for currency i in billions USD. A 1 Billion USD increase in swap line allotments reduces the spread between synthetic and direct dollar funding costs by 0.52 basis points. This is economically significant: aggregate swap line allotments reached a peak of approximately 100 Billion USD for EUR/USD, JPY/USD and 40 Billion USD for GBP/USD. Our results would attribute a narrowing of CIP deviations by approximately 50 basis points for the EUR/USD and JPY/USD pairs and 20 basis points for the GBP/USD pair according to our estimates.

4.2.3 Synthetic control method

In this section we use a synthetic control approach to estimate the causal effects of the swap line on CIP deviations. We follow the artificial counterfactual (ArCo) approach proposed by Carvalho et al. (2018). We define two potential outcomes: $Y_{i,t}^N$ refers to the CIP deviation that would be observed for currency i at time t if currency i is not exposed to the intervention, and $Y_{i,t}^I$ refers to the outcome that would be observed if currency i is exposed to the intervention.

$$Y_{i,t}^{I} = \begin{cases} Y_{i,t}^{I*}, & 1 \leq t \leq T_O - 1 \\ Y_{i,t}^{I*} + \delta_t, & T_0 \leq t \leq T \end{cases} \tag{7}$$

where $Y_{i,t}^{I*}$ is an unobserved counterfactual variable. We measure the variable in pre-intervention period with OLS matching as

$$Y_{i,t}^{I} = Y_{i,t}^{I*} = w_0 + \sum_i w_i Y_{i,t}^{N} + \epsilon_t, \quad 1 \leq t \leq T_0 - 1 \tag{8}$$

After OLS matching the pre-period, we can then construct the post-intervention difference between the actual variable and counterfactual variable at time t is $\tau_{i,t} = Y_{i,t}^{I} - Y_{i,t}^{I*}$.

Using a control group of currencies that did not activate the swap line, we match the controls in the pre-period to construct a counterfactual series of CIP deviations. The treatment group is GBP, EUR, JPY and the control group is AUD, NZD. The pre-matching period is 42 trading days before the intervention day. In Figure 7, we plot the actual and counterfactual values for the EUR/USD, GBP/USD and JPY/USD CIP deviations, using March 19th, 2020 as the date of the intervention in the analysis.[11]

We then proceed to test the hypothesis that the difference between the actual and counterfactual values are statistically significant over different horizons. Defining the actual and counterfactual variable at each time as τ_t, we can test the joint significance of the average τ_t over a defined period following the swap lines at T_0. Defining the average τ_t from T_0 to T as Δ_T, we construct a test statistic with the null hypothesis that $\Delta_T = 0$.[12]

$$H_0 : \Delta_T = \frac{1}{T - T_0 + 1} \sum_{t=T_0}^{T} \tau_t = 0, \quad T_0 \leq t \leq T \tag{9}$$

Table 5 presents the results of Δ_T and its statistical significance for different horizons. Consistent with our hypothesis, we observe a significant difference between the observed values and the counterfactual following the swap line for all currencies and maturities. In particular, the magnitude of CIP deviations with the swap line is lower than implied by the counterfactual. The results for the 1 week maturity are strongest for the EUR/USD with

[11] Specifically, we use March 19th, 2020 as T_0 in our analysis, which is the date at which we construct a counterfactual for our treatment.

[12] The test is based on Newey and West (1987) covariance matrix with prewhitening. The lag is calculated based on rule of thumb $lag = .75 * (T - T_0 + 1)^{1/3}$

a narrowing of deviations within 4 days, however the JPY/USD deviation narrows over a longer horizon of 2-3 weeks. Across all pairs, we find the largest effects for the 1 month maturities, with a peak difference between observed and counterfactual estimates of 90 basis points for the EUR/USD, 70 basis points for the GBP/USD and 110 basis points for the JPY/USD pairs. In contrast, the results for the 3 month maturity find significant differences only for the EUR/USD and GBP/USD pairs, with a peak effect of 40 basis points and 30 basis points respectively. In summary, the results of the synthetic control method support our panel DiD specification with estimates of the net impact on CIP deviations in the same order of magnitude of 50 basis points for the EUR/USD and JPY/USD pairs.

4.3 Volatility Effects

In this section we test for alternative measures of pricing efficiency in the FX market. Our second hypothesis is that reducing the ceiling on CIP deviations, and by providing dollars to dealers that have high FX exposures, these dealers are able to provide dollars to counterparties at more favorable forward rates. In particular, swap lines should help anchor forward prices and reduce the dispersion of quotes in the market.

An aggregate measure of price-quote dispersion is to test the effects of swap lines on realized volatility. We use the HAR model introduced in Corsi (2009). The specification is in equation (10). The outcome variable RV_t is the daily realized volatility of forward rates based on intra-day data. The realized volatility is calculated as the square root of the sum of square log returns based on 5 minute intervals. Controls include lags of realized volatility, where $RV_{t-1:t-6}$ is realized volatility in the last week, and $RV_{t-1,:t-26}$ is realized volatility over the last month. $\text{Swap line}_{set,t}$ is the dummy variable and take 1 on the day of settlement. Following Ferrara et al. (2021), we control for the Covid pandemic with variables Covid_{t-1} and $\text{Covid}_{US,t-1}$ that measure the change in hospitalizations with Covid-19 symptoms for the corresponding country and U.S, respectively. The estimation period is from March 1, 2020 to September 30, 2020, and we exclude days with no trading in our sample.[13]

$$RV_t = \alpha + \beta_d RV_{t-1} + \beta_w RV_{t-1:t-6} + \beta RV_{t-1,:t-26} + \delta_1 \text{Swap line}_{set,t} + \delta_2 \text{Swap line}_{set,t-1} + \gamma_1 \text{Covid}_{t-1} + \gamma_2 \text{Covid}_{US,t-1} + \epsilon_t \quad (10)$$

Table 6 presents the results. Columns (I) to (III) are results using 1 week EUR/USD,

[13]The U.S. FX market closes on Friday at 5pm EST and opens on Sunday 5pm EST. Therefore we exclude Saturdays in our analysis.

GBP/USD and JPY/USD. The next two sets of columns are for 1 month and 3 month maturities respectively. We find that across all currencies and maturities, there is a significant negative effect on volatility the day after settlement. The effects are strongest for the EUR/USD with a 3 per cent decline in volatility, and weakest for the JPY/USD with a 1.8 per cent decline in volatility on the day following settlement. Interestingly, we find no significant effects on the day of settlement. One possibility for the delayed effect is that swap line auctions are endogenous to periods of increased volatility in the FX market. For example, central bank auctions are often timed following an increase in volatility and increased dollar funding costs in interbank markets.

4.4 FX Exposures

In this section we test our third research hypothesis on whether dealers that receive swap line funding reduce demand for dollars in the FX market, which we denote a substitution effect, or increase the supply of dollars through arbitrage activity.

In our analysis on FX exposures, we classify dealer-counterparty Buy, Sell and Net positions. A Buy position is when the dealer buys USD and sells GBP, EUR or JPY at the forward leg of the FX forward and swap contract. Sell positions are recorded when the dealer sells USD and buys GBP, EUR or JPY at the forward leg. Dealers that have drawn on the 3 month BOE repo are classified as "treated", and the remaining set of dealers are the control group in our setting. Figures 9 and 10 plot aggregate Buy, Sell and Net exposures for dealers with respect to commercial bank counterparties. FX exposures are aggregated across the two groups and are the outstanding notional positions at end of month, from September 2019 to November 2020. The dotted line indicates March 2020 which is when Covid swap lines were activated.

To identify the effect of FX exposures of dealers that received a swap line relative to dealers that did not receive a swap line, we use a DiD framework. The granularity of data allow us to identify FX exposures at a dealer-counterparty level. Following Cenedese et al. (2019) and Khwaja and Mian (2008), we use both dealer-counterparty and counterparty-time fixed effects to control for idiosyncratic demand for FX hedging by counterparties. We also restrict our sample to only include dealers that trade with multiple counterparties, and exclude dealer-counterparty observations that have zero net FX exposures in a given month.[14]

[14] We drop dealer-counterparty observations with zero net funding exposures at the end of a reporting month. For example, if a dealer has a Buy trade of 1000 USD and a Sell trade of 1000 USD at the end of the month, the net FX exposure (dollar funding gap) is zero. In Cenedese et al. (2019), the authors study the effects of the leverage rule on pricing in the FX market. In robustness checks, their results find much stronger pricing effects for dealer-counterparty pairs that have non-zero net FX exposures.

Our final assumption is that we only include dealers that received a 3 month repo from the BOE. This is because our Buy, Sell and Net FX positions are measured at end-of-month and the effects of 1 week repos will have short-term effects on FX exposures that cannot be observed. In contrast to swap lines in 2008 and 2009, which had maturities of 1 week and 1 month, a significant fraction of allotments are concentrated at 3 months (see Figure 2).

Our specification is in equation (11). For a dealer i and counterparty j at the end of month t, we measure the outstanding Buy and Sell positions of dollars at the forward leg of FX forwards and swaps. The outcome variables include gross Buys, Sells and Net exposures of dealer i and counterparty j in month t. $D_{swapline,t}$ takes value of 1 during months of March, April and May, 2020. $D_{treatment,i}$ takes value of 1 for dealers that draw on the 3 month BOE dollar repo line. The variable of interest is the interaction term $D_{swapline,t} \times D_{treatment,i}$

$$\mathrm{Y}_{i,j,t} = \alpha_{i,j} + \alpha_{j,t} + \gamma D_{swapline,t} + \delta D_{swapline,t} \times D_{treatment,i} + \mathrm{controls}_{i,t} + \epsilon_{i,j,t} \tag{11}$$

Tables 7 and 8 present the results for counterparty commercial banks and non-financial sector respectively. In each table, columns (I), (III) and (V) test for FX exposure effects (Buy, Sell and Net) without controls, and the remaining columns test for effects with controls. The DiD results show that dealers that received a swap line reduced their demands for dollars at the forward leg of FX forwards and swaps transactions for the counterparty of commercial banks. Our estimates in table 7 suggest that gross Buy transactions decline by 490 USD Million relative to dealers that did not access BOE Repos. Sell exposures also declined relative to the control group by 520 USD Million. There are no significant effects on the net exposures with respect to exposures with commercial banks. In summary, our results support the substitution effect for commercial banks. As dealers now receive dollars via the swap line, they reduce their demands for dollars in the months of swap line auctions.

In Table 8, we find insignificant effects on the gross Buy and Sell exposures with respect to non-financial institutions. However, we find significant effects on net exposures. The dollar funding gap significantly decreases by 47 USD Million. This is consistent with dealers that received the swap line providing net dollar liquidity to non-financial counterparties in the FX market. While the swap lines cannot fund non-financial corporations directly, the dealers that draw on the swap line are in net terms supplying more dollars at the forward leg of FX forward and swap contracts. We now provide a series of robustness tests, including an analysis of the determinants of swap line access, a dynamic DiD framework and accounting for long-term maturities.

4.4.1 Dynamic DiD Specification

Our baseline specification used a period of 3 months (March, April and May) for our period of swap line activation. While this period is relevant as it corresponds to the period of BOE repo drawings, it is interesting to see more precisely the substitution channel and the increase in net supply of dollars to non-financial institutions using a dynamic DiD setting. As before, the outcome variables include Buy, Sell and Net exposures for dealers with respect to counterparty commercial banks and the non-financial sector.

The specification we estimate is equation (12). A dummy variable for dealers that activated the BOE dollar repo is interacted with each month in the sample, using a pre and post window of 6 months. A value of $k = 0$ corresponds to February 2020. Therefore the interaction of the treatment with each monthly dummy provides an estimate of the difference in FX exposures for treated dealers versus un-treated dealers relative to the pre-swap line month of February, 2020. Controls include the distance from the minimum leverage ratio and CET1 ratio regulatory requirements, and the share of risk-weighted assets. The sample is monthly from September 2019 to November 2020.

$$\mathrm{Y}_{i,j,t} = \alpha_{i,j} + \gamma D_{swapline,t} + \sum_{m=-6}^{m=6} \delta_m \mathbb{1}[k = m] \times D_{treatment,i} + \text{controls}_{i,t} + \epsilon_{i,j,t} \tag{12}$$

Table 10 presents the results for Buy, Sell and Net Funding Gap for both commercial bank and non-financial counterparties.[15] Columns (I) to (III) test for FX exposure effects (Buy, Sell and Gap) for commercial banks, and columns (IV) to (VI) measure FX exposure effects for non-financial institutions. For counterparty commercial banks, we note a significant decline in both Buy and Sell FX positions relative to the months of December 2019 and January 2020. For non-financial counterparties, we find a significant decline in Buy positions and the net funding gap in the months of April and May 2020, which were the two latter months of our period of BOE repo lines. According to our estimates, we observe a decline relative to the control group in Buy and net positions of 30 Billion USD to non-financial institutions in May 2020. This is of a similar magnitude to the DiD coefficient for the funding gap in table 8.

[15]The results from hedge fund counterparty regression analyses were statistically insignificant, while we did not have enough outstanding trades to run the regression analyses for pension funds.

4.4.2 Long-term maturities

A final test is whether the FX exposures for longer-term maturities are significantly affected. Given dealers obtain swap lines at short-term maturities of 1 week to 3 months, it is unclear if the substitution channel should impact their demand for long-term dollar funding in the FX market.

We estimate a DiD specification using the same baseline specification in equation (11). The only difference in our regressions is that we now examine Buy, Sell and Net FX (Gap) exposures for maturities greater than 3 months. Controls include the distance from the leverage ratio and CET1 ratio requirements, and the ratio of risk-weighted assets to total assets. The variable of interest is the interaction of the dummy variable for dealers that activated the BOE dollar repo D_{treat}, with a dummy variable $D_{swapline}$ for the months of March, April and May 2020 in which the BOE repo lines were drawn.

Table 11 presents the results. Columns (I) to (III) test for FX exposure effects (Buy, Sell and Gap) for commercial bank counterparties, and columns (IV) to (VI) measure FX exposure effects for non-financial counterparties. We find qualitatively similar effects on FX exposures for commercial bank counterparties. For example, based on our DiD estimates, we find Buy exposures reduce by approximately 140 Million USD and Sell exposures reduce by 110 million USD for treated dealers during the months of BOE drawings. We find a negative but insignificant impact on the dollar funding gap. For non-financial counterparties, we find zero effects on Buy, Sell and Gap positions for long-term maturities. One potential explanation for insignificant findings is a small sample size: our sample cuts in approximately half when only including dealer-counterparty pairs that have FX exposures in long-maturities. In sum, we find some evidence for substitution effects that occur over longer-term maturities, however for non-financial counterparties our effects on FX exposures are only apparent for short-term maturities, suggesting segmentation in the demand for short vs long-term funding for non-financial institutions.

4.4.3 Predictors of Swap Line Access

A potential source of endogeneity is that our results are due to a selection in treatment. For example, suppose dealers that access BOE repos face higher default risk, and are more leverage constrained. These dealers are likely to have the largest dollar funding gaps. Therefore our results would be driven by dealer credit risk, which jointly explains their FX exposures and propensity to draw BOE repos.

We test for the determinants of swap line usage in equation (13). Outcome variables

D_{treat} is a dummy variable for dealers that activated the BOE dollar repo. Explanatory variables include the distance from the leverage ratio and CET1 ratio requirements, and the share of cash and risk-weighted assets to total assets. All balance sheet variables are taken at a snapshot of February 2020.

$$D_{treatment,i} = \beta x_t + \epsilon_{i,j,t} \tag{13}$$

Table 9 presents the results. Interestingly, dollar repos are drawn by institutions that are better capitalized, with a higher distance from the minimum leverage ratio and capital ratio requirements, have higher ratios of cash and lower ratios of risk weighted assets to total assets. Alternatively, a credit risk story, as reflected in CDS spreads, cannot explain the propensity to draw on BOE Repos. [16] We offer a potential explanation of why dealers with a higher distance from the leverage ratio requirements are more likely to draw on BOE repos. Mechanically, drawing on BOE repos reduces the distance to the leverage ratio requirement as it reduces the ratio of equity to total assets. Therefore dealers that are close to the minimum leverage ratio required cannot borrow further using the BOE swap lines, in fact they are more likely to use the FX market for funding as FX swaps are off-balance sheet. [17]

5 Conclusion

In this paper, we provide the first micro-level evidence of central bank swap line drawings on FX exposures. The novel contribution is to use detailed data on individual dealer drawings of BOE repos and micro-level evidence on the response of their currency exposures to the central bank swap line. We combine the data on BOE drawings of swap lines with the BOE trade repository data, which contains details of both forward and FX swap contracts. We use this rich data set to measure the demand and supply of dollars at the forward leg of FX forwards and swaps for dealers and different client segments that include commercial banks and non-financial institutions. Using this data set, we then proceed to test the effects of central bank swap lines using a DiD framework that tests how FX exposures for dealers that receive dollars through BOE repos change relative to a set of control dealers. Critically, we follow Khwaja and Mian (2008) by controlling for counterparty-time and dealer-counterparty fixed

[16] We exclude CDS as an explanatory variable in table 9 but in additional analysis we find there are no effects of CDS spreads on the propensity to draw on the BOE repos.

[17] Our results on who uses the central bank swap line is in stark contrast to other types of central bank lending. For example, Drechsler et al. (2016) examines the lender of last resort function in Euro debt crisis and find that weakly capitalized banks are more likely to borrow from the central bank. While dealers receiving dollars may not be distressed firms, we argue that the swap lines may have indirect effects on firms facing significant dollar shortages through reducing pricing inefficiency in the FX market.

effects, which absorb variation due to counterparty FX hedging demand and idiosyncratic variation in dealer-client relationships. Through this framework, we can disentangle supply and demand factors by identifying the effects of swap lines on treated dealer FX demand and supply of FX forward and swap contracts.

We show that the swap lines during the Covid recession led to a reduction in pricing inefficiencies in the FX market, using measures of the CIP deviation and forward rate volatility. This supports earlier work on the price effects of central bank swap lines (Bahaj and Reis, 2020a, 2021a; Goldberg and Ravazzolo, 2021). Turning to our results using FX exposures, our results support demand side factors: dealers reduced their demand for dollars at the forward leg of FX forwards and swaps due to a substitution toward dollars received via BOE repos. Dealers also increased their net supply of dollars to non-financial institutions, which suggests swap lines are a useful tool in providing marginal dollar liquidity to non-financial institutions during a period of elevated risk in financial markets. Our work has several policy implications. We show that swap lines largely achieve the intended goal of alleviating dollar liquidity in FX forward and swap markets through lowering the ceiling on CIP deviations. It helps restore equilibrium FX forward pricing through reducing forward rate volatility, and it can support cross-border liquidity to corporates during periods of dollar shortages in the economy.

We point to future areas of research. What are the incentives for particular dealers to bid in dollar repo auctions, and the role of collateral supplied in auctions? Do collateral requirements limit the institutions that can access the swap line? More research using dealer-level swap line data can be done to understand the macroeconomic and financial stability effects of swap lines, how they can affect the risk-taking behavior, and the lending and funding of bank balance sheets.

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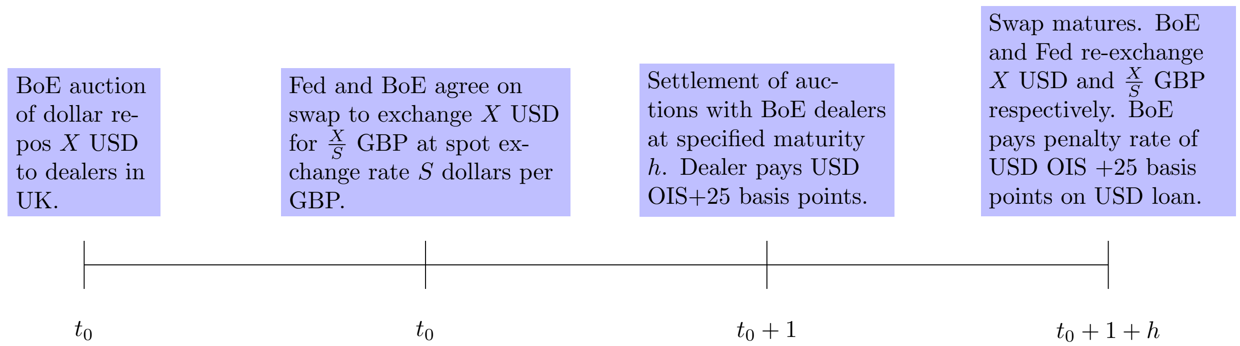
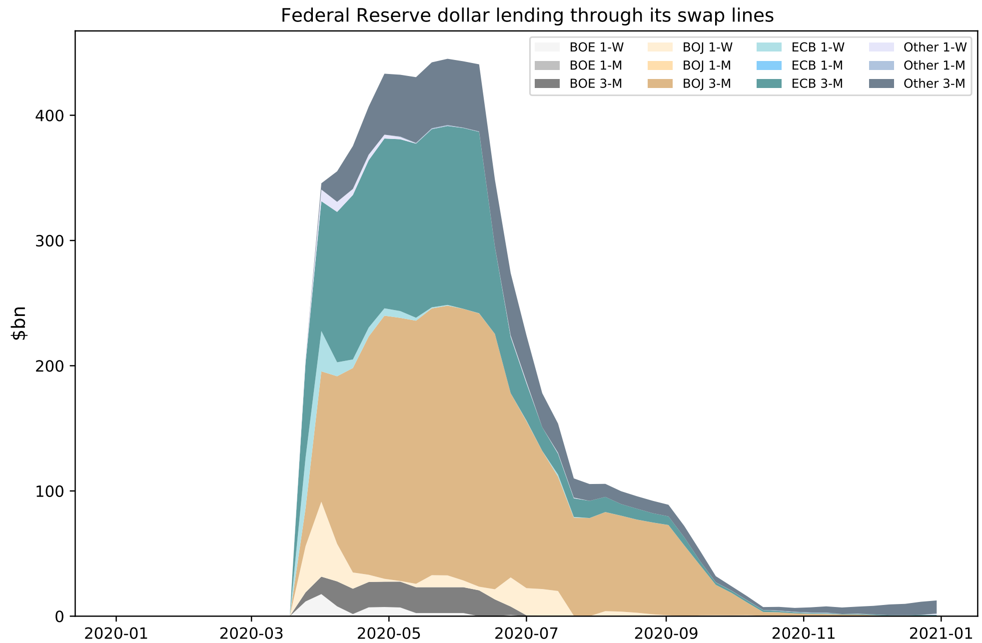
Figures

Figure 1: Swap Line Auctions Timeline



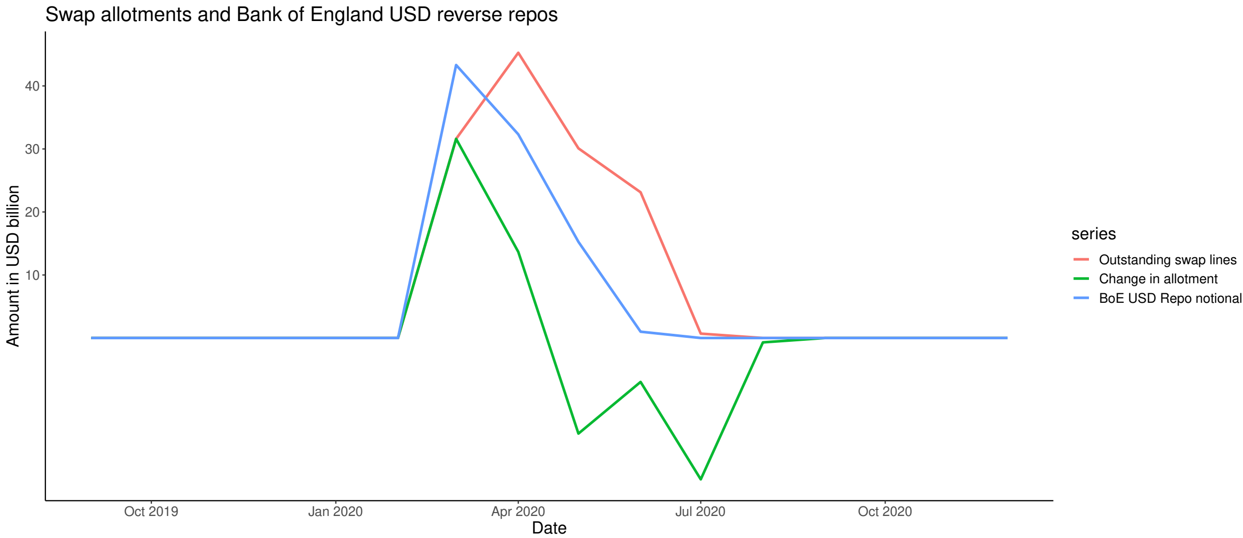
Note: Figure presents timeline of swap line auctions between the Federal Reserve and Bank of England. t_0 is the date of the auctions between the BOE and dealers in the UK, and is also the date of agreement between the Federal Reserve and BOE. $t_0 + 1$ is the day of settlement of auctions. $t_0 + 1 + h$ is the date of expiry.

Figure 2: Swap Line Allotments during Covid



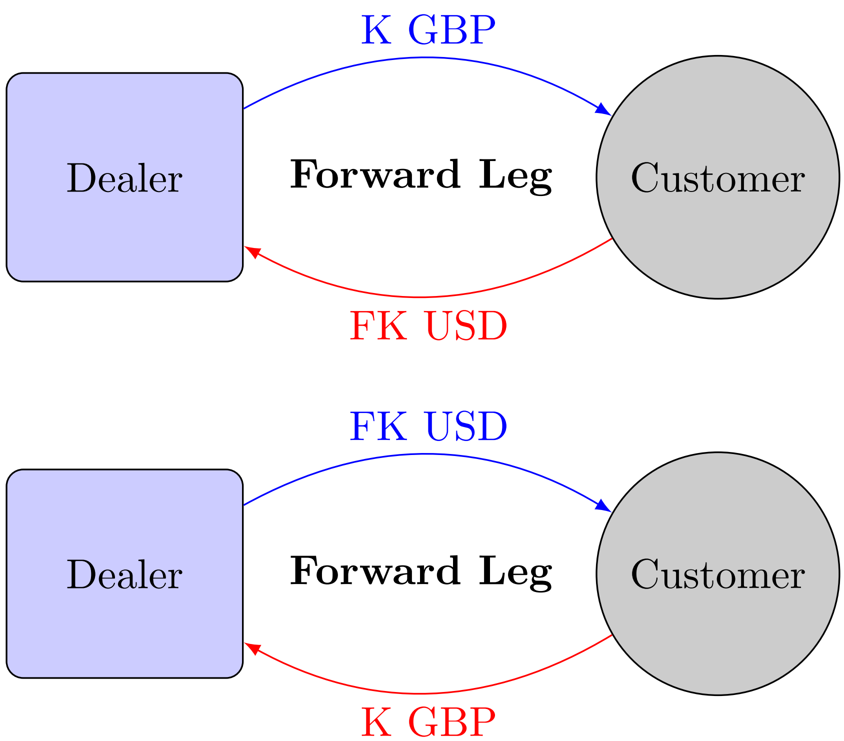
Note: Figure presents outstanding Federal Reserve Swap Lines made to Bank of Japan, Bank of England, European Central Bank and other central banks during 2020. Maturities are 1 week, 1 month and 3 month. Data is taken from the New York Federal Reserve.

Figure 3: Validity Test: BOE Repo Drawings and NY Fed Auctions



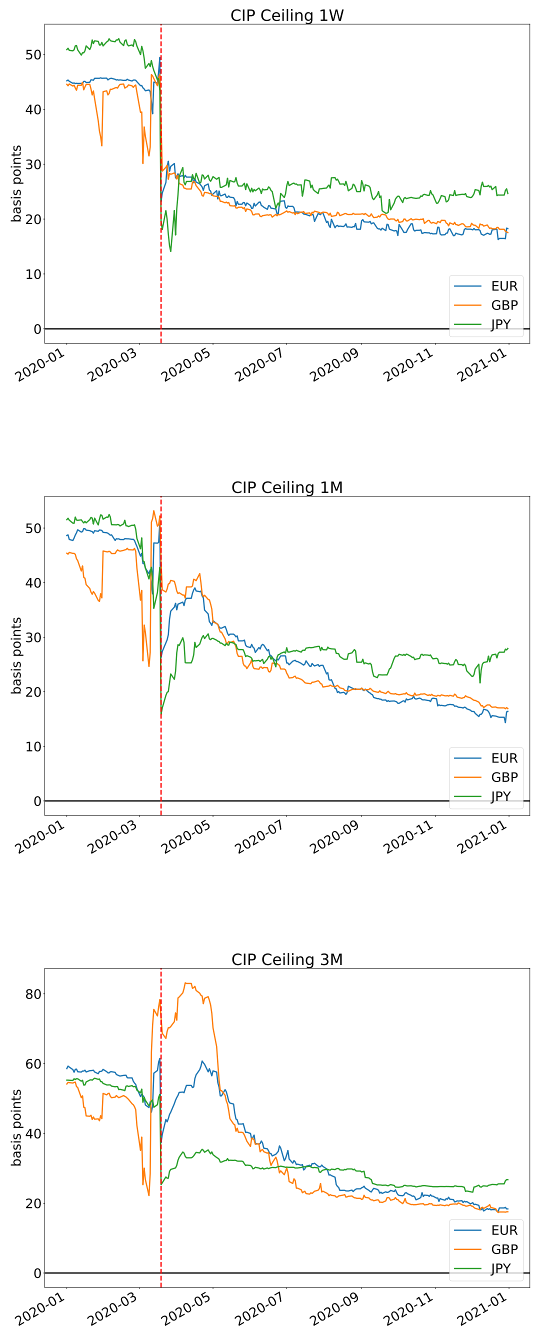
Note: Figure presents outstanding Federal Reserve Swap Lines made to Bank of England. Drawings from the BOE repos are aggregated for all dealers and the outstanding repos at the end of each month is calculated. This is compared to the aggregate auctions of funds from the Federal Reserve to the BOE based on New York Federal Reserve data on swap line drawings. Data is aggregated for swaps of maturities 1 week, 1 month and 3 month. Changes in allotments are measured as the first difference in outstanding swap lines based on New York Federal Reserve data on swap line drawings to the BOE.

Figure 4: FX Exposures, Top panel: dealer transactions of buying USD at forward leg Bottom panel: dealer transactions of selling USD at forward leg.



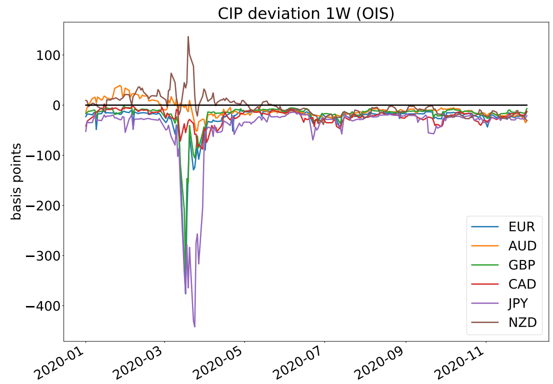
Note: Figure schematic shows how FX exposures Buy and Sell transactions are measured. In the top panel, a dealer that buys USD at the forward leg and sells GBP forward is recorded as a Buy transaction. In the bottom panel, a dealer that buys GBP at forward leg and sells USD forward is recorded as a Sell transaction.

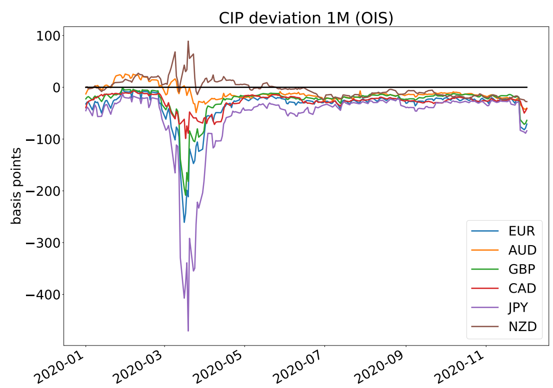
Figure 5: CIP Deviations during Covid: Ceiling Tests

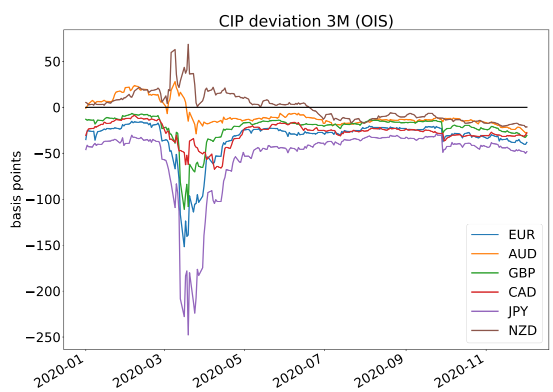


Note: Figure presents the ceiling on CIP deviations for advanced economies for maturities of 1 week, 1 month and 3 month. Data is daily and sample period is from January 1st 2020 to December 31st 2020. Data for OIS rates, forward and spot rates and interbank and policy rates used to construct the ceiling are taken from Bloomberg.

Figure 6: CIP Deviations during Covid: Control and Treatment Currencies

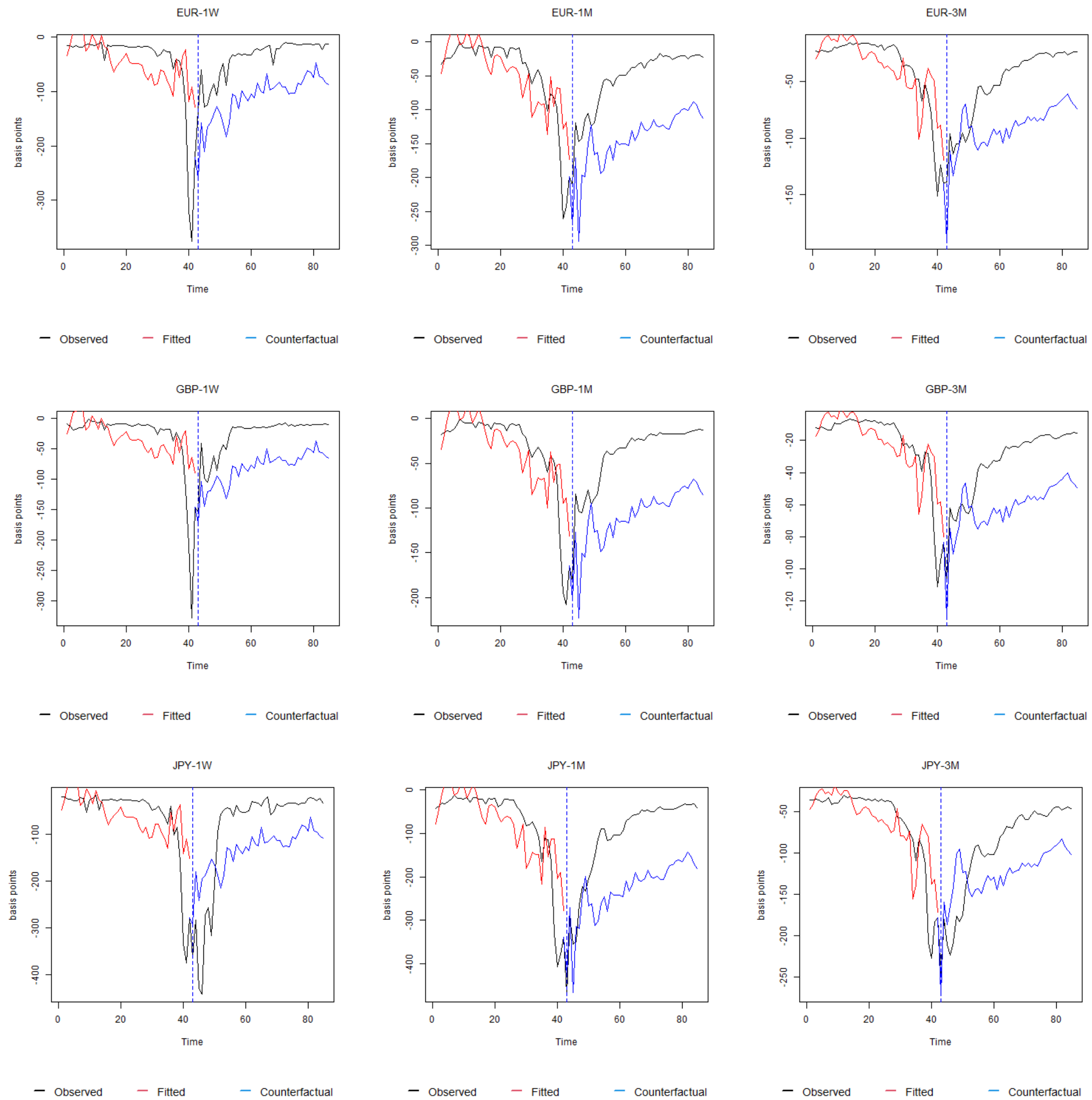






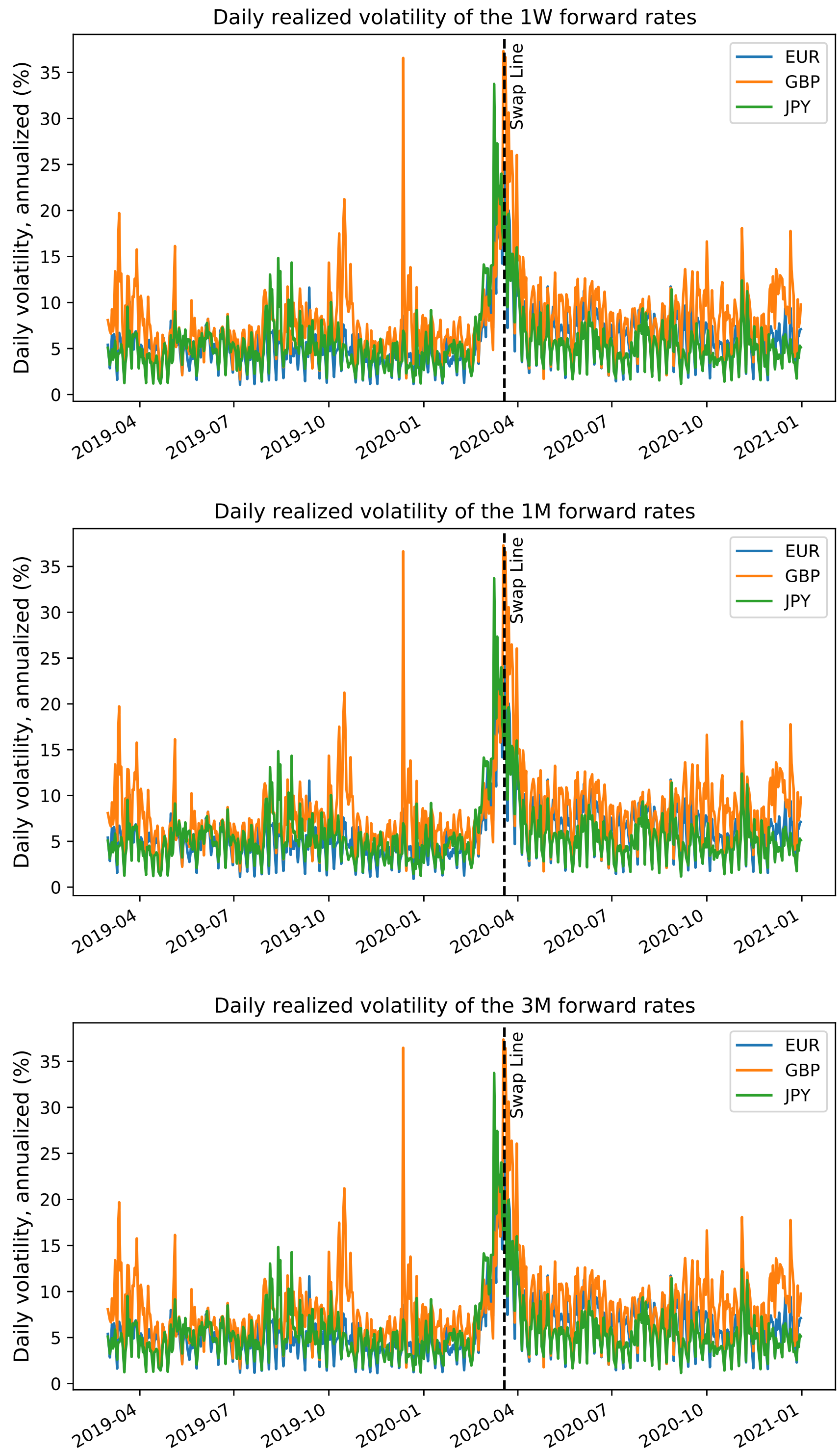
Note: Figure presents CIP deviations (benchmark OIS rate) for advanced economies for maturities of 1 week, 1 month and 3 month. Data is daily and sample period is from January 1st 2020 to November 20th 2020. Data for OIS rates, forward and spot rates are taken from Bloomberg.

Figure 7: CIP Deviations: Counterfactual vs Actual Using Synthetic Controls



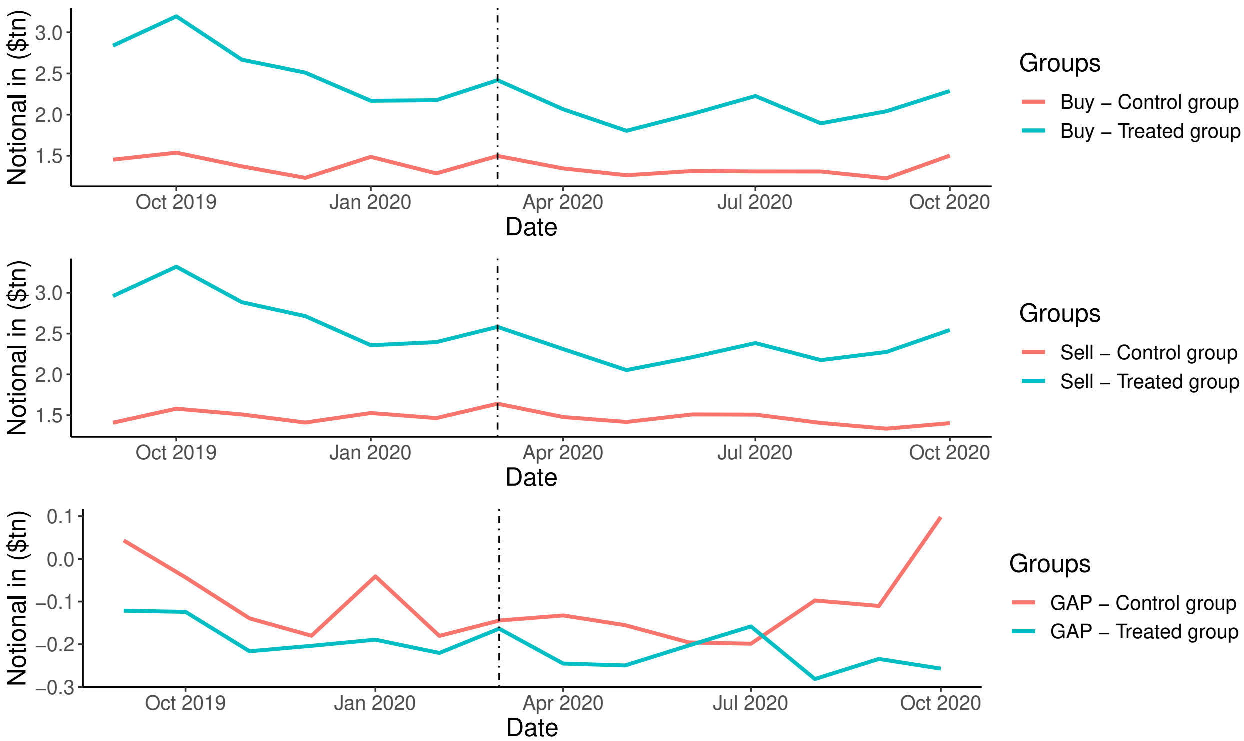
Note: Figure presents CIP deviations (benchmark OIS rate) for EUR/USD, GBP/USD and JPY/USD maturities of 1 week, 1 month and 3 month. Counterfactual CIP deviations are constructed using a synthetic control method, based on a control group of currencies that did not activate the swap line (AUD/USD and NZD/USD). Data for OIS rates, forward and spot rates are taken from Bloomberg. Dotted line indicates Federal Reserve settlement date of March 19th, 2020.

Figure 8: Forward Rate Volatility: 1 Week, 1 Month and 3 Month



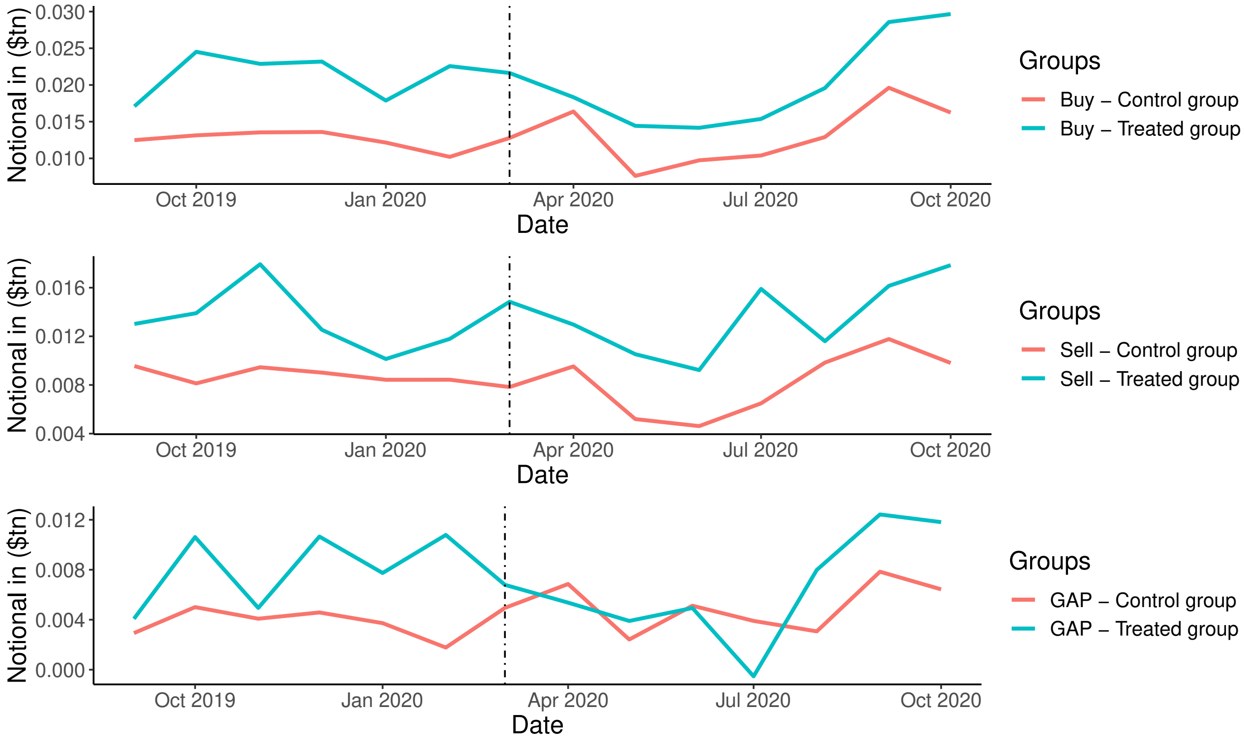
Note: Figure presents daily realized volatility of the EUR/USD, GBP/USD and JPY/USD forward rate for 1 week, 1 month and 3 month maturities. It is calculated using intra-day data taken from Thomson Reuters tick history. Dotted line indicates Federal Reserve settlement date of March 19th, 2020.

Figure 9: Dealer FX exposures with commercial bank counterparties



Note: Figure presents aggregate Buy, Sell and Net FX (Gap) exposures for dealers with respect to counterparty commercial banks. Dealers that have drawn on BOE repos are classified as "treated", and the set of dealers that did not draw on BOE repos are "control". FX exposures are aggregated across the two groups and are the outstanding notional positions at end of month. Sample period is from September 2019 to November 2020. Dotted line indicates March 2020 which is when Covid swap lines were activated.

Figure 10: Dealer FX exposures with non-Financial counterparties



Note: Figure presents aggregate Buy, Sell and Net FX (Gap) exposures for dealers with respect to counterparty non-financial. Dealers that have drawn on BOE repos are classified as "treated", and the set of dealers that did not draw on BOE repos are "control". FX exposures are aggregated across the two groups and are the outstanding notional positions at end of month. Sample period is from September 2019 to November 2020. Dotted line indicates March 2020 which is when Covid swap lines were activated.

Tables

Table 1: Summary Statistics CIP Deviations

ticker	maturity	count	mean	std	min	25%	50%	75%	max
AUD	1M	241.0	-11.6336	13.3709	-48.9205	-19.2562	-14.1811	-10.7404	25.6246
	1W	241.0	-9.6211	14.8024	-51.7389	-17.8174	-12.8280	-7.1070	39.2151
	3M	241.0	-8.5968	12.4008	-28.8911	-15.8186	-13.3068	-6.9131	27.9645
CAD	1M	241.0	-27.8233	15.3231	-98.9089	-29.5292	-24.9021	-19.4680	-7.2059
	1W	241.0	-23.5510	13.9235	-87.7985	-28.7256	-20.9109	-14.8276	2.3307
	3M	241.0	-27.5181	11.1793	-67.4104	-30.8768	-25.3747	-21.6974	-8.6429
EUR	1M	241.0	-35.4576	34.7870	-260.8301	-31.0260	-25.9459	-21.7743	-1.1150
	1W	241.0	-27.1465	37.3687	-376.3558	-23.9274	-17.8493	-15.2576	-9.4049
	3M	241.0	-33.4913	21.8315	-151.7875	-33.3120	-27.3625	-23.1721	-15.1927
GBP	1M	241.0	-25.4783	28.0707	-208.4684	-22.4256	-18.0506	-14.6971	-0.5657
	1W	241.0	-19.6559	30.1869	-329.0601	-17.0460	-13.0853	-10.2204	-0.9319
	3M	241.0	-22.0334	15.1014	-111.0227	-23.2635	-18.3410	-15.0092	-6.7289
JPY	1M	241.0	-56.3742	67.9096	-470.7259	-47.9777	-34.9833	-28.4677	-12.4672
	1W	241.0	-44.5181	64.9019	-442.1727	-35.0796	-27.2906	-22.5068	-14.0107
	3M	241.0	-53.2375	38.4388	-247.7134	-46.9396	-41.1928	-35.3749	-28.9152
NZD	1M	241.0	-2.6283	17.1728	-27.5873	-15.7704	-5.7870	7.4376	89.0939
	1W	241.0	-3.2889	21.2507	-38.4681	-18.4023	-7.7653	7.7899	136.5972
	3M	241.0	0.1465	15.7790	-21.4597	-12.5235	0.8074	9.7328	68.5067

Note: Table presents summary statistics on CIP deviations (benchmark OIS rate) for advanced economies for maturities of 1 week, 1 month and 3 month. Data is daily and sample period is from January 1st 2020 to November 20th 2020. Data for OIS rates, forward and spot rates are taken from Bloomberg.

Table 2: Summary Statistics Balance Sheet Variables

	count	mean	std	min	25%	50%	75%	max
Total_Asset (USD Billion)	496.0	1344280	797289	182286	725686	1101276	1900303	3386071
$\frac{Loan}{Asset}$	496.0	0.43	0.16	0.08	0.33	0.40	0.52	0.81
$\frac{RWA}{Asset}$	496.0	0.36	0.13	0.12	0.27	0.35	0.47	0.65
distance$_{CET1Ratio}$(%)	496.0	9.48	3.97	5.88	7.31	8.30	10.20	30.00
distance$_{LeverageRatio}$(%)	496.0	2.14	1.05	0.90	1.40	1.90	2.55	8.40

Note: Table presents summary statistics on balance sheet variables: total assets (USD Billion), the share of loans to total assets, the share of risk-weighted assets, and the distance to the leverage ratio and CET1 ratio. Sample is monthly from September 2019 to December 2020. Data source is Bloomberg.

Table 3: CIP Deviations: Ceiling Test

	I	II	III	IV	V	VI	VII	VIII	IX
	EUR 1W	GBP 1W	JPY 1W	EUR 1M	GBP 1M	JPY 1M	EUR 3M	GBP 3M	JPY 3M
post	-1.19***	-0.41	-1.38***	-1.65***	-0.44*	-2.06***	-1.05***	-1.44***	
	(0.25)	(0.28)	(0.23)	(0.23)	(0.26)	(0.23)	(0.25)	(0.42)	
Constant	1.35***	1.47***	1.15***	0.99***	1.35***	0.73***	1.35***	2.10***	0.92***
	(0.24)	(0.25)	(0.22)	(0.20)	(0.24)	(0.19)	(0.24)	(0.40)	(0.20)
Observations	241	241	241	241	241	241	241	241	56

Note: Table estimates a probit model for the effects of swap lines on CIP deviations for maturities of 1 Week, 1 Month and 3 Month. Outcome variable is a dummy variable which takes a value of 1 when the CIP deviation exceeds (in absolute value) the ceiling, which is the sum of the swap line penalty (25 basis points) and the difference between the interbank and reserve rates. *post* is a dummy variable which takes a value of 1 when swap line auctions were first settled on March 19th, 2020. The coefficient on *post* is omitted for JPY 3M as there are no observations in the post period that are below the ceiling. Sample period is from January 1st, 2020 to November 20th, 2020. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors are clustered at the dealer-counterparty level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 4: Panel Differences-in-Differences Specification: CIP Deviations (OIS)

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
constant	-4.584***	-3.951***	-0.606***	-0.309
	(1.098)	(1.122)	(0.055)	(0.557)
$Swapline_i \times Post_t$	12.731***	10.651***		
	(3.295)	(3.041)		
$Allotment_{i,t} \times Post_t$			0.558***	0.523***
			(0.115)	(0.094)
i		-30.078		-22.196
		(23.776)		(28.386)
broad dollar		-2.210*		-3.123**
		(1.312)		(1.314)
log(vix)		-32.003***		-40.812***
		(8.529)		(11.636)
fwd bid-ask		0.291		-0.216
		(2.109)		(1.95)
HKM		-2.433***		-2.839***
		(0.781)		(0.833)
Observations	756			
Treatment	EUR, GBP, JPY, and CAD			
Control	AUD and NZD			

Note: Table estimates a panel DiD specification. Outcome variable is the change in CIP deviation $\Delta x_{i,j,t}$. Treatment currencies include central banks that engaged in a swap line. Control currencies include central banks that did not engage in a swap with the Federal Reserve. Controls include the daily changes in the broad dollar index, VIX index, interest-rates of the foreign currency (OIS) and bid-ask spreads, as well as the level of the intermediary capital risk factor of He et al. (2017), which measures shocks to the equity capital ratio. Additional controls include currency and maturity fixed effects. Standard errors clustered at the currency level are reported in parantheses. Estimation period is a 1 month pre and post the swap line settlement date of March 19, 2020.

Table 5: Synthetic Control; Estimates of Difference between Actual and Counterfactual

	4	**7**	**14**	**21**	**28**	**35**	**43**
EUR-1W	86.07**	67.94	79.97**	78.31***	75.36***	76.34***	72.62***
GBP-1W	35.58*	33.24	52.15**	55.24	55.06	55.81	53.64
JPY-1W	-152.18**	-134.49**	-23.28	11.81	27.00	37.31	41.95
EUR-1M	77.86***	62.61**	79.74***	86.75***	88.80***	90.41***	88.09***
GBP-1M	57.24***	46.51**	60.99***	68.14***	69.90***	70.79***	69.05***
JPY-1M	3.26	7.63	74.20	96.85**	110.31***	117.96***	119.28***
EUR-3M	25.40**	6.93	19.72	29.15	35.07*	38.80**	39.63***
GBP-3M	17.13**	7.54	15.24	21.98	25.42**	27.48***	27.68***
JPY-3M	-20.08	-44.30***	-11.28	5.78	18.81	26.11	29.93

Note: Table estimates the average δ_t over different horizons, where δ_t measures the difference between the counterfactual and actual values at time t. The average difference between the actual and counterfactual is estimated for different horizons ranging from 4 to 43 days following the swap line date of March 19th. CIP deviations (benchmark OIS rate) for EUR/USD, GBP/USD and JPY/USD maturities of 1 week, 1 month and 3 month. Counterfactual CIP deviations are constructed using a synthetic control method, based on a control group of currencies that did not activate the swap line (AUD/USD and NZD/USD). Data for OIS rates, forward and spot rates are taken from Bloomberg. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 6: HAR Model Results: Forward Volatility 1W, 1M and 3M

	I	II	III	IV	V	VI	VII	VIII	IX
	EUR 1W	GBP 1W	JPY 1W	EUR 1M	GBP 1M	JPY 1M	EUR 3M	GBP 3M	JPY 3M
Const	1.589	2.407**	1.517***	1.593	2.390**	1.513***	1.491	2.407**	1.518***
	(1.064)	(1.125)	(0.411)	(1.066)	(1.122)	(0.409)	(1.049)	(1.121)	(0.415)
RV_{t-1}	0.032	0.216**	0.314***	0.034	0.217**	0.317***	0.046	0.218**	0.307***
	(0.064)	(0.106)	(0.114)	(0.064)	(0.106)	(0.114)	(0.064)	(0.106)	(0.116)
$RV_{t-1:t-6}$	1.059***	0.818***	0.654***	1.058***	0.818***	0.650***	1.047***	0.816***	0.664***
	(0.146)	(0.155)	(0.149)	(0.145)	(0.155)	(0.148)	(0.146)	(0.156)	(0.15)
$RV_{t-1:t-26}$	-0.173	-0.252**	-0.103	-0.173	-0.250**	-0.101	-0.161	-0.252**	-0.106
	(0.154)	(0.118)	(0.099)	(0.155)	(0.119)	(0.098)	(0.151)	(0.118)	(0.099)
Swap $line_{set,t}$	0.241	0.79	-0.138	0.237	0.773	-0.137	0.211	0.769	-0.122
	(0.406)	(0.997)	(0.371)	(0.406)	(0.996)	(0.37)	(0.4)	(0.993)	(0.372)
Swap $line_{set,t-1}$	-3.048***	-2.624**	-1.744***	-3.048***	-2.625**	-1.747***	-3.055***	-2.614**	-1.739***
	(0.412)	(1.06)	(0.386)	(0.412)	(1.059)	(0.386)	(0.41)	(1.057)	(0.39)
$Covid_{t-1}$	-0.861	0.286	-0.049	-0.85	0.28	-0.047	-0.935	0.293	-0.052
	(0.689)	(0.397)	(0.368)	(0.695)	(0.397)	(0.368)	(0.686)	(0.397)	(0.366)
$Covid_{US,t-1}$	0.434**	0.204	0.185	0.431**	0.202	0.183	0.440**	0.204	0.184
	(0.189)	(0.204)	(0.121)	(0.188)	(0.204)	(0.12)	(0.187)	(0.204)	(0.121)
N	184	184	184	184	184	184	184	184	184
R2	0.6	0.6	0.74	0.6	0.6	0.74	0.61	0.6	0.74

Note: Table estimates a HAR model specification to test the effects of swap lines on forward rate volatility for maturities of 1 Week, 1 Month and 3 Month. Outcome variable is forward rate volatility calculated using intra-day data taken from Thomson Reuters tick history. Explanatory variables include lagged realized volatility. $Swapline_{set,t}$ is a dummy variable for Federal Reserve settlement dates of auctions with the Bank of England, Bank of Japan and the European Central Bank. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors are clustered at the dealer-counterparty level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 7: FX Exposures for maturities less or equal to 3 months: counterparty Commercial Banks

	I	II	III	IV	V	VI
	Buy	Buy	Sell	Sell	GAP	GAP
D_{treat}	1669.3818**	2823.7673**	1755.4510**	3275.0664**	-201.5053*	-451.2991**
	(764.4143)	(1305.3792)	(693.9651)	(1467.2981)	(115.8088)	(212.8922)
$D_{swapline} \times D_{treat}$	-585.3502**	-486.9576**	-518.6646**	-520.7244**	76.7367	33.7668
	(284.7379)	(242.1697)	(215.4139)	(229.6649)	(69.0184)	(69.6598)
$\frac{RWA}{Assets}$		5629.3553**		5743.3572*		-114.0020
		(2651.2771)		(3101.4125)		(706.8223)
$distance_{CET1Ratio}$		-17.6605		-107.1667		89.5062
		(57.1402)		(84.9530)		(60.7120)
$distance_{LeverageRatio}$		-379.4334		-487.3873		107.9539*
		(363.1662)		(395.8769)		(61.1920)
constant	1229.5924***	-511.6249	1379.5560***	547.9659	-135.8122**	-1059.5908**
	(361.8578)	(1186.6702)	(327.5546)	(897.6071)	(58.4392)	(439.2696)
R2	0.409	0.414	0.372	0.380	0.137	0.140
N	12806	12806	13331	12806	12806	12806

Note: Table estimates a difference-in-difference specification to test the effects of swap lines on FX exposures for maturities less or equal to 3 months. Outcome variables include Buy, Sell and Net FX (Gap) exposures for dealers with respect to commercial bank counterparties. D_{treat} is a dummy variable for dealers that activated the BoE dollar repo. $D_{swapline}$ is a dummy variable for the months of March, April and May 2020 in which the BoE repo lines were drawn. Controls include the distance from the leverage ratio and CET1 requirements, and the ratio of risk-weighted assets to total assets. Sample is monthly from September 2019 to November 2020, and aggregates GBP/USD, EUR/USD and JPY/USD FX swaps for maturities less than 3 months. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors are clustered at the dealer-counterparty level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 8: Dealer FX exposures for maturities less or equal to 3 months: non-financial counterparties

	I	II	III	IV	V	VI
	Buy	Buy	Sell	Sell	GAP	GAP
D_{treat}	61.9193	81.6182	28.7118	59.2571**	33.2075	22.3611
	(44.6938)	(51.0806)	(17.7492)	(28.1408)	(28.8548)	(28.3220)
$D_{swapline} \times D_{treat}$	-54.6671*	-54.9084*	-9.6300	-7.7601	-45.0371**	-47.1484**
	(31.6980)	(31.9439)	(14.3598)	(13.3359)	(20.4809)	(22.1920)
$\frac{RWA}{Assets}$		276.0417		350.8949*		-74.8532
		(172.8225)		(178.7838)		(59.6074)
$\text{distance}_{CET1Ratio}$		10.1067		14.1313		-4.0246*
		(7.8937)		(8.6039)		(2.2613)
$\text{distance}_{LeverageRatio}$		-4.2904		-21.8876**		17.5971**
		(4.8634)		(8.3679)		(7.7839)
constant	94.1765***	-102.1483	64.8724***	-168.1365	29.3040**	65.9882*
	(21.3371)	(161.0783)	(8.4565)	(144.8964)	(13.9172)	(34.4949)
R2	0.311	0.314	0.276	0.290	0.348	0.350
N	2002	2002	2002	2002	2002	2002

Note: Table estimates a difference-in-difference specification to test the effects of swap lines on FX exposures for maturities less or equal to 3 months. Outcome variables include Buy, Sell and Net FX (Gap) exposures for dealers with respect to non-financial counterparies. D_{treat} is a dummy variable for dealers that activated the BoE dollar repo. $D_{swapline}$ is a dummy variable for the months of March, April and May 2020 in which the BoE repo lines were drawn. Controls include the distance from the leverage ratio and CET1 requirements, and the ratio of risk-weighted assets to total assets. Sample is monthly from September 2019 to November 2020, and aggregates GBP/USD, EUR/USD and JPY/USD FX swaps for maturities less than 3 months. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors are clustered at the dealer-counterparty level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 9: Determinants of Swap Line Access

	I	II	III	IV	V
	D_{treat}	D_{treat}	D_{treat}	D_{treat}	D_{treat}
$\text{distance}_{CET1Ratio}$	0.4571***				0.3222***
	(0.000)				(0.006)
$\text{distance}_{LeverageRatio}$		0.8735***			0.5191**
		(0.000)			(0.041)
$\frac{Cash}{Assets}$			12.4293***		7.1324**
			(0.000)		(0.046)
$\frac{RWA}{Assets}$				-5.1516***	-2.3936**
				(0.000)	(0.049)
constant	-4.2424***	-1.6408***	-1.2990***	1.5201***	-3.6937***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.003)
R-sq	0.243	0.125	0.163	0.160	0.371
N	88	88	88	88	88

Note: Table estimates a probit specification to test the determinants of access to BoE Repos. Outcome variables D_{treat} is a dummy variable for dealers that activated the BoE dollar repo. Explanatory include the distance from the leverage ratio and CET1 ratio, and the share of cash and risk-weighted assets. All balance sheet variables are taken at a snapshot of February 2020. Standard errors are White Heteroscedasticity robust. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 10: FX exposures to commercial bank and non-financial counterparties: Dynamic DiD

	I	II	III	IV	V	VI
		Commercial			Non-Financial	
	Buy	Sell	Gap	Buy	Sell	Gap
treat	2583.9910**	2983.3013**	-399.3104*	90.6422*	54.8618**	35.7804
	(1150.3371)	(1343.3897)	(235.3335)	(44.9004)	(21.8878)	(36.7983)
$D_{swapline} \times \mathbb{1}[k=-1]$	314.7323	505.5828	-190.8505	-36.0080*	-12.0735	-23.9345
	(335.2548)	(309.2042)	(135.1873)	(18.5134)	(17.8561)	(21.7688)
$D_{swapline} \times \mathbb{1}[k=-2]$	735.7680**	745.3405***	-9.5724	11.2730	13.6964	-2.4234
	(301.9277)	(222.8113)	(130.1639)	(37.6134)	(13.8690)	(35.4374)
$D_{swapline} \times \mathbb{1}[k=1]$	-11.5340	-75.5659	64.0319	-72.9412*	-21.9462	-50.9950*
	(117.9548)	(85.7398)	(96.4346)	(37.8376)	(14.4746)	(26.4621)
$D_{swapline} \times \mathbb{1}[k=2]$	-256.8731**	-166.1433	-90.7297	-82.5067**	-5.5892	-76.9175*
	(128.2094)	(156.2420)	(144.9236)	(40.6285)	(20.3375)	(37.9495)
$D_{swapline} \times \mathbb{1}[k=3]$	-518.1804**	-487.6885*	-30.4919	-33.9092	18.0683	-51.9775*
	(214.4721)	(251.1161)	(128.1063)	(25.9595)	(22.1127)	(29.9997)
$D_{swapline} \times \mathbb{1}[k=4]$	-239.4202	-369.2281	129.8079	-49.8939	5.4649	-55.3588
	(174.7663)	(226.8223)	(153.4487)	(34.2678)	(14.5239)	(37.2695)
$D_{swapline} \times \mathbb{1}[k=5]$	-110.7589	-247.0298	136.2710	-82.2852	-17.6406	-64.6446
	(177.0615)	(156.8038)	(128.4781)	(54.1217)	(21.9575)	(43.5474)
$D_{swapline} \times \mathbb{1}[k=6]$	-476.2818**	-340.6283*	-135.6535	-33.5881	-17.3315	-16.2566
	(209.6168)	(187.2462)	(152.4682)	(25.0198)	(13.7112)	(29.4767)
$\frac{RWA}{Assets}$	5677.1363**	5776.9073*	-99.7710	282.8262	352.7197*	-69.8935
	(2662.3858)	(3113.7863)	(702.6401)	(177.7417)	(181.0148)	(60.9526)
distanceCET1 Ratio	1.0129	-90.3774	91.3903	10.0026	13.7918	-3.7891
	(57.0977)	(79.9365)	(61.8613)	(7.9089)	(8.3461)	(2.2538)
$\text{distance}_{LeverageRatio}$	-419.0007	-523.4127	104.4119*	-3.7412	-21.4347**	17.6935**
	(372.9458)	(403.6330)	(59.4747)	(4.9480)	(7.9755)	(7.7180)
constant	-629.7708	446.8559	-1076.6267**	-105.4800	-167.0805	61.6005
	(1227.8809)	(929.4058)	(444.8840)	(164.4475)	(144.9438)	(36.6733)
R2	0.414	0.381	0.140	0.315	0.291	0.352
N	12806	12806	12806	2002	2002	2002

Note: Table estimates a dynamic difference-in-difference specification . Outcome variables include Buy, Sell and Net FX (Gap) exposures for dealers with respect to counterparty commercial banks and non-financials. A dummy variable for dealers that activated the BoE dollar repo is interacted with each month in the sample, with $k = 0$ corresponding to February 2020. Controls include the distance from the leverage ratio and CET1 requirements, and the ratio of risk-weighted assets to total assets. Sample is monthly from September 2019 to November 2020. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors are clustered at the dealer-counterparty level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 11: FX exposures for maturities > 3 months, commercial banks and non-financial counterparties

	I	II	III	IV	V	VI
		Commercial			Non-Financial	
	Buy	Sell	Gap	Buy	Sell	Gap
D_{treat}	964.4186**	883.1349**	81.2837	85.0150*	55.0945	29.9205
	(467.5186)	(408.0686)	(89.2776)	(40.9010)	(43.3368)	(19.5881)
$D_{swapline} \times D_{treat}$	-141.5106*	-107.7917*	-33.7189	-18.4047	14.8010	-33.2057
	(77.6609)	(60.2375)	(32.8739)	(33.1070)	(12.3319)	(25.4967)
$\frac{RWA}{Assets}$	2582.9765**	2486.5638*	96.4127	-245.7270	114.0643	-359.7913
	(1268.1235)	(1293.1417)	(321.0636)	(376.1800)	(119.0028)	(472.0421)
$\text{distance}_{CET1Ratio}$	68.6259**	45.1353*	23.4906	61.1218	29.1313	31.9905
	(34.1886)	(24.4978)	(17.7242)	(42.4830)	(27.2204)	(18.6259)
$\text{distance}_{LeverageRatio}$	-261.9649**	-251.5721**	-10.3928	18.1061	25.5900	-7.4838
	(130.5490)	(123.6565)	(47.8946)	(31.4477)	(26.8862)	(10.4271)
constant	-892.4766	-600.5482	-291.9284	-282.9330	-264.6689	-18.2640
	(748.5328)	(650.0327)	(234.6176)	(335.5766)	(350.0534)	(144.9050)
R2	0.398	0.368	0.120	0.166	0.115	0.217
N	11380	11380	11380	952	952	952

Note: Table estimates a difference-in-difference specification to test the effects of swap lines on FX exposures for maturities greater than 3 months. Outcome variables include Buy, Sell and Net FX (Gap) exposures for dealers with respect to counterparty commercial banks and non-financials. D_{treat} is a dummy variable for dealers that activated the BoE dollar repo. $D_{swapline}$ is a dummy variable for the months of March, April and May 2020 in which the BoE repo lines were drawn. Controls include the distance from the leverage ratio and CET1 ratio, and the share of risk-weighted assets. Sample is monthly from September 2019 to November 2020, and aggregates GBP/USD, EUR/USD and JPY/USD FX swaps for maturities greater than 3 months. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors are clustered at the dealer-counterparty level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Online Appendix to

"Central Bank Swap Lines: Micro-Level Evidence"

(Not for publication)

Appendix A: Model

In this section, we introduce a stylized model of the FX market. We generate testable predictions on FX market demand and pricing in response to central bank swap lines. We introduce two types of agents in the model; customers and arbitrageurs. Customers include banks that manage currency mismatch between assets and liabilities by hedging their positions via FX swaps. Arbitrageurs supply dollars in the FX market to earn arbitrage profits from mis-pricing of the forward rate. We show that in an equilibrium with swap lines, CIP deviations are constrained by the penalty rate on swap line borrowing. The equilibrium demand for dollars by customers is reduced through a substitution effect. Banks that formerly relied on the FX market for dollar funding now obtain dollars via a FX market.

Banks

There is a continuum of risk-neutral banks with a fixed amount of dollar assets $\bar{A}$. The bank has two ways to fund their dollar asset position. The first is through borrowing dollars directly, for example via commercial paper markets or dollar bond issuance. Alternatively, they may borrow dollars *synthetically* by borrowing in domestic currency and swapping them into dollars in the FX market. [18] Formally, they can borrow dollars directly at a cost of r, or via FX swaps at $r + \Delta + F(X)$, where Δ is a premium for swapping domestic currency into dollars, and is equal to the CIP deviation, and $F(X) = aX, a > 0$ is a marginal hedging cost which is increasing in the size of the FX swap position.[19] Banks aim to minimise the costs of dollar funding, and are subject to a constraint on direct dollar borrowing, where the direct dollar funding B_j is less than a fraction γ_j of bank equity K.

$$B_j \leq \gamma_j K \qquad \gamma_j \sim U[0,1] \tag{14}$$

The bank's currency neutral balance sheet is given by:

[18] In our setting, we are assuming the bank is domiciled outside the U.S., for example a British, European, or Japanese Bank. The bank is therefore able to borrow domestic currency and swap them into dollars in the FX market to fund their dollar balance sheet.

[19] This is consistent with micro-level evidence in Abbassi and Bräuning (2020) that finds a higher forward premium is charged on banks with a larger hedging demand.

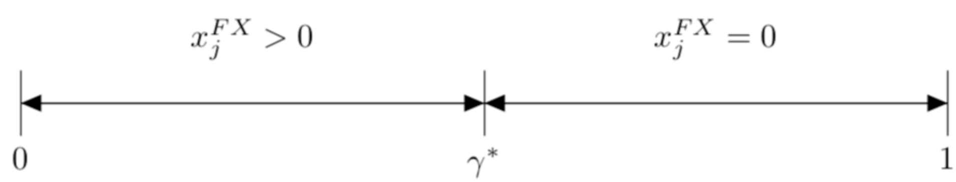
$$\bar{A} = B_j + x_j^{FX} \tag{15}$$

Dollar constrained banks have a low γ_j, this means they cannot borrow dollars directly and are therefore inclined to borrow dollars in the FX market to hedge their balance sheet. The demand for dollar funding via FX swaps is given by the following piecewise function, where the threshold $\gamma_0^* = \frac{\bar{A}}{K}$.

$$x_j^{FX} = \begin{cases} \bar{A} - \gamma_j K, \gamma_j < \gamma_0^*. \\ 0, \qquad\qquad \gamma \geq \gamma_0^* \end{cases} \tag{16}$$

Figure A1 illustrates the distribution of FX swap demand x_j^{FX} for banks in a continuum of [0,1]. Sufficiently dollar constrained banks, with $\gamma \in [0, \gamma_0^*]$ borrow dollars via the FX market, $x_j^{FX} > 0$. Banks with $\gamma \in [\gamma_0^*, 1]$ are not constrained in borrowing dollars directly, and do not use the FX market for dollar funding, $x_j^{FX} = 0$

Figure A1: Allocation of FX Swap Funding for Banks in continuum $\gamma_j \in [0, 1]$



Arbitrageur

A risk-neutral arbitrageur in the continuum [0,1] borrows a fraction of their wealth, ΓW, to invest in a project, or to lend dollars in the FX market in a CIP arbitrage trade. We assume the arbitrageur's investment project return has a rate of return given by a uniform distribution $U \sim [\alpha_L, \alpha_U]$. If they decide to lend dollars in the FX market, they will make a return equal to Δ, which is the CIP deviation.[20] Each arbitrageur draws a return on the project, and will decide to lend dollars in the FX market if the return on CIP arbitrage exceeds the outside opportunity cost. The share dollar wealth that is invested in the CIP arbitrage is given by:

[20]If they borrow dollars at the risk-free rate $r_\$$, and lend them in the FX market to make $r_d + f - s - r_\$$, where $f - s$ is the forward premium on the trade, the CIP arbitrage profit is equal to $\Delta = r_d + f - s - r_\$$

$$x^{FX} = \Gamma W \frac{\Delta - \alpha_L}{\alpha_U - \alpha_L} \tag{17}$$

Equilibrium

Market clearing conditions state that the demand and supply of dollars in FX market by banks and arbitrageurs. We equate the level of dollar funding via FX swaps with the supply of dollar funding by arbitrageurs.

$$\int_0^{\gamma_0^*} x_j^{FX} d\gamma_j = \Gamma W \frac{\Delta - \alpha_L}{\alpha_U - \alpha_L} \tag{18}$$

Solving for the equilibrium demand for dollars in the FX market.

$$\int_0^{\gamma_0^*} x_j^{FX} d\gamma_j = \int_0^{\gamma_0^*} \bar{A} - \gamma_j K d\gamma_j \tag{19}$$

$$= [\bar{A}\gamma_j - \frac{\gamma_j^2}{2} K]_0^{\gamma_0^*} \tag{20}$$

$$= \frac{\bar{A}^2}{K} - \frac{\bar{A}^2}{2K} \tag{21}$$

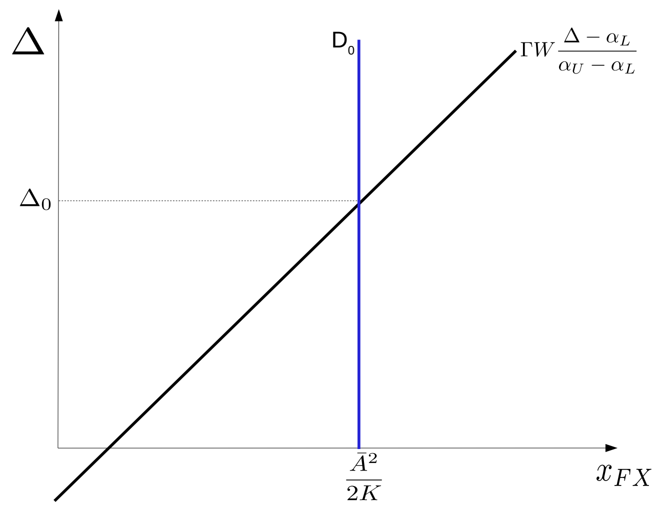
$$= \frac{\bar{A}^2}{2K} \tag{22}$$

We can substitute this into the market clearing condition to solve for the equilibrium Δ

$$\Delta = \alpha_L + \frac{\bar{A}^2(\alpha_U - \alpha_L)}{2K\Gamma W} \tag{23}$$

The equilibrium price and FX swap demand is illustrated in figure A2.

Figure A2: FX market Equilibrium



Swap Line

Central Bank swap line offers direct dollar borrowing at a penalty rate to the risk-free rate, at a cost $r + \eta$. [21]

The new balance sheet constraint includes dollars borrowed via a central bank swap line as an additional source of dollar funding.

$$\bar{A} = B_j + x_j^{FX} + x_j^{CB} \tag{24}$$

Direct dollar borrowing is still the cheapest marginal source of dollar funding, however there is now a tradeoff between borrowing dollars in the FX market or via a swap line.

Figure A3 illustrates the distribution of FX swap demand x_j^{FX} for banks in after the swap line is introduced. Similar to the pre-swap lines equilibrium, banks in $\gamma \in [\gamma_0^*, 1]$ do not use the FX market for dollar funding, $x_j^{FX} = 0$.

We find a departure for sufficiently dollar constrained banks, with $[0, \gamma_1^*]$ borrow dollars via the central bank swap line. To determine the threshold γ_1^*, we equate the marginal costs

[21] Empirically, the penalty rate is currently 25 basis points above the dollar OIS rate, based on the swap line announcement made on March 15th, 2020. The relevant excerpt from the announcement reads *These central banks have agreed to lower the pricing on the standing U.S. dollar liquidity swap arrangements by 25 basis points, so that the new rate will be the U.S. dollar overnight index swap (OIS) rate plus 25 basis points.* . For more details, refer to https://www.federalreserve.gov/newsevents/pressreleases/monetary20200315c.htm

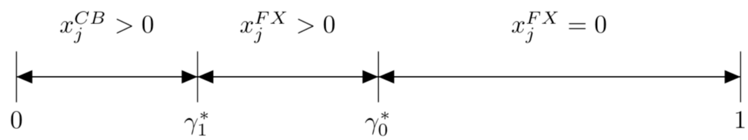
of FX swap funding with the marginal cost of the swap line.

$$r + \eta = r + \Delta + a x_j^{FX} \tag{25}$$

$$r + \eta = r + \Delta + a(\bar{A} - \gamma_1^* K) \tag{26}$$

$$\gamma_1^* = \frac{\bar{A} - \frac{\eta - \Delta}{a}}{K} \tag{27}$$

Figure A3: Allocation of FX Swap Funding after introduction of Central Bank Swap Line



For banks with $\gamma < \gamma_1^*$, the cost of borrowing via FX swaps exceeds the cost of borrowing dollars via the swap line. For banks with $\gamma \in [\gamma_1^*, \gamma_0^*]$, they alternatively prefer to source dollar funding via FX swaps. The piecewise function for borrowing dollars in the FX market and central bank swap line is given by:

$$x_j^{FX} = \begin{cases} 0, & \gamma \leq \gamma_1^* \\ \bar{A} - \gamma_j K, & \gamma_1^* < \gamma_j < \gamma_0^*. \\ 0, & \gamma \geq \gamma_0^* \end{cases} \tag{28}$$

$$x_j^{CB} = \begin{cases} \bar{A} - \gamma_j K, & \gamma \leq \gamma_1^* \\ 0, & \gamma \geq \gamma_1^* \end{cases} \tag{29}$$

Equilibrium with swap line

In the equilibrium with central bank swap lines, the set of banks that borrow dollars via the swap line are the most dollar constrained banks, given by $[0, \gamma_1]$, then there is a set of banks that still use the FX market but do not use the swap line, given by $[\gamma_1, \gamma_0]$, and finally there is a set of banks that do not use FX swaps, $[\gamma_0, 1]$.

Following our market clearing condition from before, we equate the level of dollar funding via FX swaps with the supply of dollar funding by arbitrageurs. Critically, only banks in the continuum $[\gamma_1^*, \gamma_0^*]$ are borrowing dollars via the FX market.

$$\int_{\gamma_1^*}^{\gamma_0^*} x_j^{FX} d\gamma_j = \Gamma W \frac{\Delta - \alpha_L}{\alpha_U - \alpha_L} \tag{30}$$

Solving for the new level of demand for dollars in the FX market.

$$\int_{\gamma_1^*}^{\gamma_0^*} x_j^{FX} d\gamma_j = \int_0^{\gamma_0^*} \bar{A} - \gamma_j K d\gamma_j \tag{31}$$

$$= [\bar{A}\gamma_j - \frac{\gamma_j^2}{2} K]_{\gamma_1^*}^{\gamma_0^*} \tag{32}$$

$$= \frac{\bar{A}^2}{K} - \frac{\bar{A}^2}{2K} - \bar{A}\frac{\bar{A} - \frac{\eta - \Delta}{a}}{K} + \frac{K}{2}\left(\frac{\bar{A} - \frac{\eta - \Delta}{a}}{K}\right)^2 \tag{33}$$

$$= \frac{1}{2K}\left(\frac{\eta - \Delta}{a}\right)^2 \tag{34}$$

Solving for the equilibrium Δ.

$$\frac{1}{2K}\left(\frac{\eta - \Delta}{a}\right)^2 = \frac{\Gamma W(\Delta - \alpha_L)}{\alpha_U - \alpha_L} \tag{35}$$

$$\frac{1}{2Ka^2}\left(\eta^2 + \Delta^2 - 2\eta\Delta\right) = \frac{\Gamma W}{\alpha_U - \alpha_L}(\Delta - \alpha_L) \tag{36}$$

$$\eta^2 + \Delta^2 - 2\eta\Delta = 2Ka^2\frac{\Gamma W}{\alpha_U - \alpha_L}(\Delta - \alpha_L) \tag{37}$$

We set $\lambda = Ka^2\frac{\Gamma W}{\alpha_U - \alpha_L}$, and λ is a positive variable.

$$\eta^2 + \Delta^2 - 2\eta\Delta = 2\lambda(\Delta - \alpha_L) \tag{38}$$

$$\Delta^2 - 2(\eta + \lambda)\Delta + \eta^2 + 2\lambda\alpha_L = 0 \tag{39}$$

The roots of equation (39) is:

$$\Delta = \frac{1}{2}\left[2(\eta + \lambda) \pm \sqrt{(2(\eta + \lambda))^2 - 4(\eta^2 + 2\lambda\alpha_L)}\right] \tag{40}$$

$$= \eta + \lambda \pm \sqrt{(\eta + \lambda)^2 - (\eta^2 + 2\lambda\alpha_L)} \tag{41}$$

$$= \eta + \lambda \pm \sqrt{\lambda^2 + 2\lambda(\eta - \alpha_L)} \tag{42}$$

The validity of Δ need to be smaller than the penalty rate of Swap line η. Therefore, the equilibrium Δ is:

$$\Delta = \eta + \lambda - \sqrt{\lambda^2 + 2\lambda(\eta - \alpha_L)} \tag{43}$$

The Δ is strictly no larger than η because of $\eta - \alpha_L \geq 0$ and $\lambda - \sqrt{\lambda^2 + 2\lambda(\eta - \alpha_L)} \leq 0$. It meets the validity requirement on Δ.

A.1 Testable Implications

The model provides the following testable implications.

Prediction 1: A decline in the penalty rate, all else equal, will result in a decline in the equilibrium level of CIP deviations.

Taking the first deriative of the equilibrium price with respect to the penalty rate η:

$$0 < \frac{\partial \Delta}{\partial \eta} = 1 - \frac{\lambda}{\sqrt{\lambda^2 + 2\lambda(\eta - \alpha_L)}} < 1 \tag{44}$$

The derivative is bounded between 0 and 1. The effect of the penalty rate on CIP deviation is consistent with evidence in Bahaj and Reis (2021a) that the penalty rate imposes a ceiling on CIP deviations.

Prediction 2: The introduction of central bank swap lines causes a decline in the aggregate dollars demanded via FX swaps, $x^{FX} \downarrow$ and a narrowing of CIP deviations $\Delta \downarrow$.

We represent the new equilibrium with the introduction of swap lines graphically in figure A4. In this setup we interpret central bank swap lines as a demand side factor for dollar funding in the FX market. As dollar constrained banks substitute toward the swap line, we see a decline in the equilibrium CIP deviation, and a reduction in the demand for dollar funding via FX swaps.

Figure A4: Allocation of FX Swap Funding after introduction of Central Bank Swap Line