Central Bank Swap Lines: Micro-Level Evidence

Gerardo Ferrara* Philippe Mueller† Ganesh Viswanath-Natraj‡ Junxuan Wang§¶

First version: 6 May 2022

This version: 15 May 2023

Abstract

This paper investigates the impact of central bank swap lines during the 2020 pandemic on price, volatility, and micro-level effects. Institutions relying on these swap lines tend to be larger, better capitalized, and have a lower ratio of risk-weighted assets to total assets due to stringent collateral requirements. Using micro-level data on FX derivative contracts, we find that swap line participants engage in more favorable pricing of forward contracts, reduce their gross FX exposures, and increase their net supply of dollars to non-financial institutions. Our findings support the use of swap lines in reducing FX market mis-pricing and providing cross-border liquidity.

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

*gerardo.ferrara@bankofengland.co.uk, Bank of England

†philippe.mueller@wbs.ac.uk, Warwick Business School

‡ganesh.viswanath-natraj@wbs.ac.uk, Warwick Business School

§junxuan.wang.19@mail.wbs.ac.uk, Warwick Business School

¶For detailed comments, we would like to thank discussants Benedikt Ballensiefen, Joseph Barunik, Falk Bräuning, Pasquale Della Corte, Phillipp Gnan and Steven Kamin. For helpful comments, we would like to thank Saleem Bahaj, Carlos Canon Salazar, Robert Czech, Darrell Duffie, Fernando Eguren-Martin, Eddie Gerba, Arie Gozluklu, Sinem Hacioglu, Edward Kent, Lauren Rana, Matt Roberts-Sklar, Farzad Saidi, Nicholas Sander, David Skeie, Olav Syrstad, John Thannasoulis, Nicholas Vause, Paul Whelan and seminar participants at the Bank of England, BIS-BdI-ECB 12th Workshop on Exchange Rates, CEPR IFM Annual Meeting, IFABS Annual Meeting, Federal Reserve "Day Ahead" Conference on Financial Markets and Instiutions, Finance Management Annual Meeting, MMF Annual Meeting, NY Fed Inaugural Conference on the International Roles of the U.S.. Dollar, New Zealand Finance Meeting, SGF Conference, Annual Financial Market Liquidity Conference, Australasian Finance and Banking Conference and the University of Warwick. We are particularly grateful for the assistance given by Melissa Faglia and Stephen Newell in collecting the data. All errors remain those of the authors. The views expressed in this paper are those of the authors and not necessarily those of the Bank of England, University of Warwick, or any other institution with which the authors may be affiliated or associated.

1 Introduction and Motivation

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). [1]

The dollar's continued dominance as the global reserve currency has led to swap lines being used as a policy tool by the Federal 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 inter-bank 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 (Cesa-Bianchi et al., 2022; 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, 2022, 2020a; Eren et al., 2020; Goldberg and Ravazzolo, 2021; Choi et al., 2021; Schellekens et al., 2022).

While the price effects of swap lines are well understood, there is less research on how swap lines affect financial market participants balance sheets and their hedging of FX exposures. This paper uses micro-level evidence on the response of currency exposures of FX forward and swap participants to the central bank swap line. 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

[1] 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.

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, our paper is the first to use confidential drawings of repos data.[2] 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., 2021). 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 (2022, 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.

Our initial inquiry is focused on understanding the underlying balance sheet characteristics of institutions that rely on dollar repos. Specifically, we investigate if such institutions tend to be financially constrained, indicated by higher credit default swap (CDS) spreads, or better capitalized, with a higher proportion of risk-free assets. Our analysis of BOE repo draws reveals that dealers who utilized the swap lines were generally larger and better capitalized, with greater distance from leverage ratio and tier 1 capital ratio limits. Additionally, these institutions had lower ratios of risk-weighted assets to total assets and higher cash reserves. In contrast, CDS measures have not predictive power on the propensity to draw BOE repos. We attribute these findings to the stringent collateral requirements that restrict access to BOE dollar repos, which typically discount illiquid and high-risk assets with haircuts that exceed 15% of the collateral value. Consequently, better capitalized institutions are more likely to access the swap line.

We then proceed to test the effects of central bank swap lines using micro-level data on FX exposures and transaction prices. Testing for the effects on FX pricing 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 pricing relative to dealers that did not receive a swap line (control group). The granularity of data allow us to identify

[2]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.

FX transaction prices at a dealer-counterparty level. Following Cenedese et al. (2021) 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 with all counterparties, we find that dealers that had access to the swap line reduced the forward premia charged to customers in FX swaps relative to dealers that did not access the swap line following the settlement of swap line auctions on 19 March 2020.

Finally, in addition to prices, we can also conduct a similar analysis using FX exposures at a dealer-counterparty level. Focusing on transactions between dealers and commercial banks, treated dealers reduced their gross FX exposures.[3] As dealers now receive dollars via the swap line, the dealer therefore requires less dollar liquidity through forward contracts, resulting in a reduction in the demand for dollars at the forward leg.

For transactions between dealers and non-financial institutions, we find a significant decline in dealer demand for dollars at the forward leg of FX forward and swap transactions. 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 indicated by the Net International Investment position data borrowing more from swap lines.

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, describe the data sources for our empirical work, and motivate our paper with a set of stylized facts on the price and volatility effects of swap lines using benchmark rates. In section 4 we conduct our empirical analysis using the BOE repository and matching transaction level data on FX forward and swaps with dealer data on access to BOE dollar repos. Section 5 concludes the paper.

[3]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. 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. Gross exposures are the aggregate of Buy and Sell transactions for a specific dealer-counterparty pair.

[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.

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., 2021; 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. (2021), 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, 2022; 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; Schellekens et al., 2022; Cesa-Bianchi et al., 2021). Topics include price effects, the macro-financial determinants of swap line access, 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 Cesa-Bianchi et al. (2022) for a theory of swap lines in a macroeconomic framework. To study price effects, Bahaj and Reis (2020a)

[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.

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; Schellekens et al., 2022). Cesa-Bianchi et al. (2021) show that the pandemic led to a dash for dollars by banks and non-financial firms to meet debt obligations, and find support for this through the sharp rise in USD corporate credit spreads relative to other currencies. We complement this analysis by looking at how the demand for liquidity in USD can be alleviated through swap lines, reducing the need for dollars in FX forward and swap contracts.

A final strand of research focuses on using micro-level evidence on FX derivative positions during quarter-ends (Abbassi and Bräuning, 2020), discrimination in derivative pricing with respect to non-financial counterparties (Hau et al., 2021), the balance sheet effects of central bank swap lines (Aldasoro et al., 2020; Eren et al., 2020), the role of order flow in price-setting of FX swap and forward contracts (Syrstad and Viswanath-Natraj, 2022), and the role of FX hedging in understanding the dynamics of spot rates and spillovers to domestic markets (Liao and Zhang, 2020; Czech et al., 2021; Bräuer and Hau, 2022). 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.

3 Definitions and Data

3.1 Federal Reserve Swap lines

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 four major steps in a swap line between the Federal Reserve, which we label the source central bank, and the BOE, which is the recipient central bank. First, the BOE auction dollar repos to dealers in the UK, which is known as the trade date of the auction. Second, the Federal Reserve swaps USD for the BOE's currency at a specified exchange rate. Therefore there is no exchange rate risk in the swap contract. Third, the BOE then distributes these dollars in their jurisdiction through dollar repo auctions on the settlement date. Fourth, 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.

3.2 BOE Repos

Eligible institutions for BOE dollar repos are in accordance with the Sterling Monetary Framework.[6] All participants are charged the same 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.

[6] See https://www.bankofengland.co.uk/markets/market-notices/2020/consolidated-market-notice-for-usd-repo-operations-march-2020 for more details on eligible institutions

The swap between central banks is executed on the same day as the BOE US dollar repo operation, with settlement typically on a T+1 basis. The US dollars funds are then deposited in participant accounts on the day of settlement.[7]

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 the BOE Repo USD Notional follows the new swap line allotments made to the BOE. This suggests the confidential BOE repo line data that we have matches publicly available aggregate data provided by the Federal Reserve.

To access the Repo facility, institutions are required to post collateral. Table 1 summarizes the characteristics of the collateral, including the types of collateral, credit ratings and haircuts applied. The sterling monetary framework classifies these collateral types in buckets A, B and C. Collateral in bucket A includes government securities issued by US, UK, Canada, Germany, France, Netherlands. Collateral in bucket B includes sovereign government securities in other advanced economies of the Euro Area, Australia, New Zealand, Japan, Switzerland, Sweden, Norway and Denmark. It also includes the AAA tranche of mortgage and asset backed securities. Finally, collateral in bucket C includes mortgage or asset backed securities at a tranche of A3 or above. Depending on the category of collateral, different haircuts are applied to the amount of swap lines borrowings that a dealer can receive. For collateral in bucket A and with maturity less than 1 year haircuts for floating debt are 0.5 per cent. Haircuts for collateral in bucket B are typically in the range of 0.5 to 12 per cent. Finally, assets in bucket C typically have a haircut ranging from 15 to 30 per cent on riskier assets such mortgage backed securities. A similar pecking order applies when considering haircuts on maturities exceeding 30 years. While collateral in bucket A typically has a haircut of 15 per cent for long-term bonds, collateral in bucket C ranges from 27 to 42 per cent. These haircuts can potentially lead to excessive costs of providing risky assets as collateral to receive swap lines.

[7] 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.

3.3 BOE 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., 2021).[8] The dataset covers trades in FX forwards, currency swaps, futures and options for 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.[9]

For each FX forward and swap transaction, we have an identifier which allows us to

[8] This is based on estimates in Cenedese et al. (2021) that show the sample coverage is approximately 42% of global outstanding trades in FX forward and swap markets based on the BIS derivative statistics.

[9] 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.

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.[10]

3.4 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 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. In addition to calculating CIP deviations, we calculate a realized volatility measure using intra-day (5 minute level) data on forward rates obtained from Reuters Refinitiv. Our measure of intra-day volatility is calculated as the square root of the daily average sum of squared returns over 5 minute intervals.

Balance Sheets

Quarterly data on total assets, liabilities, Tier 1 Capital and Leverage Ratios, cash and risk-weighted assets from Bloomberg. Table 3 presents summary statistics. 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

[10] 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).

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.

3.5 Stylized facts: price and volatility effects of swap lines using benchmark rates

Stylized fact #1:: *The reduction in the penalty rate on Covid swap lines from OIS+50 basis points to OIS+25 basis points lowers the ceiling on CIP deviations.*

Bahaj and Reis (2022, 2020a) derive a no-arbitrage condition in which CIP deviations are governed by a ceiling that is based on the discount rate on borrowing dollars from the Fed. 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),

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

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 inter-bank markets. If hedging interest rate risk is costly for the arbitrageur, the spread between the inter-bank 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. 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. Further evidence in Appendix A shows 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.

Stylized fact #2: *There is a reduction in CIP deviations of currencies that accessed the swap line relative to a control group that did not activate the swap line*

Figure 6 presents CIP deviations (benchmark OIS rate) for advanced economies for maturities of 1 week, 1 month and 3 month, and Table 2 presents summary statistics. After an initial spike in CIP deviations in March for the EUR/USD, GBP/USD and JPY/USD, 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.

In particular, we can use a difference-in-differences (DiD) specification to compare currencies that activated the swap line with a control group that did not activate it. 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. Results in Appendix B 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 relative to the control group.

Stylized fact #3: *There is a reduction in the price dispersion of dealer quotes and a decline in the intra-day volatility of CIP deviations*

Figure 7 plots the intra-day forward rate volatility of the EUR/USD, GBP/USD and JPY/USD pairs for the 1 week, 1 month and 3 month maturities. The plots show an increase in volatility in the days preceding the swap lines settled on March 19th, 2020, and a reversal of volatility shortly after, consistent with the price effects. To more formally test for the reduction in volatility, Appendix C presents a HAR model to measure the effects of swap lines on realized volatility, controlling for COVID-19 variables. The results show that the day after settlement, there is a significant negative effect on volatility across all currencies and maturities, with the strongest effect on the EUR/USD and the weakest on the JPY/USD. Interestingly, no significant effects were found on the day of settlement, which may be due to swap line auctions being endogenous to periods of increased volatility in the FX market.

4 Empirical Evidence

4.1 Predictors of Swap Line Access

H1: *Dealers that use swap lines are highly capitalized and use high quality liquid assets as collateral due to strict collateral requirements.* In Table 1, we summarize the different collateral requirements. Institutions must post collateral to access the Repo facility, which is classified into buckets A, B, and C based on their credit ratings and types. Collateral in bucket A includes government securities issued by certain countries, bucket B includes securities from other advanced economies and AAA tranches of mortgage/asset-backed securities, and bucket C includes lower-rated mortgage/asset-backed securities. Different haircuts are applied to the amount of swap lines borrowings based on the category of collateral, with bucket A collateral having the lowest haircuts and bucket C collateral having the highest, leading to higher costs for providing risky assets as collateral.

To test this hypothesis, we identify potential determinants of swap line usage in equation (5). 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.

$$D_{treatment,i} = \beta x_t + \epsilon_{i,j,t} \tag{5}$$

Table 4 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. [11] 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. 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. We rationalise these differences through the collateral requirements to access the swap line. As there are significant haircuts on risky mortgage and asset backed securities, dealers that use the swap line have a lower share of risk-weighted assets and higher cash.

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. We now turn to these effects using transaction level price and derivative exposures data.

4.2 Transaction Level Prices

H2: *Dealers that indirectly receive swap line funding charge lower forward premia and have a larger decline in dispersion of quotes, relative to a control group of dealers that did not receive swap line funding.*

In this analysis, we exploit transaction-level heterogeneity in forward prices charged by dealers. We hypothesize that dealers that indirectly receive swap line funding charge lower forward premia and have a larger decline in dispersion of quotes, relative to a control group of dealers that did not receive swap line funding. Our hypothesis is that dealers that access the swap line now have additional dollar liquidity at their disposal to provide customers in forward and FX swap contracts. Therefore, all else equal, the spread between the synthetic and direct dollar borrowing rate, which is captured by the CIP deviation, should fall for treated dealers relative to control dealers.

For a dealer i and counterparty j, we calculate a transaction-level CIP deviation based on the forward rate quoted by dealer i in the transaction in equation (6). All other variables,

[11] We exclude CDS as an explanatory variable in Table 4 but in additional analysis we find there are no effects of CDS spreads on the propensity to draw on the BOE repos.

including risk-free rates in dollar and domestic currency, and the spot rate are based on benchmark rates in Section 3.5.

$$x_{\$,d,i,j} = 1 + r_{\$}^{f} - \frac{F_{i,j}}{S}(1 + r_{d}^{f}) \tag{6}$$

We construct intra-day transaction level CIP deviations for the dates of March 17th to March 20th 2020. We choose these dates as they correspond to the largest allotment of swap line auctions during the pandemic. The 18th of March corresponds to the day in which the Federal Reserve announced the swap line auctions, which is known as the trade date, for the Bank of England and the ECB, and 17th of March is the trade date for auctions with the Bank of Japan. The 19th of March is the settlement date of the auctions for all three central banks. We use all transactions between dealer and non-dealer clients. This includes commercial banks, hedge and insurance funds and non-financials. We subdivide our sample into a control and treated group, where treated dealers receive dollar repos from the BOE. We provide box plots of the EUR, GBP and JPY CIP deviations for the control and treatment groups in Figures 8, 9 and 10 respectively. We note considerable dispersion in the FX pricing across dealer-counterparty transactions, which is consistent with evidence on discriminary pricing in Hau et al. (2021).

Table 5 estimates two-paired t-tests for the differences in EUR, GBP and JPY CIP deviations on the principal days of the auction from 17th March to 20th March 2020. The mean transaction-level CIP deviations are calculated for the control and treatment groups on each day. The two-paired test measures a statistical difference in the means. While differences between control and treatment groups are insignificant for all currency pairs on the 17th of March, we note significant differences in EUR 3M on the 18th and 20th of March, and for the GBP on the 20th of March. For all currency pairs, we note a significant decline in CIP deviations in both groups on 20th of March, which is the day after settlement.

While the t-tests provide some evidence there is differential pricing between the control and treatment groups, we estimate a difference-in-difference specification in (7) to test the effects of swap lines on transaction price CIP violations for the currency pairs of EUR/USD, GBP/USD and JPY/USD. Outcome variables include individual currency CIP deviations measured using dealer-commercial banks. Maturities range from 80 to 100 days. D_{treat} is a dummy variable for dealers that activated the BoE dollar repo. $D_{03/18}$, $D_{03/19}$ and $D_{03/20}$ are dummy variables for the 18th, 19th and 20th of March respectively. Following Cenedese et al. (2021) and Khwaja and Mian (2008), we use both dealer-counterparty and counterparty-time fixed effects

$$\mathrm{Y}_{i,j,t} = \alpha_{i,j} + \alpha_{j,t} + \sum_{j=1}^{3} \delta_j D_{03/17+j} \times D_{treatment,i} + \epsilon_{i,j,t} \tag{7}$$

Table 6 present the results for transactions involving dealers and commercial banks. Column (I) is the panel specification pooling all currencies, and columns (II), (III) and (IV) are for individual currencies of EUR/USD, GBP/USD and JPY/USD respectively. The DiD results show that dealers that received a swap line had a net decline in CIP deviations and forward rate mis-pricing relative to the control group in the days following the announcement. These results are strongest for the GBP/USD in column (III). The coefficients on the interaction of the treated dealers with March 19th and March 20th are more positive, which suggests an attenuation of CIP deviations for transactions with treated dealers relative to the control group. Taken together, our estimates in Table 6 suggest that there are differential effects on swap line pricing. As dealers now receive dollars via the swap line, they reduce the extent of mis-pricing in FX swaps.

4.3 Outstanding Derivative Exposures

H3.1: *Dealers that receive swap line funding reduce their need for dollar liquidity through FX forward and swap contracts.*

If a dealer requires a set amount of dollar liquidity to meet debt obligations or hedging purposes, it could obtain that through USD repos with a central bank or FX forward and swap trades with other market participants. The dealer therefore requires less dollar liquidity through forward contracts, resulting in a reduction in the demand for dollars at the forward leg. Alternatively, dealers may reduce their demand for dollars at the spot leg of FX swap contracts, which would result in a corresponding reduction in the supply of dollars at the forward leg of FX swap contracts. In both cases, we expect gross FX exposures to decline.

H3.2: *Dealers that receive swap line funding provide dollar liquidity to non-financial institutions.*

Non-financial institutions cannot directly access the swap line. Increased uncertainty during the pandemic lead to an increased demand for hedging by non-financials. We therefore expect an increase in the supply of dollars through forward contracts.

As a starting point, we plot the gross notional outstanding FX exposures for different counterparty segments and maturities in Figures 11 and 12. Figure 11 presents gross notional positions of dealers with respect to the following 5 counterparty sectors: asset managers, commercial banks, hedge funds, ICPF and Non-Financial. FX exposures are aggregated across all maturities and are the outstanding notional positions at the end of each day. The left panel of each Figure reports Buy positions, and the right panel reports Sell 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.

The aggregate gross notional of both Buy and Sell positions are approximately 1.5 Trillion USD each day for the EUR-USD pair, and is closer to 1 Trillion USD each day for the GBP-USD and JPY-USD pairs. The largest counterparty segment is commercial banks, accounting for over half of the gross notional exposures for the EUR-USD and JPY-USD pairs. A dotted line in each the Figure indicates the date of March 18th, 2020, which is the trade date for the swap line auctions. The key trend in the Figure is a decline in the gross notional outstanding positions on March 18th, 2020 for dealers across all currency pairs. The decline in gross exposures are mostly confined to dealer-counterparty transactions. Examining maturities in Figure 12, we note that most of the decline in Buy and Sell positions is coming from maturities less than 1 week.

To test hypotheses H3.1 and H3.2 more formally, we compute outstanding FX derivative exposures at the end of month, from September 2019 to November 2020. For our empirical analysis, we will focus on the 3 month maturity. [12] 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 13 and 14 plot aggregate Buy, Sell and Net exposures for dealers with respect to commercial bank and non-financial counterparties. 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. (2021) 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.[13]

[12] We focus on this maturity because over the duration of the swap lines, which were activated in the months of March-September 2020, effects of swap lines on short-term exposures less than 1 month will not be identified at a monthly frequency. We include maturities between 80 and 100 days.

[13] 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. (2021), 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 (8). 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 $D_{swapline,t} \times D_{treatment,i}$

$$\mathrm{Y}_{i,j,t} = \alpha_{i,j} + \alpha_{j,t} + \gamma D_{swapline,t} + \delta D_{swapline,t} \times D_{treatment,i} + \mathrm{controls}_{i,t} + \epsilon_{i,j,t} \tag{8}$$

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. The dealer less dollar liquidity through forward contracts, resulting in a reduction in the demand for dollars at the forward leg. Sell exposures also declined relative to the control group by 520 USD Million. This result is consistent with a decline in the demand for dollars at the spot leg of FX swap contracts, which would result in a corresponding reduction in the supply of dollars at the forward leg of FX swap contracts. In summary, our results for dealer-commercial bank transactions support a decline in gross FX exposures, but we find no significant change in net exposures.

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.

4.3.1 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 (9). 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.

$$\text{Y}_{i,j,t} = \alpha_{i,j} + \gamma D_{swapline,t} + \sum_{m=-6}^{m=6} \delta_m \mathbb{1}[k = m] \times D_{treatment,i} + \text{controls}_{i,t} + \epsilon_{i,j,t} \tag{9}$$

Table 9 presents the results for Buy, Sell and Net Funding Gap for both commercial bank and non-financial counterparties.[14] 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.

[14]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.

4.3.2 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 (8). 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 10 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.

5 Conclusion

In this paper, we provide micro-level evidence of central bank swap line drawings on FX exposures and make the following contributions. First, we aimed to understand the balance sheet characteristics of institutions that rely on dollar repos. Through our examination of BOE repo draws, we found that institutions that utilized swap lines tended to be larger and better capitalized, with lower ratios of risk-weighted assets to total assets and higher cash reserves. In contrast, measures of financial constraints such as CDS spreads did not predict the propensity to draw BOE repos. We attribute these findings to the stringent collateral requirements that restrict access to BOE dollar repos and favor better capitalized institutions.

Second, 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. 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. We follow Khwaja and Mian (2008) by controlling for counterparty-time and dealer-counterparty fixed 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 our transaction-level measure of the CIP deviation. Our results show that dealers that accessed the swap line charged lower forward premia (as measured by CIP violations) relative to the control group on the days following the swap line announcement on March 18 2020.

We can also 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. Our analysis on FX exposures shows that dealers reduced their gross FX exposures due to a substitution toward dollar liquidity 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.

Finally, we point to future areas of research. For instance, what are the incentives for particular dealers to bid in dollar repo auctions? Do the reduction in FX exposures and net supply of dollars to non-financial institutions lead to further lending in the economy? 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.

References

Abbassi, Puriya and Falk Bräuning, "Demand Effects in the FX Forward Market: Micro Evidence from Banksâ Dollar Hedging," *Review of Financial Studies, forthcoming*, 2020.

Aizenman, Joshua, Hiro Ito, and Gurnain Kaur Pasricha, "Central bank swap arrangements in the covid-19 crisis," *Journal of International Money and Finance*, 2022, *122*, 102555.

Aldasoro, Iñaki, Christian Cabanilla, Pitti Disyatat, Torsten Ehlers, Patrick McGuire, and Goetz von Peter, "BIS Bulletin," 2020.

Andersen, Leif, Darrell Duffie, and Yang Song, "Funding value adjustments," *The Journal of Finance*, 2019, *74* (1), 145–192.

Avdjiev, Stefan, Wenxin Du, Catherine Koch, and Hyun Song Shin, "The dollar, bank leverage, and deviations from covered interest parity," *American Economic Review: Insights*, 2019, *1* (2), 193–208.

Baba, Naohiko and Frank Packer, "Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08," *Journal of Banking & Finance*, 2009, *33* (11), 1953–1962.

Bahaj, Saleem and Ricardo Reis, "Central bank swap lines during the covid-19 pandemic," *Covid Economics*, 2020, *2.*

_ and _ , "Jumpstarting an International Currency," 2020.

_ and _ , "Central bank swap lines: Evidence on the effects of the lender of last resort," *The Review of Economic Studies*, 2022, *89* (4), 1654–1693.

Borio, Claudio EV, Robert N McCauley, Patrick McGuire, and Vladyslav Sushko, "Covered interest parity lost: understanding the cross-currency basis," *BIS Quarterly Review September*, 2016.

Bräuer, Leonie and Harald Hau, "Can Time-Varying Currency Risk Hedging Explain Exchange Rates?," *Swiss Finance Institute Research Paper*, 2022, (22-77).

Bräuning, Falk and Kovid Puria, "Uncovering covered interest parity: The role of bank regulation and monetary policy," *Federal Reserve Bank of Boston Research Paper Series Current Policy Perspectives Paper*, 2017, (17-3).

Bruno, Valentina and Hyun Song Shin, "Capital flows and the risk-taking channel of monetary policy," *Journal of Monetary Economics*, 2015, *71*, 119–132.

Carvalho, Carlos, Ricardo Masini, and Marcelo C Medeiros, "Arco: an artificial counterfactual approach for high-dimensional panel time-series data," *Journal of econometrics*, 2018, *207* (2), 352–380.

Cenedese, Gino, Pasquale Della Corte, and Tianyu Wang, "Currency mispricing and dealer balance sheets," *The Journal of Finance*, 2021, *76* (6), 2763–2803.

Cerutti, Eugenio M, Maurice Obstfeld, and Haonan Zhou, "Covered Interest Parity Deviations: Macrofinancial Determinants," Technical Report, National Bureau of Economic Research 2019.

Cesa-Bianchi, Ambrogio, Fernando Eguren Martin, and Andrea Ferrero, "Dollar shortages and central bank swap lines," 2022.

_ , Robert Czech, and Fernando Eguren-Martin, "Staff Working Paper No. 932 Dash for dollars," 2021.

Choi, Mark, Linda S Goldberg, Robert Irving Lerman, and Fabiola Ravazzolo, "The Fed's central bank swap lines and FIMA repo facility," Technical Report, Staff Report 2021.

Committee on the Global Financial System, "US dollar funding: an international perspective," Technical Report, Bank for International Settlements 2020.

Corsi, Fulvio, "A simple approximate long-memory model of realized volatility," *Journal of Financial Econometrics*, 2009, *7* (2), 174–196.

Czech, Robert, Shiyang Huang, Dong Lou, Tianyu Wang et al., "An unintended consequence of holding dollar assets," *Bank of England Staff Working Paper*, 2021, (953).

Drechsler, Itamar, Thomas Drechsel, David Marques-Ibanez, and Philipp Schnabl, "Who borrows from the lender of last resort?," *The Journal of Finance*, 2016, *71* (5), 1933–1974.

Du, Wenxin, Alexander Tepper, and Adrien Verdelhan, "Deviations from covered interest rate parity," *The Journal of Finance*, 2018, *73* (3), 915–957.

Eren, Egemen, Andreas Schrimpf, and Vladyslav Sushko, "BIS Bulletin," 2020.

Ferrara, Gerardo, Maria Flora, and Roberto Renò, "The COVID-19 Auction Premium," Technical Report, Working paper 2021.

Goldberg, Linda, Craig Kennedy, and Jason Miu, "Central bank dollar swap lines and overseas dollar funding costs," *Economic Policy Review*, 2011, (May), 3–20.

Goldberg, Linda S and Fabiola Ravazzolo, "The Fed's International Dollar Liquidity Facilities: New Evidence on Effects," *FRB of New York Staff Report*, 2021, (997).

Griffoli, T Mancini and A Ranaldo, "Deviations from Covered Interest Parity during the crisis: A story of funding liquidity constraint," Technical Report, Working Paper, Swiss National Bank 2009.

Hau, Harald, Peter Hoffmann, Sam Langfield, and Yannick Timmer, "Discriminatory pricing of over-the-counter derivatives," *Management Science*, 2021, *67* (11), 6660–6677.

He, Zhiguo, Bryan Kelly, and Asaf Manela, "Intermediary asset pricing: New evidence from many asset classes," *Journal of Financial Economics*, 2017, *126* (1), 1–35.

Iida, Tomoyuki, Takeshi Kimura, and Nao Sudo, "Deviations from covered interest rate parity and the dollar funding of global banks," *55th issue (September 2018) of the International Journal of Central Banking*, 2018.

Ivashina, Victoria, David S Scharfstein, and Jeremy C Stein, "Dollar Funding and the Lending Behavior of Global Banks," *The Quarterly Journal of Economics*, 2015, *130* (3), 1241–1281.

Khwaja, Asim Ijaz and Atif Mian, "Tracing the impact of bank liquidity shocks: Evidence from an emerging market," *American Economic Review*, 2008, *98* (4), 1413–42.

Liao, Gordon and Tony Zhang, "The Hedging Channel of Exchange Rate Determination," *Available at SSRN 3612395*, 2020.

Liao, Gordon Y, "Credit migration and covered interest rate parity," *Journal of Financial Economics*, 2020.

Martin, Fernando Eguren, Matias Ossandon Busch, and Dennis Reinhardt, "Global banks and synthetic funding: the benefits of foreign relatives," 2018.

Newey, Whitney K. and Kenneth D. West, "A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica*, 1987, *55* (3), 703–708.

Rime, Dagfinn, Andreas Schrimpf, and Olav Syrstad, "Covered interest parity arbitrage," *Review of Financial Studies, Forthcoming*, 2022.

Schellekens, Kai, Patty Duijm et al., "Effectiveness of Central Bank Swap Lines in Alleviating the Mispricing of FX Swaps at the Start of the COVID-19 Pandemic," Technical Report 2022.

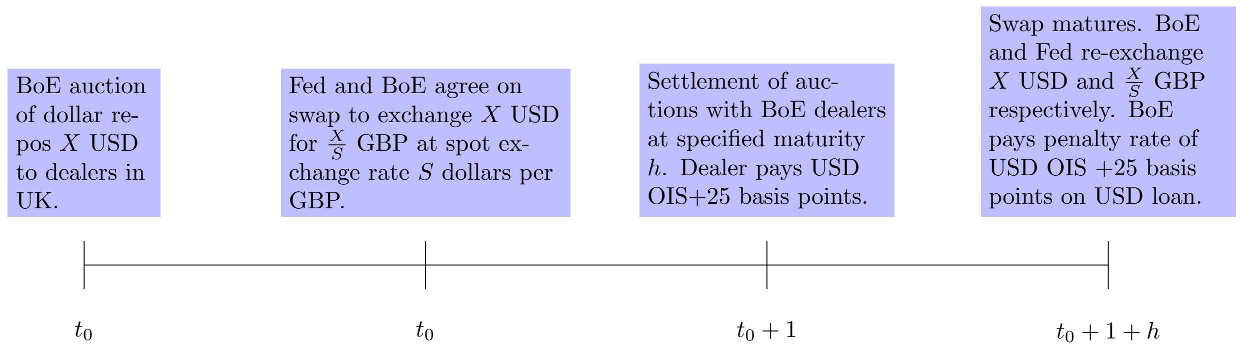
Syrstad, Olav, "Covered Interest Parity in long-dated securities," *Available at SSRN 3611635*, 2020.

_ **and Ganesh Viswanath-Natraj**, "Price-setting in the foreign exchange swap market: Evidence from order flow," *Journal of Financial Economics*, 2022, *146* (1), 119–142.

Viswanath-Natraj, Ganesh, "Unconventional Monetary Policy and Covered Interest Rate Parity Deviations: is there a Link?," 2020.

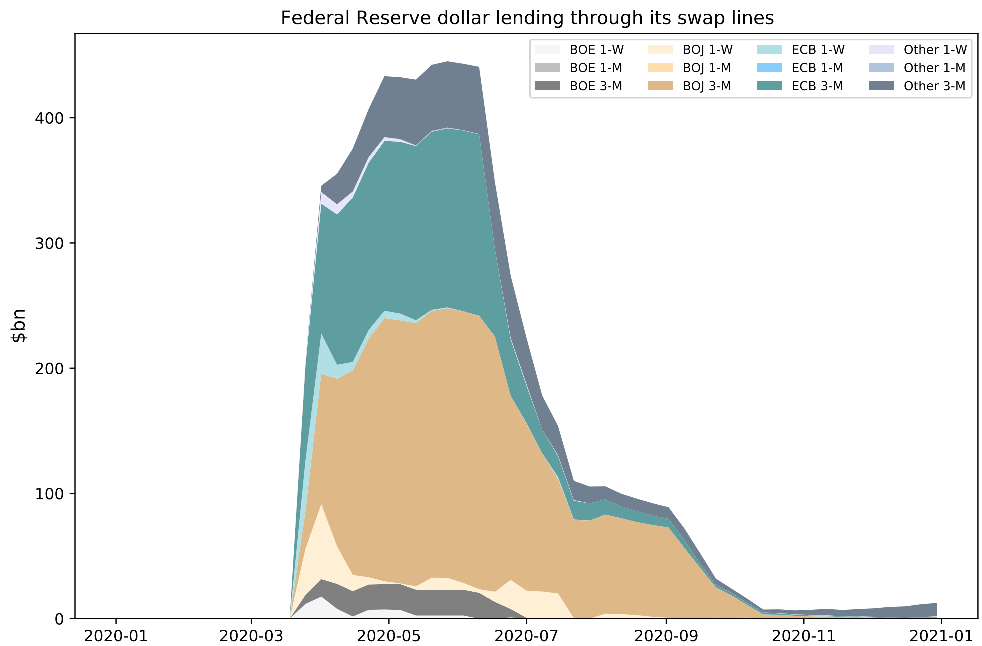
Figures

Figure 1: Swap Line Auctions Timeline



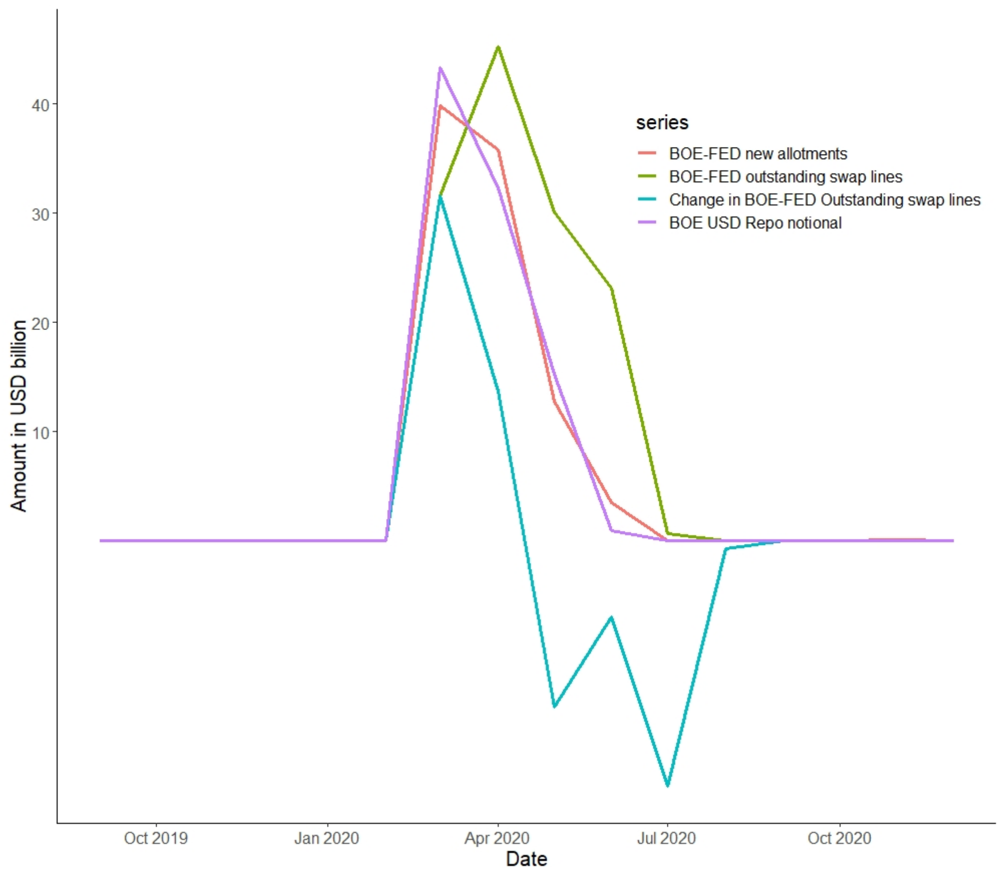
Note: Figure presents timeline of swap line auctions between the Federal Reserve and Bank of England. t_0 is the date of the auctions between the BOE and dealers in the UK, and is also the date of agreement between the Federal Reserve and BOE. $t_0 + 1$ is the day of settlement of auctions. $t_0 + 1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

Figure 2: Swap Line Allotments during Covid



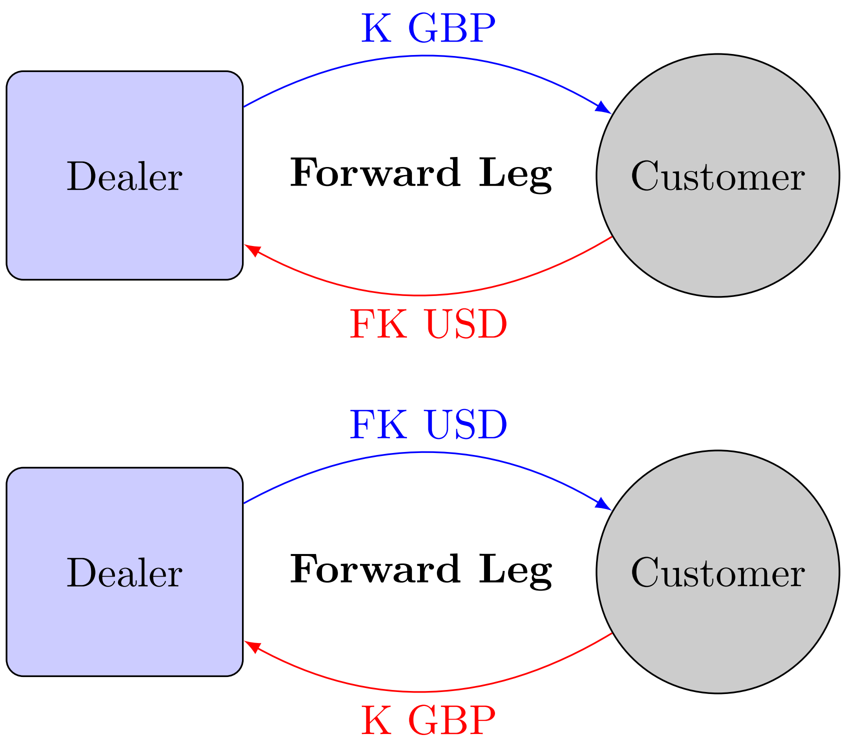
Note: Figure presents outstanding Federal Reserve Swap Lines made to Bank of Japan, Bank of England, European Central Bank and other central banks during 2020. Maturities are 1 week, 1 month and 3 month. Data is taken from the New York Federal Reserve.

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



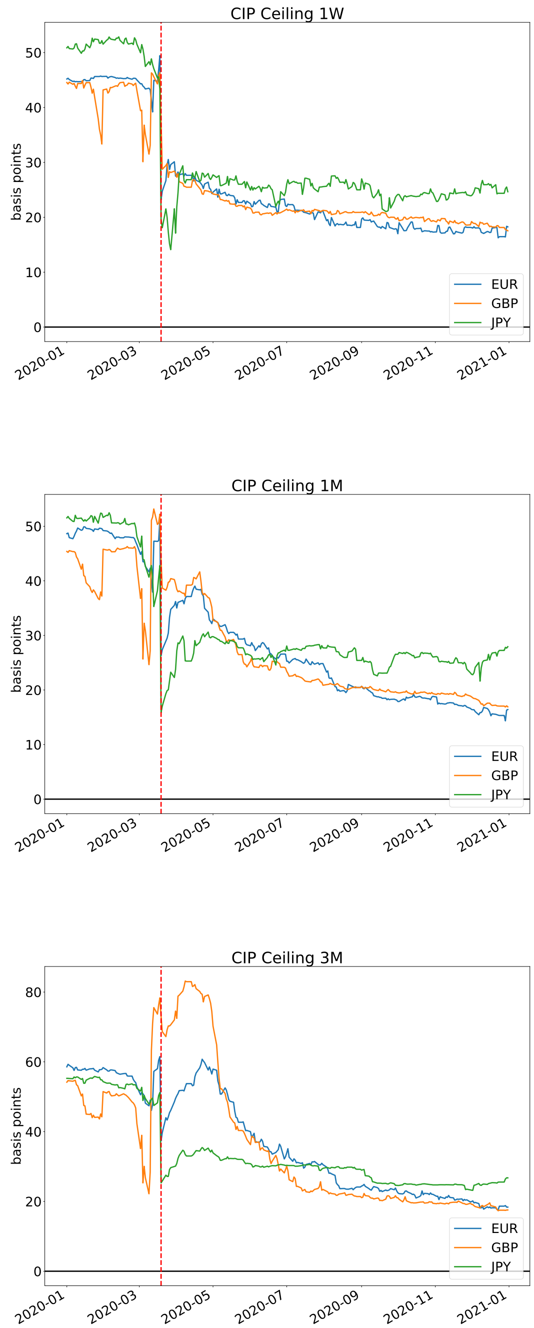
Note: Figure presents outstanding Federal Reserve Swap Lines made to Bank of England. Drawings from the BOE repos are aggregated for all dealers and the BOE USD repo notional at the end of each month is calculated. This is compared to the aggregate auctions of funds from the Federal Reserve to the BOE 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.



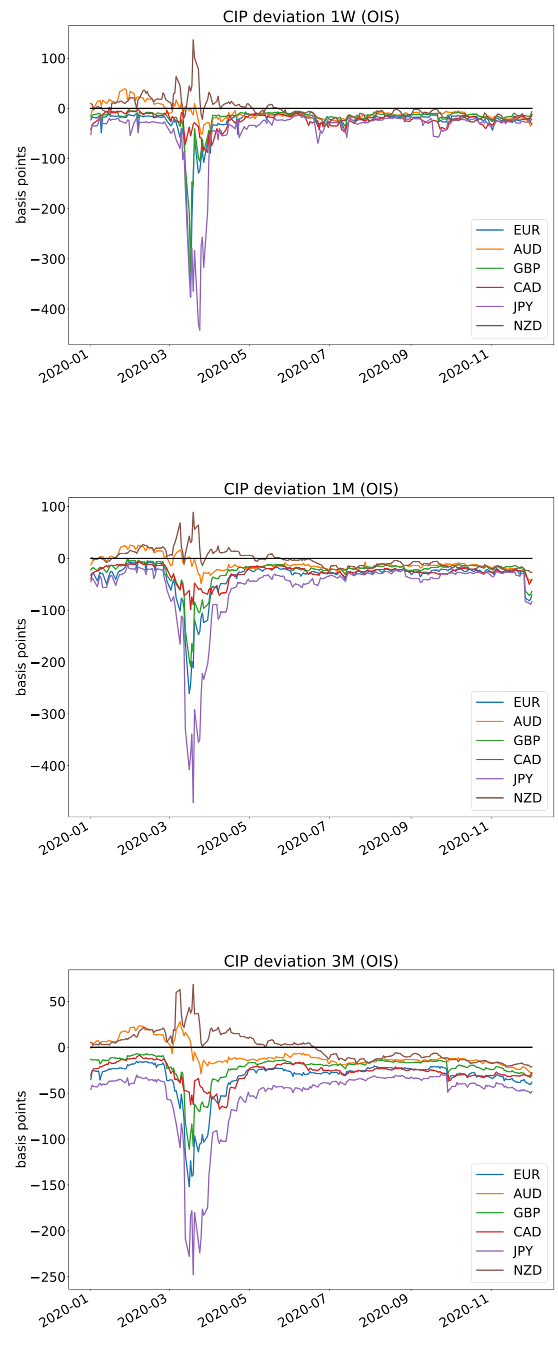
Note: Figure schematic shows how FX exposures Buy and Sell transactions are measured. In the top panel, a dealer that buys USD at the forward leg and sells GBP forward is recorded as a Buy transaction. In the bottom panel, a dealer that buys GBP at forward leg and sells USD forward is recorded as a Sell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

Figure 5: CIP Deviations during Covid: Ceiling Tests



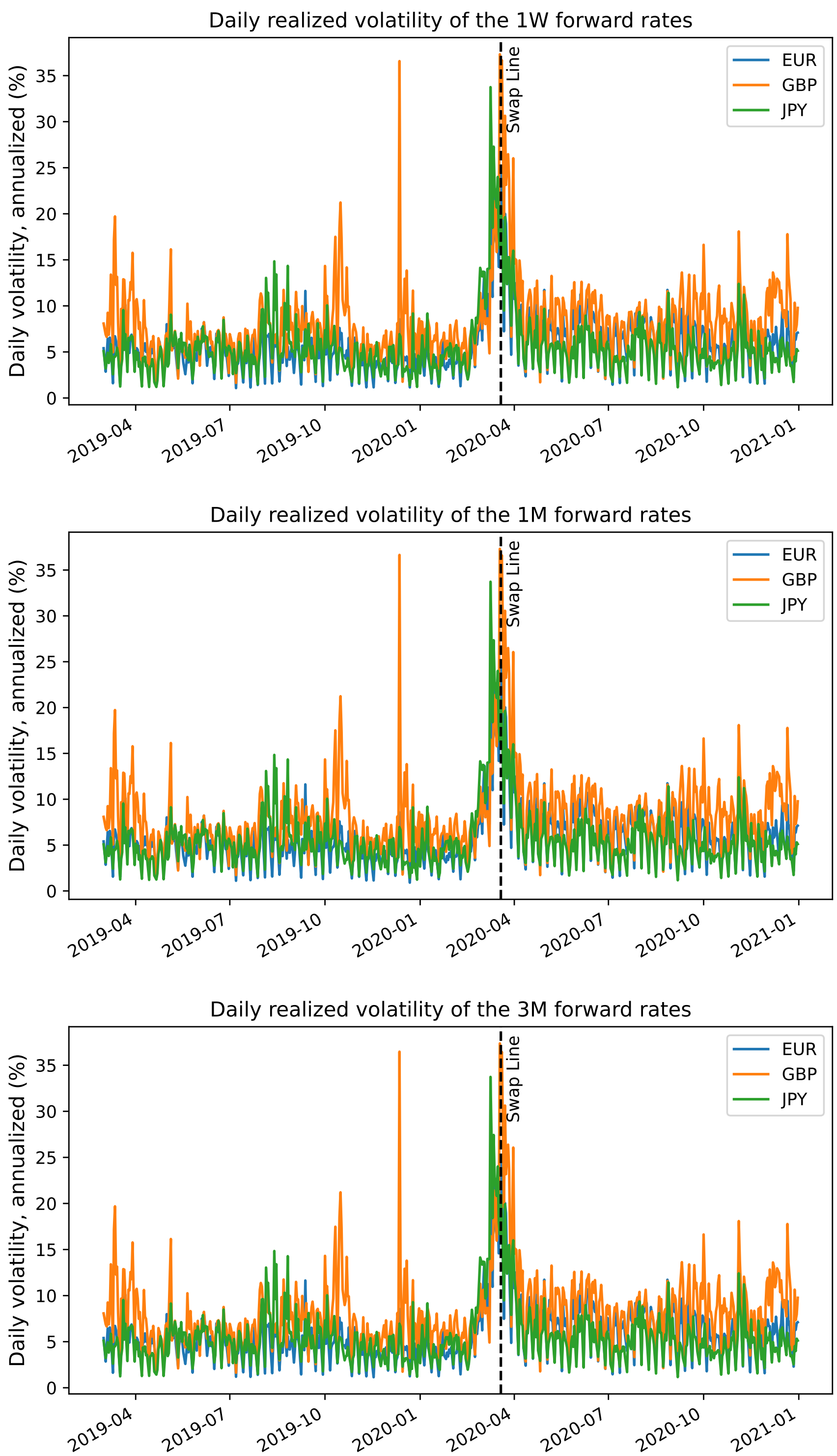
Note: Figure presents the ceiling on CIP deviations for advanced economies for maturities of 1 week, 1 month and 3 month. Data is daily and sample period is from January 1st 2020 to December 31st 2020. Data for OIS rates, forward and spot rates and interbank and policy rates used to construct the ceiling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

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



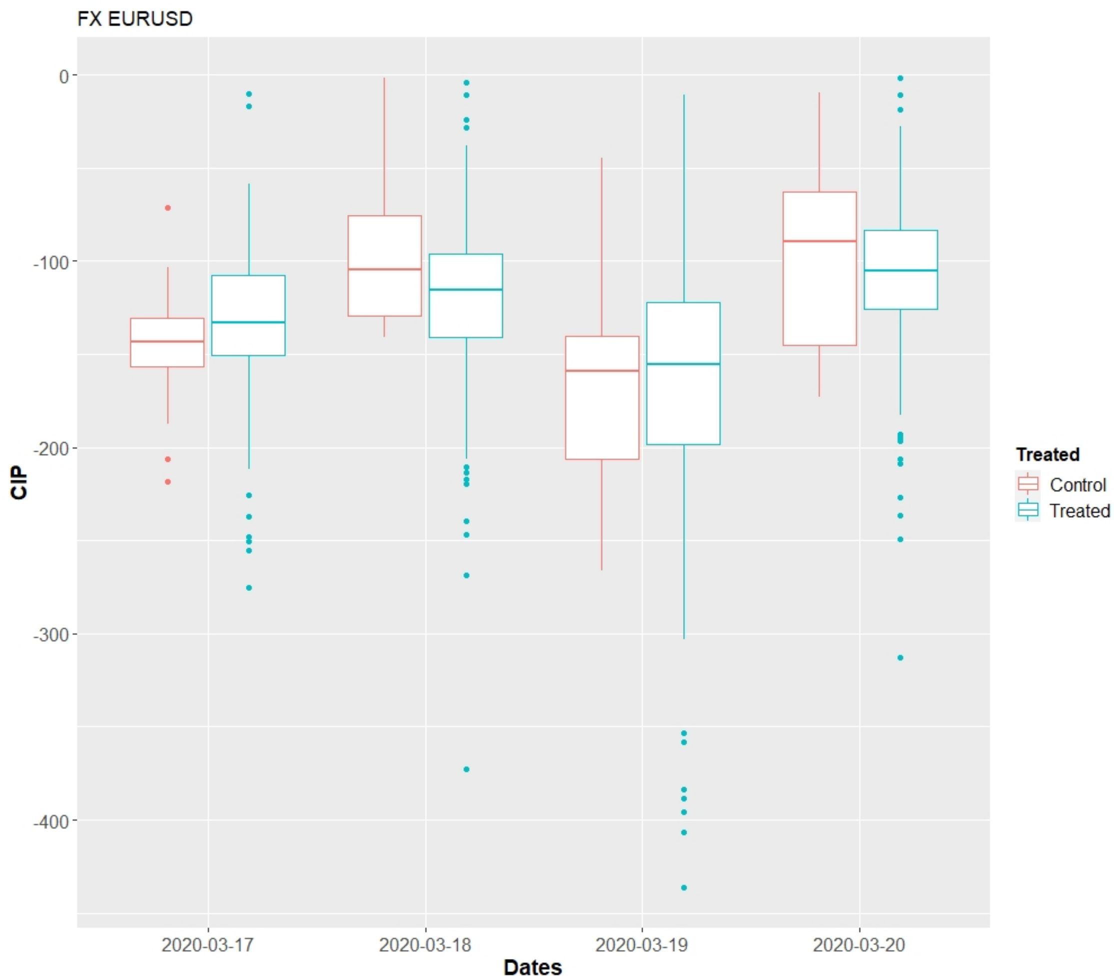
Note: Figure presents CIP deviations (benchmark OIS rate) for advanced economies for maturities of 1 week, 1 month and 3 month. Data is daily and sample period is from January 1st 2020 to November 20th 2020. Data for OIS rates, forward and spot rates are taken from Bloomberg.

Figure 7: Forward Rate Volatility: 1 Week, 1 Month and 3 Month



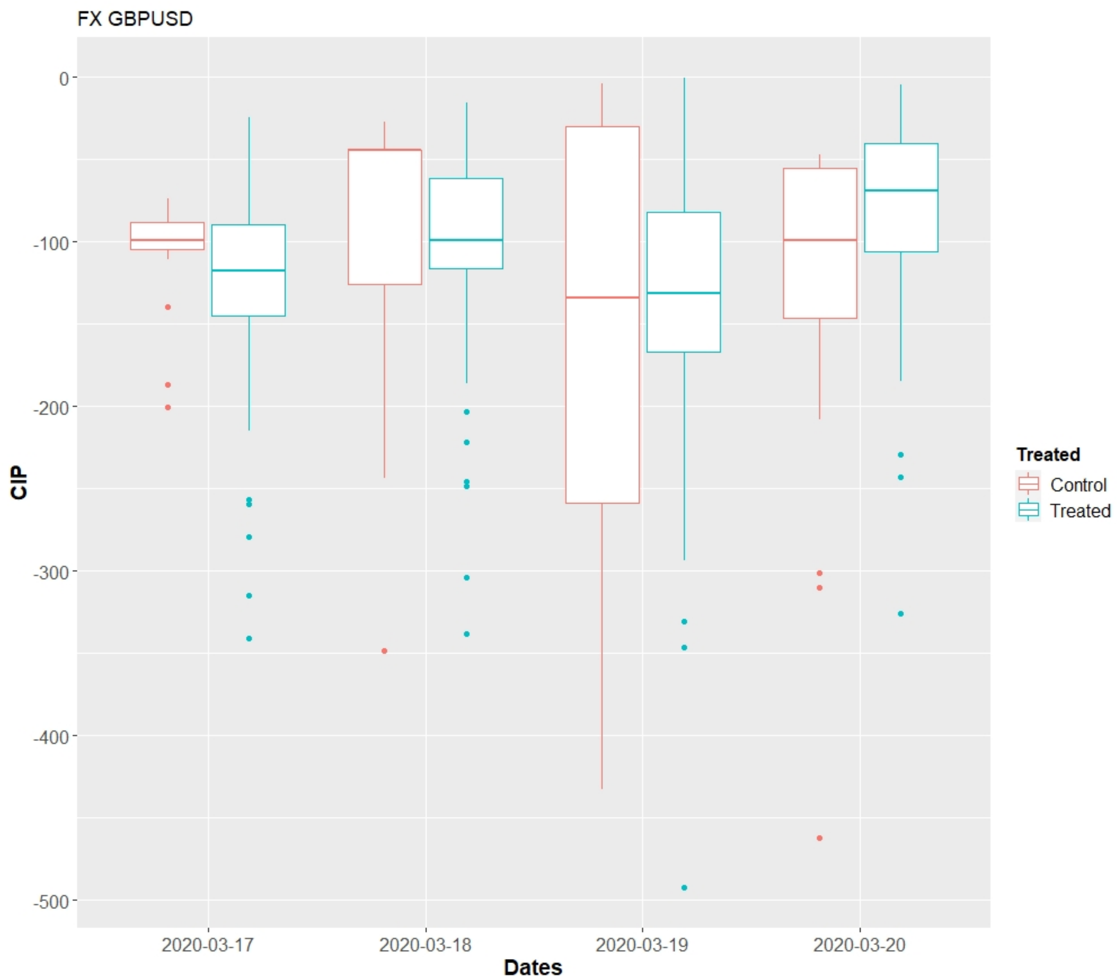
Note: Figure presents daily realized volatility of the EUR/USD, GBP/USD and JPY/USD forward rate for 1 week, 1 month and 3 month maturities. It is calculated using intra-day data taken from Thomson Reuters tick history. Dotted line indicates Federal Reserve settlement date of March 19th, 2020.

Figure 8: Box Plot of Transaction Level CIP Violations- EUR/USD 3M



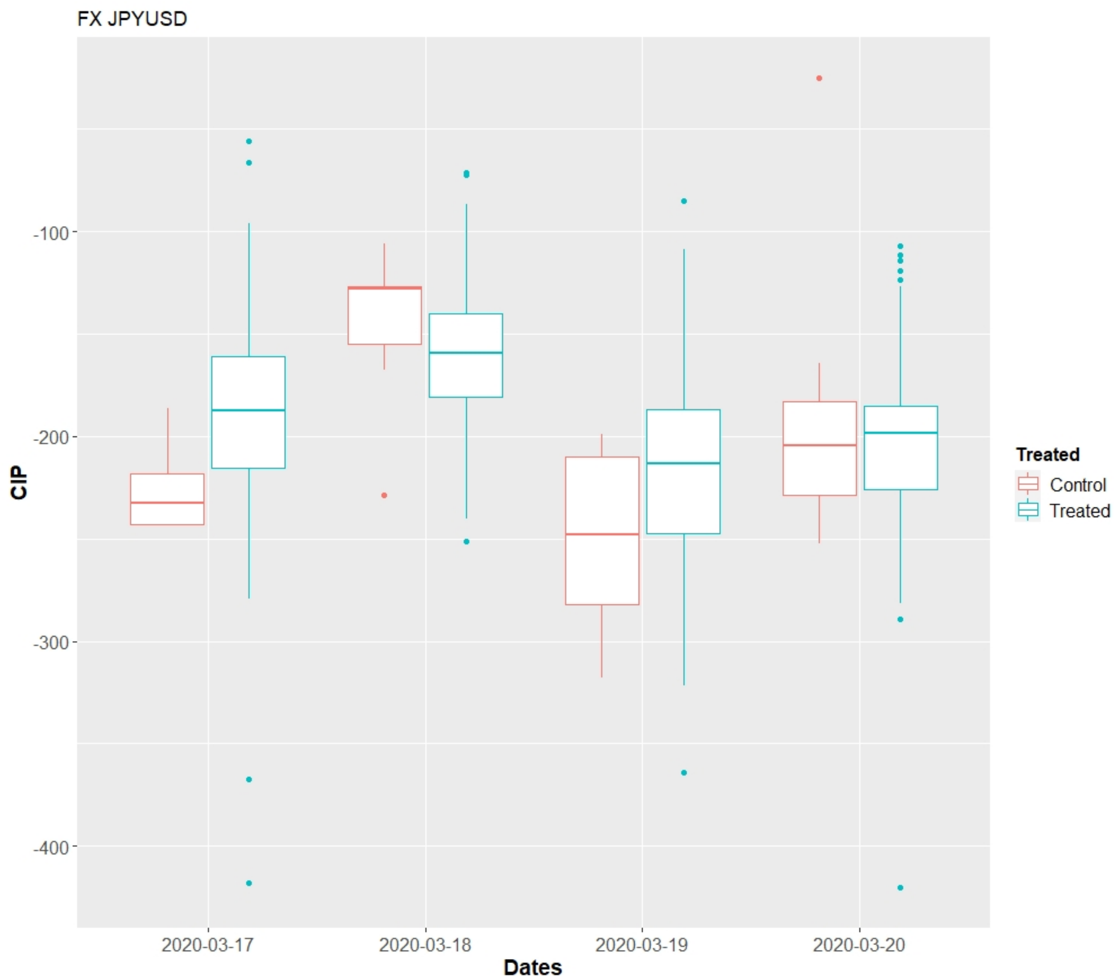
Note: Figure presents box plot of EUR/USD transaction level CIP deviations, for the dates of 17th to 20th of March, 2020. The announcement date is 18th of March, and the settlement date is March 19th. Transactions are between dealers and commercial banks, and sub-divided into treated and control dealers, where treated dealers received swap line liquidity from the Bank of England on the 19th of March.

Figure 9: Box Plot of Transaction Level CIP Violations- GBP/USD 3M



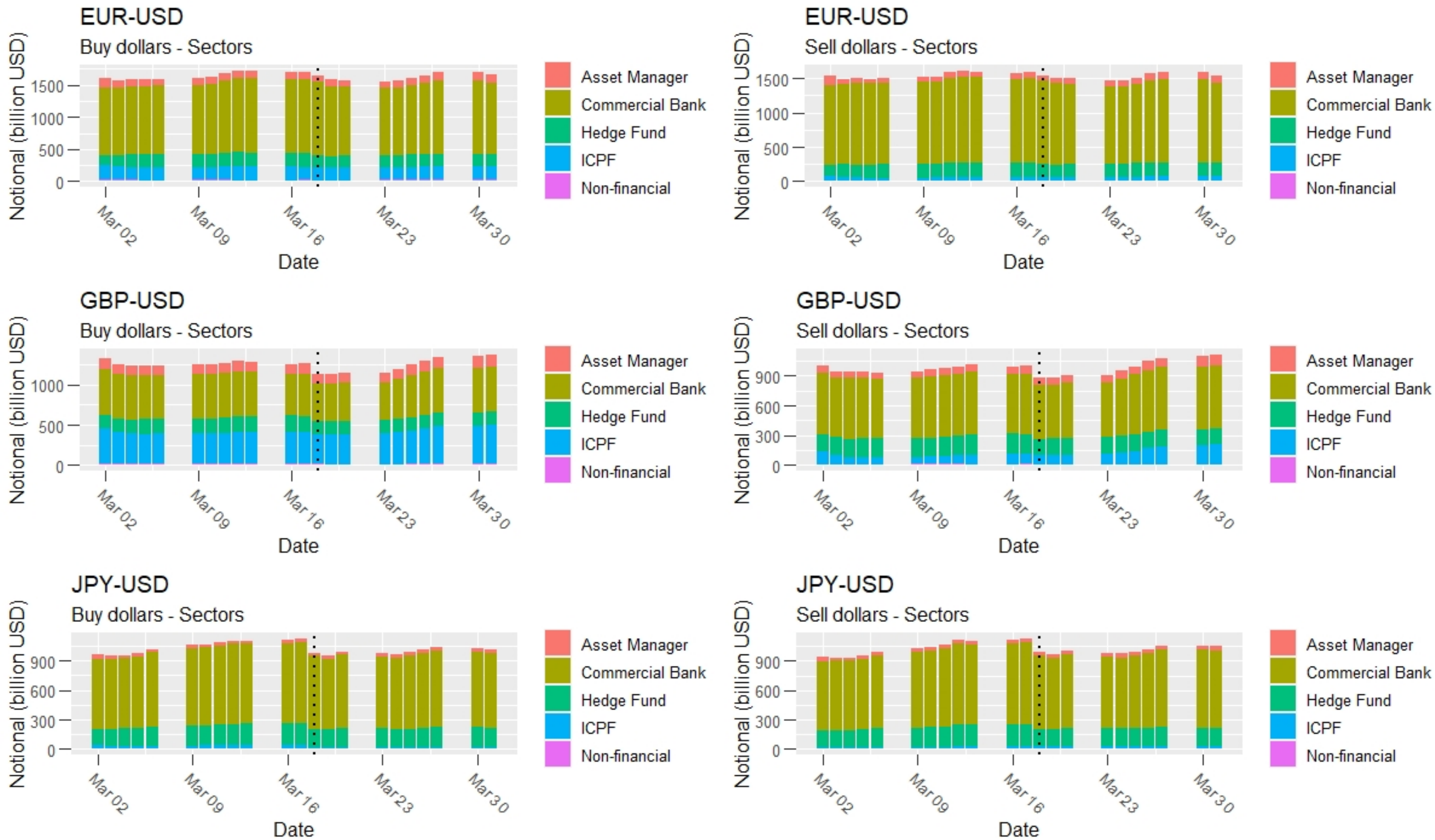
Note: Figure presents box plot of GBP/USD transaction level CIP deviations, for the dates of 17th to 20th of March, 2020. The announcement date is 18th of March, and the settlement date is March 19th. Transactions are between dealers and commercial banks, and sub-divided into treated and control dealers, where treated dealers received swap line liquidity from the Bank of England on the 19th of March.

Figure 10: Box Plot of Transaction Level CIP Violations- JPY/USD 3M



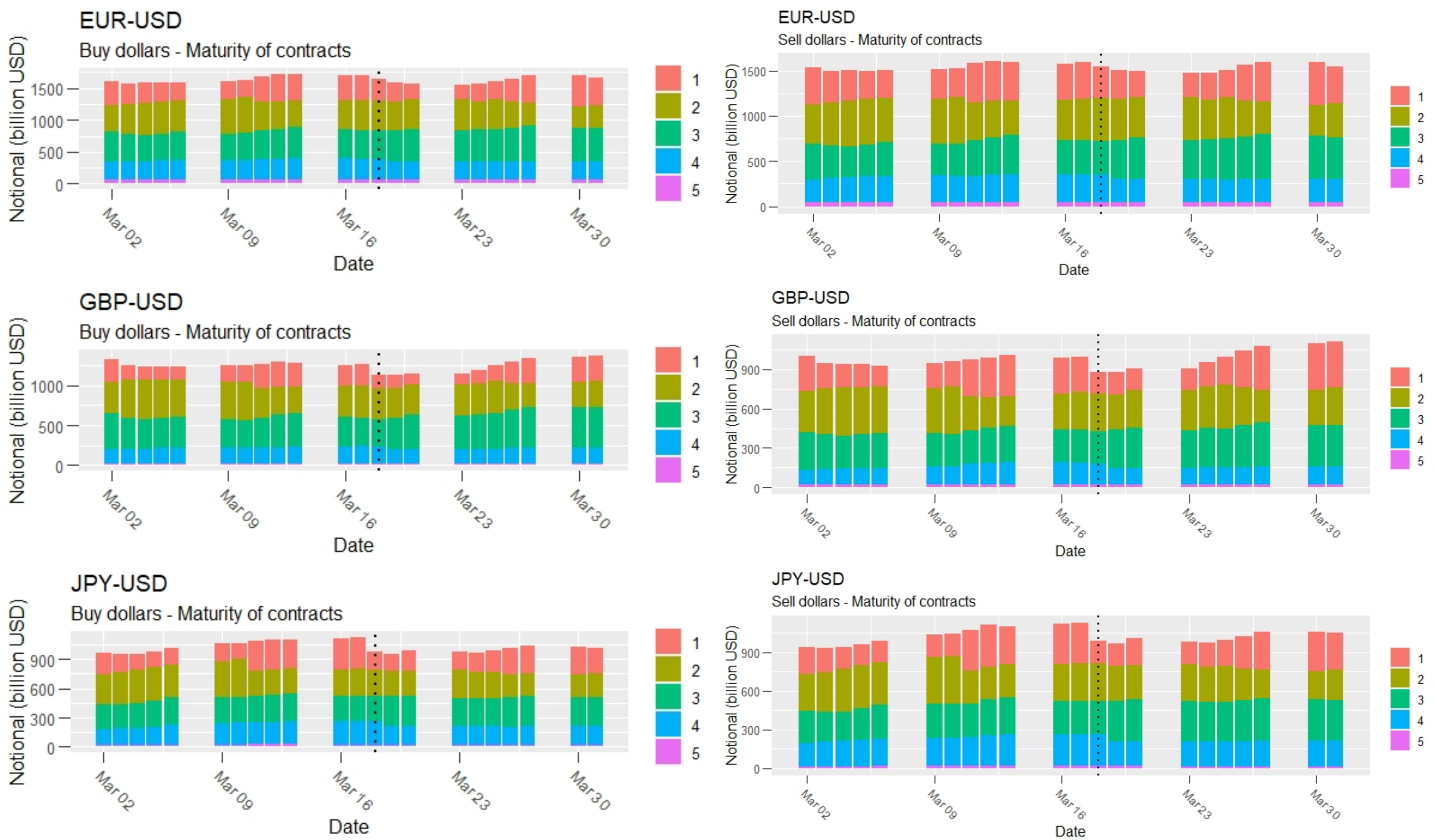
Note: Figure presents box plot of JPY/USD transaction level CIP deviations, for the dates of 17th to 20th of March, 2020. The announcement date is 18th of March, and the settlement date is March 19th. Transactions are between dealers and commercial banks, and sub-divided into treated and control dealers, where treated dealers received swap line liquidity from the Bank of England on the 19th of March.

Figure 11: FX Exposures (Gross Notional) by sector: left panel: Buy USD right panel: Sell USD



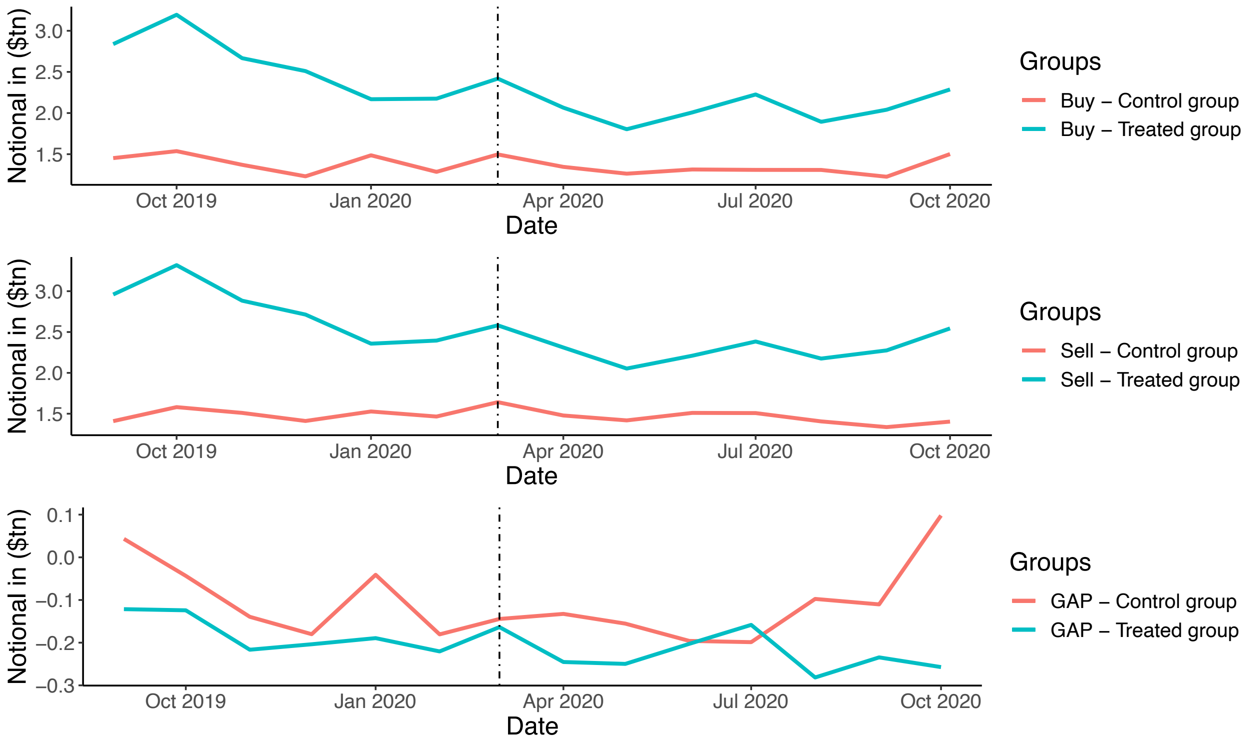
Note: Figure presents aggregate Buy and Sell positions for dealers with respect to the following 5 counterparty sectors: asset managers, commercial banks, hedge funds, ICPF and Non-Financial. FX exposures are aggregated across all maturities and are the outstanding notional positions at the end of each day. The left panel is outstanding notional positions in which dealers buy USD and sell EUR, GBP and JPY at the forward leg. The right panel is outstanding notional positions in which dealers sell USD and buy EUR, GBP and JPY at the forward leg. Sample period is from March 1st to March 31st 2020. Dotted line indicates March 18th, 2020 which is when Covid swap lines were activated.

Figure 12: FX Exposures (Gross Notional) by maturity: left panel: Buy USD right panel: Sell USD



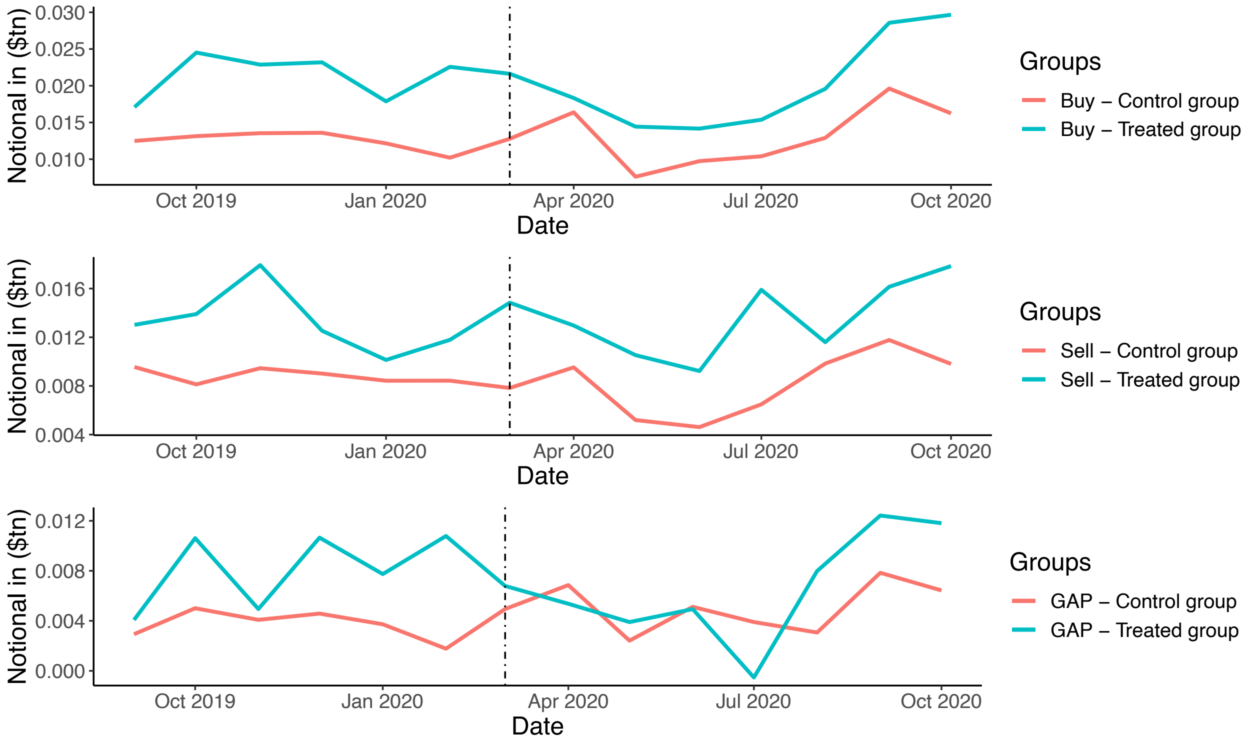
Note: Figure presents aggregate Buy and Sell positions for dealers with respect to the following 5 maturity groups: (1) less or equal to 1 week, (2) greater 1 week and less than 1 month, (3) greater than 1 month and less than 3 months, (4) greater than 3 months and less than 1 year, (5) greater than 1 year. FX exposures are aggregated across all maturities and are the outstanding notional positions at the end of each day. The left panel is outstanding notional positions in which dealers buy USD and sell EUR, GBP and JPY at the forward leg. The right panel is outstanding notional positions in which dealers sell USD and buy EUR, GBP and JPY at the forward leg. Sample period is from March 1st to March 31st 2020. Dotted line indicates March 18th, 2020 which is when Covid swap lines were first announced.

Figure 13: 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 at a maturity between 80 and 100 days 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 14: 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 at a maturity between 80 and 100 days 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: BOE Repo Collateral requirements

Collateral Bucket	Eligible Securities	Credit Rating	Haircut (< 1yr)	Haircut (> 30y)
A	Sterling, euro, US dollar and Canadian dollar denominated securities issued by the governments and central banks of the UK, Canada, France, Germany, the Netherlands and the United States.	AAA	0.5 %	15 %
B	Sovereign and central bank debt of Australia, Austria, Belgium, Denmark, Finland, Ireland, Italy, Japan, Luxembourg, New Zealand, Norway, Portugal, Spain, Sweden and Switzerland, issued in either the domestic currency or in sterling, euro or US dollar. Debt issued by Federal Home Loan Mortgage Corporation (Freddie Mac), the Federal National Mortgage Corporation (Fannie Mae) and the Federal Home Loan Banks, UK and EEA residential mortgage-backed securities (RMBS), credit cards, consumer loans and student loans	AAA	0.5-12%	15-24%
C	UK, US and EEA residential mortgage-backed securities (RMBS), credit cards, consumer loans and student loans. Can also include US, UK and EEA senior tranches of Asset-Backed Commercial Paper, listed senior corporate bonds, and mortgage, consumer, corporate loans to a non-bank.	A3/A- or above	15-30%	27-42%

Note: Table presents collateral requirements of BOE repos. Based on the Sterling monetary framework, collateral is listed in three buckets, with varying credit rating and haircuts. Information is consolidated from Bank of England statements on collateral. See https://www.bankofengland.co.uk/markets/eligible-collateral for more details on collateral types. Details on haircuts for specific collateral types can be found on https://www.bankofengland.co.uk/-/media/boe/files/markets/eligible-collateral/summary-tables-of-haircuts-for-bank-lending-operations.pdf.

Table 2: 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 3: 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
$\text{distance}_{\text{CET1 Ratio}}$ (%)	496.0	9.48	3.97	5.88	7.31	8.30	10.20	30.00
$\text{distance}_{\text{Leverage Ratio}}$ (%)	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 4: Determinants of Swap Line Access

	I	II	III	IV	V
	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$
$\text{distance}_{\text{CET1 Ratio}}$	0.4571***				0.3222***
	(0.000)				(0.006)
$\text{distance}_{\text{Leverage Ratio}}$		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 5: Transaction-Level CIP Deviations for EUR/USD, GBP/USD and JPY/USD:two-paired t-tests

Date	Currency	Control CIP	Treatment CIP	N	p-val (t test)
17 March 2020	EUR	-145.95	-133.93	274	0.178
17 March 2020	GBP	-111.07	-124.05	187	0.383
17 March 2020	JPY	-224.69	-190.88	145	0.160
18 March 2020	EUR	-91.07	-118.19	309	0.009***
18 March 2020	GBP	-99.08	-105.31	173	0.653
18 March 2020	JPY	-149.64	-160.60	185	0.432
19 March 2020	EUR	-159.32	-167.10	260	0.566
19 March 2020	GBP	-152.78	-125.71	160	0.128
19 March 2020	JPY	-239.21	-215.40	147	0.143
20 March 2020	EUR	-95.15	-113.43	161	0.080*
20 March 2020	GBP	-172.94	-86.35	125	0.000***
20 March 2020	JPY	-192.50	-204.05	154	0.433

Note: Table estimates two-paired t-tests for the differences in EUR, GBP and JPY CIP deviations on 17th March, 18th March, 19th March and 20th March. The mean transaction-level CIP deviations are calculated for the control and treatment groups on each day. The 18th of March corresponds to the day in which the Federal Reserve announced the swap line auctions, which is known as the trade date, for the Bank of England and the ECB, and 17th or March is the trade date for auctions with the Bank of Japan. The 19th of March is the settlement date of the auctions for all three central banks. The two-paired test measures a statistical difference in the means. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 6: Transaction-Level CIP Deviations for EUR/USD, GBP/USD and JPY/USD: All counterparties

	I	II	III	IV
	Panel	EUR 3M	GBP 3M	JPY 3M
$D_{treat} \times D_{03/18}$	-27.3376*	-29.2257**	-4.6552	-8.9691
	(10.8271)	(5.7671)	(18.1059)	(7.2881)
$D_{treat} \times D_{03/19}$	-3.3794	-13.1570**	46.1210*	28.5460**
	(6.7608)	(3.6286)	(16.3555)	(8.9291)
$D_{treat} \times D_{03/20}$	-18.7965	-20.5335*	67.3384	-5.3686
	(11.0745)	(7.9440)	(31.5169)	(2.8132)
constant	-132.5710***	-118.4106***	-134.5626***	-193.5048***
	(5.1419)	(3.0842)	(9.6533)	(0.0548)
R-sq	0.138	0.190	0.201	0.252
N	2272	992	644	630

Note: Table estimates a difference-in-difference specification to test the effects of swap lines on transaction price CIP violations for the currency pairs of EUR/USD, GBP/USD and JPY/USD. Outcome variables include individual currency CIP deviations measured using transaction level data for dealers with respect to all counterparties. Maturities range from 80 to 100 days. D_{treat} is a dummy variable for dealers that activated the BoE dollar repo. $D_{03/18}$, $D_{03/19}$ and $D_{03/20}$ are dummy variables for the 18th, 19th and 20th of March respectively. The 18th of March corresponds to the day in which the Federal Reserve announced the swap line auctions, which is known as the trade date, and the 19th of March is the settlement date of the auctions. 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 3 month maturity: 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)
$D_{\text{swap line}} \times D_{\text{treat}}$	-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)
$\text{distance}_{\text{CET1 Ratio}}$		-17.6605		-107.1667		89.5062
		(57.1402)		(84.9530)		(60.7120)
$\text{distance}_{\text{Leverage Ratio}}$		-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 3 month maturity: 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)
$D_{\text{swap line}} \times D_{\text{treat}}$	-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)
$\text{distance}_{\text{CET1 Ratio}}$		10.1067		14.1313		-4.0246*
		(7.8937)		(8.6039)		(2.2613)
$\text{distance}_{\text{Leverage Ratio}}$		-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: 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)
$D_{\text{swap line}} \times \mathbb{1}[k=-1]$	314.7323	505.5828	-190.8505	-36.0080*	-12.0735	-23.9345
	(335.2548)	(309.2042)	(135.1873)	(18.5134)	(17.8561)	(21.7688)
$D_{\text{swap line}} \times \mathbb{1}[k=-2]$	735.7680**	745.3405***	-9.5724	11.2730	13.6964	-2.4234
	(301.9277)	(222.8113)	(130.1639)	(37.6134)	(13.8690)	(35.4374)
$D_{\text{swap line}} \times \mathbb{1}[k=1]$	-11.5340	-75.5659	64.0319	-72.9412*	-21.9462	-50.9950*
	(117.9548)	(85.7398)	(96.4346)	(37.8376)	(14.4746)	(26.4621)
$D_{\text{swap line}} \times \mathbb{1}[k=2]$	-256.8731**	-166.1433	-90.7297	-82.5067**	-5.5892	-76.9175*
	(128.2094)	(156.2420)	(144.9236)	(40.6285)	(20.3375)	(37.9495)
$D_{\text{swap line}} \times \mathbb{1}[k=3]$	-518.1804**	-487.6885*	-30.4919	-33.9092	18.0683	-51.9775*
	(214.4721)	(251.1161)	(128.1063)	(25.9595)	(22.1127)	(29.9997)
$D_{\text{swap line}} \times \mathbb{1}[k=4]$	-239.4202	-369.2281	129.8079	-49.8939	5.4649	-55.3588
	(174.7663)	(226.8223)	(153.4487)	(34.2678)	(14.5239)	(37.2695)
$D_{\text{swap line}} \times \mathbb{1}[k=5]$	-110.7589	-247.0298	136.2710	-82.2852	-17.6406	-64.6446
	(177.0615)	(156.8038)	(128.4781)	(54.1217)	(21.9575)	(43.5474)
$D_{\text{swap line}} \times \mathbb{1}[k=6]$	-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)
$\text{distance}_{\text{CET1 Ratio}}$	1.0129	-90.3774	91.3903	10.0026	13.7918	-3.7891
	(57.0977)	(79.9365)	(61.8613)	(7.9089)	(8.3461)	(2.2538)
$\text{distance}_{\text{Leverage Ratio}}$	-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 10: 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)
$D_{\text{swap line}} \times D_{\text{treat}}$	-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)
$\text{distance}_{\text{CET1 Ratio}}$	68.6259**	45.1353*	23.4906	61.1218	29.1313	31.9905
	(34.1886)	(24.4978)	(17.7242)	(42.4830)	(27.2204)	(18.6259)
$\text{distance}_{\text{Leverage Ratio}}$	-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: Ceiling test

We test the hypothesis through a probit specification in equation (10), 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.

$$\mathbb{1}[|x_{i,j,t}| > 25bp + i^i_{interbank} - i^i_{reserve}|] = \beta Post_t + \epsilon_{i,j,t} \tag{10}$$

The results are presented in Table A1. 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.

Table A1: 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.

Appendix B: Price Effects

B.1 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 (11), 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 and maturity differences in CIP deviations with fixed effects α_i and α_c, respectively. 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 except the Post dummy and the capital growth ratio are in first-differences.

$$\Delta x_{i,t} = \alpha_i + \alpha_c + \beta \times Post_t \times SwapLine_i + controls_{i,t} + \epsilon_{i,t} \tag{11}$$

Table A2 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. $Allotment_{i,t}$ 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 0.51 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 51 basis points for the EUR/USD and JPY/USD pairs and 20 basis points for the GBP/USD pair according to our estimates.

One empirical concern is the non-random selection of control group currencies. In this case, control group currencies like AUD and NZD have lower synthetic dollar borrowing costs, and therefore choose not to access the swap line for dollar funding. Instead, we can compare CIP deviations involving the euro, pound, and yen to currencies that had an increase in CIP deviations vis-a-vis the USD during the pandemic but did not have access to the swap line. We find our results are robust to using an alternative control group, the DKK and SEK. Table A3 reports the results. For the interaction term of $Allotment_{i,t} \times Post_t$, the DiD coefficient estimates are quantitatively similar to using AUD and NZD as the control group.

Another concern is our selection of the treatment date of March 19th, 2020, which could be problematic due to a number of confounding events during the pandemic. In Table A4, we run placebo tests using alternative treatment dates, February 1, 2020 and May 1, 2020, and find insignificant treatment effects using those dates. Finally, we test long-term maturities of 1 year, 5 year and 10 year. Consistent with swap lines providing dollars at 1 week to 3 month, we find a significantly smaller magnitude of treatment effects on longer-term maturities.

Table A2: Panel Differences-in-Differences Specification: CIP Deviations (OIS)

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
$\text{Swapline}_i \times \text{Post}_t$	13.573**	14.324*		
	(3.804)	(6.031)		
$\text{Allotment}_{i,t} \times \text{Post}_t$			0.486***	0.508***
			(0.120)	(0.111)
Post_t	-0.842	-0.966	7.745*	7.837
	(1.235)	(1.938)	(3.519)	(4.859)
Δ $(i - i\_us)$		-5.839		-5.289
		(4.710)		(2.999)
Δ board dollar		-1.948		-1.883*
		(1.247)		(0.861)
Δ log(vix)		-33.754**		-33.523**
		(11.085)		(10.794)
Δ fwd bid-ask		0.467		0.144
		(2.402)		(2.192)
HKM		-2.648**		-2.709**
		(0.814)		(0.798)
constant	-4.444**	-6.022	-4.444*	-5.760
	(1.217)	(3.702)	(1.758)	(3.084)
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 first differences in the broad dollar index, VIX index, interest-rates (OIS) difference between the foreign currency and USD 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 A3: Panel Differences-in-Differences Specification: CIP Deviations (OIS): Alternative control group with DKK and SEK currencies

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
$\text{Swapline}_i \times \text{Post}_t$	2.956	-1.075		
	(4.037)	(4.256)		
$\text{Allotment}_{i,t} \times \text{Post}_t$			0.453**	0.462***
			(0.117)	(0.106)
Post_t	9.775***	13.509**	11.313***	12.319*
	(1.831)	(3.930)	(2.314)	(5.492)
$\Delta\ (i - i\_us)$		-7.515*		-7.396
		(3.584)		(4.063)
Δ board dollar		-2.747*		-2.640**
		(1.282)		(0.982)
Δ log(vix)		-50.464***		-50.612***
		(8.071)		(8.154)
Δ fwd bid-ask		0.089		0.080
		(0.119)		(0.131)
HKM		-3.382***		-3.432***
		(0.691)		(0.667)
constant	-6.312***	-10.113*	-6.312***	-10.062*
	(1.237)	(4.307)	(1.167)	(4.727)
Observations	756			
Treatment	EUR, GBP, JPY, and CAD			
Control	SEK and DKK			

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 first differences 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 A4: Panel Differences-in-Differences Specification: CIP Deviations (OIS): Placebo tests using alternative treatment dates and maturity

	I	II	III
	Date Placebo (Feb 1, 2020)	Date Placebo (May 1, 2020)	Maturity Placebo
$\text{Swapline}_i \times \text{Post}_t$	0.494	-2.624**	1.096***
	(0.828)	(0.680)	(0.266)
Post_t	-1.629	0.426**	-0.752**
	(0.846)	(0.139)	(0.209)
$\Delta\ (i - i\_us)$	-17.666**	-22.936	0.465
	(5.609)	(21.904)	(0.239)
Δ board dollar	1.072	1.053	-0.370*
	(1.189)	(1.116)	(0.155)
Δ log(vix)	3.817	-5.945	-2.315
	(3.417)	(6.019)	(1.376)
Δ fwd bid-ask	-4.781**	-1.833	0.075
	(1.621)	(0.983)	(0.133)
HKM	1.667**	-0.435	-0.228**
	(0.520)	(0.265)	(0.080)
constant	-16.341**	0.627	0.147
	(5.534)	(0.967)	(0.177)
Observations	720	756	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. In column (I), placebo date of February 1st, 2020 is used with a 1 month pre and post window. In column (II), a placebo date of May 1st, 2020 is used with a 1 month pre and post window. In column (III), the sample a 1 month pre and post the swap line settlement date of March 19, 2020, and it tests long-term CIP deviations (1Y, 5Y and 10Y) replacing the 1W, 1M and 3M CIP deviations in the baseline specification. Controls include the daily first differences 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 parentheses.

B.2 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.

$$Y_{i,t}^I = \begin{cases} Y_{i,t}^{I*}, & 1 \leq t \leq T_0 - 1 \\ Y_{i,t}^{I*} + \delta_t, & T_0 \leq t \leq T \end{cases} \tag{12}$$

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

$$Y_{i,t}^I = Y_{i,t}^{I*} = w_0 + \sum_i w_i Y_{i,t}^N + \epsilon_t, \quad 1 \leq t \leq T_0 - 1 \tag{13}$$

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 A1, 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.[15]

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 $\Delta_T = 0$.[16]

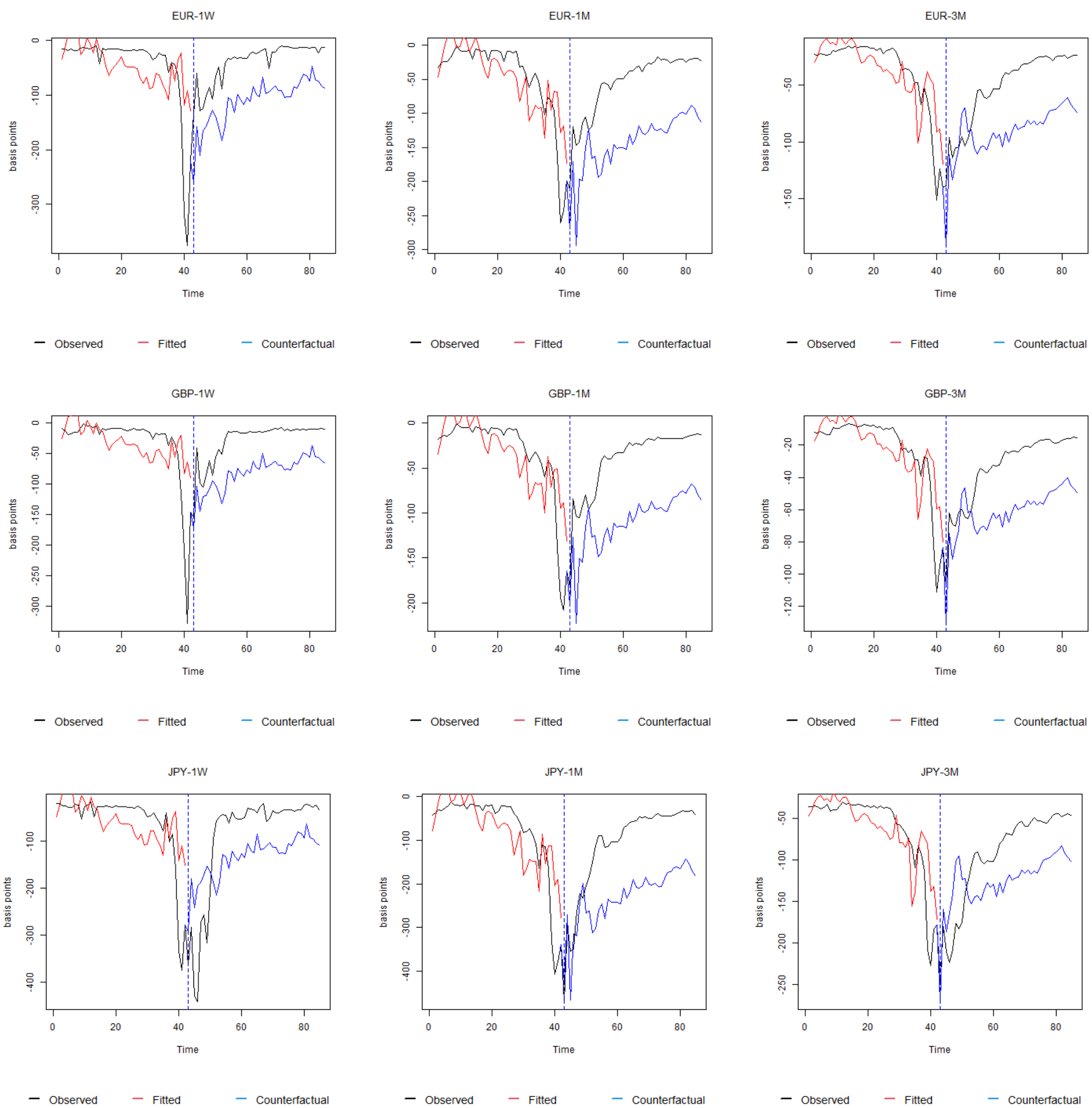
[15] Specifically, we use March 19th, 2020 as T_0 in our analysis, which is the date at which we construct a counterfactual for our treatment.

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

$$H_0 : \Delta_T = \frac{1}{T - T_0 + 1} \sum_{t=T_0}^{T} \tau_t = 0, \qquad T_0 \leq t \leq T \tag{14}$$

Table A5 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 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.

Figure A1: 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.

Table A5: 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.

Appendix C: Volatility Effects

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 (15). 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. 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 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.[17]

$$RV_t = \alpha + \beta_d RV_{t-1} + \beta_w RV_{t-1:t-6} + \beta RV_{t-1,:t-26} + \delta_1 \text{Swap line}_{set,t} + \delta_2 \text{Swap line}_{set,t-1} + \gamma_1 \text{Covid}_{t-1} + \gamma_2 \text{Covid}_{US,t-1} + \epsilon_t \quad (15)$$

Table A6 presents the results. Columns (I) to (III) are results using 1 week EUR/USD, 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.

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

Table A6: 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.